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

Final Technical Report

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ABSTRACT

The Nature Conservancy participated 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 was "Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration".

The objectives of the project were 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 Final Technical Report discusses the results of the six tasks that The Nature Conservancy undertook to answer research needs while facilitating the development of real projects with measurable greenhouse gas reductions. The research described in this report occurred between July 1st 2001 and July 10th 2008. 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

The project occurred in two phases. The first was a focused exploration of specific carbon measurement and monitoring methodologies and pre-selected carbon sequestration opportunities. The second was a more systematic and comprehensive approach to compare various competing measurement and monitoring methodologies, and assessment of a variety of carbon sequestration opportunities in order to find those that are the lowest cost with the greatest combined carbon and other environmental benefits.

In the first phase we worked in the U.S., Brazil, Belize, Bolivia, Peru, and Chile to develop and refine specific carbon inventory methods, pioneering a new remote-sensing method for cost-effectively measuring and monitoring terrestrial carbon sequestration and system for developing carbon baselines for both avoided deforestation and afforestation/reforestation projects. We evaluated the costs and carbon benefits of a number of specific terrestrial carbon sequestration activities throughout the U.S., including reforestation of abandoned mined lands in southwest Virginia, grassland restoration in Arizona and Indiana, and reforestation in the Mississippi Alluvial Delta. The most cost-effective U.S. terrestrial sequestration opportunity we found through these studies was reforestation in the Mississippi Alluvial Delta.

In Phase II we conducted a more systematic assessment and comparison of several different measurement and monitoring approaches in the Northern Cascades of California, and a broad 11-state Northeast regional assessment, rather than pre-selected and targeted, analysis of terrestrial sequestration costs and benefits.

Work was 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.

This project, *Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration*, has resulted in over 50 presentations and reports, available publicly through the Department of Energy or by visiting the links listed in Appendix 1.

More important than the reports, the project has helped to lead to the development of on-the-ground projects in Southwestern Virginia, Louisiana, and Chile while informing policy development in Virginia, the Regional Greenhouse Gas Initiative, the California Climate Action Registry and U.S. and international programs.

TABLE OF CONTENTS

LIST OF GRAPHICAL MATERIALS

FIGURES:

Task 5: New Project Feasibility Studies

TABLES:

EXECUTIVE SUMMARY

The Nature Conservancy participated 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 work was accomplished in close collaboration with NGO partners, government and academic institutions, and U.S.-based companies. This research was conducted on sites where carbon sequestration activities had been underway for several years, and on sites that offer opportunities for carbon sequestration for those interested in taking action to reduce atmospheric greenhouse gas concentrations. The Nature Conservancy identified a number of areas where research was needed to both enhance the science, and to provide guidance to policy makers. To meet these needs we undertook research 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 pilot projects on the ground. This work was accomplished through the following six tasks:

- 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

The following are some of the major accomplishments:

1) New carbon regression equations created to relate field measurements to carbon storage amounts for new species and vegetation types. These results were provided to DOE and presented and published in proceedings of the International Symposium on Forest Carbon Sequestration and Monitoring.
2) A new airborne technology and method, multi-spectral three-dimensional digital imagery (M3DADI), was successfully used to quantify carbon sequestration in pine savanna and broadleaf forests in Belize and the U.S. Results of these tests were presented at the 2004 Annual Meeting of the Ecological Society of America and published in *Ecological Applications*. This method proved to be more cost-effective than traditional carbon inventory techniques.
3) A new method, called Forest Restoration Carbon Analysis (FRCA), was developed for assessing biodiversity and baseline carbon emissions from forest conservation and reforestation. FRCA results for Selva Central, Peru were presented at 2004 Annual Meeting of the Ecological Society of America.
4) Reports detailing costs of terrestrial sequestration for grassland restoration and reforestation were developed and presented at national conferences and to the DOE. Options for sequestering carbon at the cost of $10 per ton of CO_2 were identified. One of the project concepts evaluated through this work, reforestation of bottomland hardwood forests in the Mississippi Alluvial Valley, was attractive enough to industry investors looking to reduce their CO_2 footprint that they invested in sequestration activities on the ground.

5) A screening tool, available on the internet that allows would-be project developers to input information about their project idea and receive graphical and numerical descriptions of the potential carbon growth from afforestation, along with estimated costs of measuring the carbon growth.
6) A report comparing uncertainties of estimates of aboveground forest carbon from Light Detection and Ranging (Lidar) and from QuickBird high-resolution satellite images, calibrated by field measurements of individual trees in the several different forest types found in northern California.
7) A report with tables and GIS maps showing the current characterization (as well as historical and future predictions) of eleven states in Northeast region in terms of land, climate, land-use, and population. The report spatially depicts the opportunities for improving the amount of carbon storage and management on agricultural lands and forest lands, including both carbon supply and costs for afforestation, improved forest management, and conservation tillage and is being used by policy makers working on the Regional Greenhouse Gas Initiative to identify the best opportunities for abating CO_2 emissions through forestry activities at low cost.

This project, *Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration*, has resulted in over 50 written presentations and reports, available publicly through the Department of Energy or by visiting the links listed in Appendix 1.

More important than the reports, the project has led to the development of on-the-ground projects in Southwestern Virginia, Louisiana, and Chile while informing policy development in Virginia, the Regional Greenhouse Gas Initiative, the California Climate Action Registry and U.S. and international programs.

EXPERIMENTAL

Task 1: Carbon Inventory Advancements

There are two primary components to taking carbon inventory measurements, stratification and measurement of representative carbon storage within each strata. The representative carbon storage for each strata is multiplied by the area for the given strata to determine carbon storage for the entire area. Stratification and inventories are generally done using a combination of remote-sensing techniques for stratification, combined with field measurements.

Inventories of carbon stored in with-project and without-project cases for the Brazil Guaraqueçaba project areas and in the Selva Central in Peru were carried out through this task through a carbon inventory protocol included the following components:

- Establishment of permanent sample plots geo-referenced via GPS for periodic measurements of changes in carbon pools in the project area;
- Measurements of tree diameter and height, soil carbon, forest floor litter carbon, and other carbon pools;
- Software for calculating minimum sample size, assigning sample unit locations, determining the minimum spacing for plots, calculating precision of carbon benefits, calculating costs of inventorying and monitoring, and optimizing site-specific monitoring plans;
- A database of tree biomass for developing allometric regression equations (to estimate biomass carbon based on tree measurements) for selected species.
- The following were applied to the Cachoeira and Itaqui carbon projects in Brazil in order to improve existing methods and to test new ones:

- Creation of allometric regression equations through destructive sampling for tree ferns.
- The calibration of Laser-Induced Breakdown Spectroscopy (LIBS) for measuring soil carbon.

To stratify, the boundaries of each of the vegetation communities found in the area of interest were identified using imagery from available remote sensing data, including satellite data, standard aerial photographs, and field surveys.

Task 2: Remote Sensing for Carbon Analysis

M3DADI utilizes 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 it was flown, 3-dimensional (3D) reconstruction were developed from the digital imagery and technicians interpreted the data to identify terrain features, vegetation types, and the height and crown area of individual trees. The data can also be used to measure the area of canopy cover for various vegetation types and height classes. The measurements from the M3DADI were then calibrated with the data from Task 1 to estimate carbon remotely.

For this research to be successful we developed correlations between what can be measured using digital imagery (species, crown diameter, and height) with on-the-ground measurements of carbon storage. The costs of this new remote, digital imagery approach were then compared to traditional approaches.

The digital imagery and laser profiling system provides an aerial shot of the vegetation as well as a measurement of total height, trees or other representative vegetation that cover a range of heights and diameters, and crown diameters. Given these data, for most forests or vegetation types the best model is based upon the relationship between biomass and crown diameter/total height. The total height, canopy diameter and dbh are measured for each representative piece of vegetation selected. These samples then are destructively harvested and weighed to determine biomass and associated carbon storage. With the results from this project we developed new correlations between diameter and height to predict biomass carbon for the rest of the vegetation in the strata.

The steps for the measurements for correlation with M3DADI were as follows:

1. **Measure the height of the tree:** This requires the user to stand far enough away from the tree to view the top of the tree and record two measurements: the distance between the user and the base of the tree (measured with the tape measure or DME), and the angle from the user to the top of the tree (measured with the clinometer). Tree height is calculated by multiplying the distance from the user to the tree by the tangent of the angle to the top of the tree ($hgt = x*\tan\theta$).
2. **Measure the tree crown radii:** This requires two team members to stand directly beneath the edge of the tree crown, stretching a measuring tape. Measurements are taken at two positions, ninety degrees from each other. The crown area is calculated by multiplying the two crown radii measurements by pi ($Area = a*b*\pi$).

More heterogeneous landscapes, such as the pine savanna in Belize, are sampled using clip plots. Clip plots are aluminum sample frames 60 cm in diameter that are placed on the ground at predetermined locations. All vegetation—herbaceous and other non-tree vegetation—that falls inside the clip plot frames is cut, placed in a sample bag and weighed. Once all the vegetation has been cut and weighed, a sub-sample will be collected for moisture content determination.

In addition to this work, in a second phase we tested and compared additional remote-sensing technologies, including Light Detection and Ranging (Lidar) and from QuickBird high-resolution satellite images, calibrated by field measurements of individual trees. We conducted the research in old- growth Sierra Nevada forest in the North Yuba watershed of Tahoe National Forest, in secondary coast redwood forest on private land in the Garcia River watershed, and in old-growth coast redwood forest in Mailliard Redwoods State Natural Reserve. We also analyzed forest inventory and tree ring data from thirty-two plots along a 19 km transect in the North Yuba area to detect whether climate change is shifting vegetation zones.

Task 3: Baseline Method Development

Baseline analysis was conducted using two different models. The first model is GEOMOD. GEOMOD was developed by researchers at the State University of New York (SUNY) College of Environmental Science and Forestry with funding from the U.S. Department of Energy, Carbon Dioxide Research

Program, Atmospheric and Climatic Change Division (Hall et al, 1995a). A computerized geographic model, GEOMOD simulates the pattern of land-use change in the tropics from non-developed to developed land and vice-versa. The model is IDRISI-based and requires a spatially referenced set of equally dimensioned digital grid (raster) maps as inputs. To depict “without-project” scenarios, those areas impacted by clearing or other land cover change between two points in time were identified. This allowed determination of the rate of deforestation, identification of the location of areas converted, calculation of the percentage of the total study area deforested, and rates of forestation. Each potential driver or combination of drivers will be assessed to determine which provides the greatest predictive power. Once the rate and the best set of drivers have been selected, the model can be run for a specified timeframe, looking at output every year, 5 years, 10 years, etc.

For each of the proposed study areas, the following inputs, at a minimum, were required:

1. A digital elevation model (DEM) or a digital coverage of elevation contours and maximum/minimum elevation points from which a DEM can be prepared using ARC/INFO’s (ESRI) Tin generator. Slope and aspect, which are potentially important drivers, are derived from this.
2. A digital hydrography coverage (streams, lakes). This is used in the analysis as well as in the creation of the DEM.
3. A digital coverage of roads.
4. A coverage of any other transportation routes (rail, air, boat) that give people access to the interior.
5. Classified and geo-referenced land-use maps derived from either aerial photography or satellite imagery for at least two points in time, preferably at the same scale, and no smaller than 1:24,000, with a grid cell resolution no larger than 30 x 30 meters. Existing settlements should be one of the identified land-use classes. Any land guaranteed as “set aside” (i.e. protected) should be indicated.
6. Population data over the same period of time.
7. Climate differences over the project area. If there is a considerable elevation gradient, then both mean annual temperature and precipitation measurements from one or more nearby weather monitoring stations, if available, will be useful. (The elevation and geographic coordinates of that station are required as well.)

GEOMOD produced a time series of land-use maps at a time interval to be chosen over the selected time-frame (i.e. 40 years) for each project.

In addition to GEOMOD, staff from the Nature Conservancy, Peruvian NGO ProNaturaleza, and the Universidad Nacional Agraria La Molina developed a new spatially-explicit baseline analysis method, referred to as forest restoration carbon analysis (FRCA). This method was developed through applied research on carbon sequestration in humid tropical forest in Peru. Building on the lessons of past experience with GEOMOD, FRCA constitutes an integrated spatial analysis of biodiversity, forest inventory, and remote sensing data that quantifies land use change and estimates the carbon sequestration baseline of a forest restoration project in a biologically important area. The method uses common software tools that Nature Conservancy staff already possesses and applies scientific procedures.

FRCA is similar to GEOMOD, but utilizes different, and generally more available, software (ARC instead of IDRISI).

The FRCA approach proceeds through the following steps:

1. Project area definition using biological significance
2. Forest inventories using systematic sampling
3. True color 30 m remote sensing image (1990–present)
4. Forest cover (1990–present)
5. Carbon calculation using local tree biomass and volume equations and species-specific wood densities
6. Deforestation and reforestation factor maps
7. Principal components analyses for deforestation and reforestation pixels
8. Derivation of deforestation and reforestation vs. factor equations
9. Estimation of the probability of deforestation and reforestation based on the factor equations and current forest cover
10. Weighting factors using principal component loadings
11. Spatial analyses of future deforestation and reforestation
12. Spatial analyses of future carbon with and without project

GEOMOD and FRCA vary in how they spatially assign the likelihood of future deforestation and reforestation. Both analyze past land cover change with GIS covers of environmental factors in order to determine the vulnerability of specific areas to future change. However, when projecting change, GEOMOD converts the next most vulnerable pixel candidates for baseline activity, whereas FRCA assumes statistical likelihood rather than next best candidate approach (e.g. 5% probability = 5% deforested).

For either of the models, it is necessary to identify potential project boundaries to which the models will be applied. This generally requires a basic analysis of forest conservation and/or reforestation priorities and the development of a basic scenario of what the carbon offset generating activity or activities would be.

Tasks 4, 5, and 6: Meetings, Reports, and Modeling

These tasks are either syntheses of the aforementioned work, or reports or models based on compilation of existing data. In some cases, there is some original new research conducted under these tasks – such as soil carbon sampling to determine potential carbon benefits from projects – but this is not the primary focus. Most of the results and discussion of this work will be provided in the next section, though a brief description of methods used in the 11-state study in the Northeast region are provided here.

For that study we analyzed data at a county level for existing agricultural and forest lands (Figure 1-2). On agricultural lands, the land management options that were evaluated included: afforesting (planting trees on) existing agricultural lands, changing land management to no-till but continuing crop production, altering crop production to non-cultivated crops (such as hay, pasture, or wildlife cover) and biomass energy.

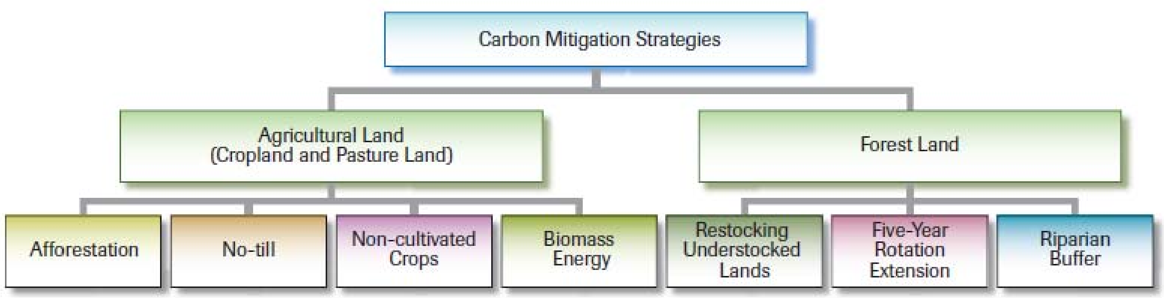

Figure 1. Overview of land management options examined

Figure 2. Eleven states included in the study

Restocking of understocked stands, increasing rotations, and increasing riparian buffers were also studied. The analysis for increasing rotations was performed for a subset of states, in particular Maine, New Hampshire, New York, and Vermont as the data were most readily available for industrially managed softwood forests in this region.

For the forestry sector, data presented are based on the assumption of a “permanent contract,” meaning that once a land owner changed their management practice, it is assumed that the change would be permanent. For agricultural practices, such as no-till and non-cultivated crops, the detailed analysis for each management option was examined at various points in time.

The cost benefit analysis produced through this effort provides a series of maps that show the cost of the various potential land management changes and their resulting impact on the increased sequestration or reduction of carbon emissions, measured in units of metric tons of carbon dioxide equivalence (CO2e), the standard unit for greenhouse gases. The costs are a sum of opportunity costs, conversion costs, annual maintenance costs, and costs of measurement and monitoring. The amounts of sequestration and emissions avoidance draw from empirical and modeled estimates of the impacts of the various changes in land management on carbon in vegetation, soils and, in the case of biomass energy, its impacts on reducing fossil fuel emissions.

Spatial and tabular data from the U.S. Forest Service Forest Inventory and Analysis (FIA), the U.S. Department of Agriculture Natural Resources Inventory (NRI), and National Agricultural Statistics Service (NASS) databases were used extensively to carry out the analysis. The analysis was performed in a Geographic Information System (GIS), allowing for county-level mapping of the potential mitigation strategy, rates of carbon sequestration, and costs.

RESULTS AND DISCUSSION

Task 1: Carbon Inventory Advancements

Summary of Objectives

Carbon inventory plans are designed to quantify the amount of carbon stored in key pools on a periodic basis. These inventories are used to estimate the differences between the with- and without-project carbon pools and are the primary basis for determination of project greenhouse gas (GHG) benefits. Through ongoing carbon inventory work in TNC's pilot projects, several aspects of the carbon inventories that could be improved or significantly strengthened were identified.

Many of the regression equations used in the traditional carbon inventories for The Nature Conservancy's projects were developed in different regions and are not species-specific. In some cases, the results that one would get using a general biomass equation instead of a species-specific equation are quite different. In light of these types of differences, new equations are needed for species that are structurally unusual relative to broad leaf trees from which general biomass equations in the tropics are derived. An additional emphasis of the carbon inventory work is on the development of regression equations relating remotely-sensed data to biomass. Since DBH can not be measured from the air, other relationships are being sought.

The primary areas of carbon inventory research under this agreement are: allometric regression equations for use in both traditional and new digital-imagery inventory methods, precisely geo-referenced sample plots, carbon inventory plots and destructive sampling for the calibration of M3DADI measurements, and soil carbon measurement. The following tasks were carried out:

- Establish permanent geo-referenced sample plots for periodic measurements of changes in carbon pools in the project area (2003).

- Measure tree diameters and heights and sample soil, forest floor litter, and understory to estimate carbon storage (2002-2003).

- Use database of tree biomass, and new data from destructive sampling of additional trees to develop and/or refine allometric regression equations (to estimate biomass carbon based on tree measurements) for selected species and forest strata (2002-2003).

- Test and calibrate LIBS for measuring soil carbon in the General Motors and AEP project areas in Brazil (2002-2003).

- Use or develop software to assist in calculation of minimum sample size, assignment of sample unit locations, determination of the minimum spacing for plots, calculation of precision of carbon benefits, calculation of costs of inventorying and monitoring, and optimization of site-specific monitoring plans (2003).

- Collect cost data to be used in a cost comparison between M3DADI and traditional carbon inventory methods. (discussed under Task 2)

Results

1. Establishing Permanent Plots and Estimating Carbon Storage

Brazil

The installation of permanent geo-referenced plots for periodic measurements and monitoring in GM's Atlantic Rainforest Restoration Project was completed. This work was done on 8,500 hectares. A total of 189 nested circular plots were installed on different forest strata (table 1). Mean carbon stocks for aboveground biomass was estimated with the 95% confidence interval being within 10% of the mean, as desired, ranging from 43-132 t C ha-1 (Table 2).

Table 1. Description of each stratum, area, and number of plots established.

Strata code	Vegetation type	Area (ha)	Number of sample plots established
MA	Medium/Advanced secondary forest	2,638.6	70
M	Medium secondary forest	2,393.1	54
IA	Very young forest	335.9	9
SM	Primary Altered forest	1,234.1	46
TB	Lowland forest	62.5	10
TOTALS		**6,664.2**	**189**

Table 2. Mean carbon content by component and by forest strata.

Strata	Area (ha)	Aboveground Woody Biomass t C ha^{-1}	Belowground Biomass t C ha^{-1}	Standing dead biomass t C ha^{-1}	Lying dead biomass t C ha^{-1}	Woody Biomass < 5 cm dbh t C ha^{-1}	Total t C ha^{-1}
Medium/Advanced(MA)	2,638.6	91.7	18.7	5.1	2.8	1.1	119.4
Medium secondary (M)	2,393.1	67.0	14.2	3.6	1.6	2.6	89.0
Very young (IA)	335.9	43.7	9.7	1.3	0.4	2.6	57.7
Primary altered (SM)	1,234.1	132.9	26.0	5.6	4.7	1.1	170.2
Lowland (TB)	62.5	94.8	19.1	1.3	2.2	0.8	118.2
Total	**6,664.2**						
Weighted mean(CI*)		88.1(6.4)	18.0(6.4)	4.4(18.6)	2.6(18.1)	1.7(15.4)	114.7(5.9)

*95% Confidence Interval expressed as a percent of the mean (+/-)

Plots were also installed to measure the carbon contained in non-forest areas. Twenty-four destructive sample plots were created to sample pasture / open areas and shrub biomass. The mean of aboveground carbon content of pasture ranged from 1.6 to 4.9 t C/ha (Table 3).

Table 3. Mean carbon and statistics for aboveground carbon in pasture.

	Shrubs	Pasture	Pasture/shrubs
N	7	7	9
Mean	4.9	1.6	2.9
Min	2.5	0.7	1.5
Max	8.3	3.4	5.0
Variance	4.7	0.8	1.6
Stand. Dev.	2.2	0.9	1.3
Error	0.8	0.3	0.4
CV %	44.2	55.0	44.7
CI			0.8

Belize

PfB installed permanent plots in the Pine Savannah. From conducting measurements in the permanent plots a full cost and accuracy comparison was made between traditional carbon inventory methods and M3DADI for both sections of the project. (results presented under Task 2). Measurements in broadleaf forests were also carried out by PfB and presented to Winrock

2. Destructive Sampling and Allometric Regression

<u>Brazil - Atlantic Forest Biome</u>

In Year 1, destructive sampling was carried out on 5 trees between 20 and 85 centimeters diameter at breast height (dbh). The preliminary results suggested that biomass for trees in the Atlantic Forest fell somewhere between the general wet biomass equation and the general moist biomass equation (Brown, S. 1997), and that the wet equation that was being used in the project was possibly underestimating the total biomass and carbon stocks. Bill Stanley of TNC, and Sandra Brown from Winrock International reviewed the preliminary results, and agreed that more data needs to be collected to verify the accuracy of the equations.

In Year 2, further destructive sampling was conducted on large trees as part of the effort to adjust and/or define a new equation to estimate biomass as a function of dbh. TNC and SPVS destructively harvested a total of 23 trees to verify the appropriateness of the biomass regression equation that was being used to estimate forest carbon tree stocks. The following new biomass equation of the actual measured biomass was developed:

$$\textbf{Biomass (kg)} = 202.91e^{0.0442x} \quad (r^2 = 0.8328)$$

All the data that was collected and the procedures used in the carbon inventory were een revised by a independent adviser. Using the destructive sampling data the measured biomass was compared with estimates of biomass using the wet and moist equations (from Brown 1997). Results are reported below (Table 4).

Table 4. Brazil destructive sampling data. Total measured biomass and estimated biomass using the wet and moist equations.

Tree no.	Common name or Species	Tree dbh (cm)	Height (m)	Total measured Biomass (kg)	Wet equation Biomass (kg)	Moist Equation Biomass (kg)
1	Talauma ovata	54.6	19.0	1,765	1,848	2,896
2	Schizolobium parahybum	64.0	28.0	4,000	2,607	4,293
3	Machaerium	21.3	24.4	239	209	275
4	Brosimum lactescens	77.0	27.0	7,478	3,873	6,778
5	Vochysia bifalcata	83.5	24.1	4,899	4,600	8,277
6	Cryptocaria aschersoniana	41.8	25.5	1,749	1,024	1,490
7	Ficus insipida	70.0	26.0	4,259	3,161	5,357
8	Pterocarpus	70.0	26.0	3,293	3,161	5,357
9	Myrcia	29.3	17.3	1,450	453	613
10	Ficus	92.0	30.0	7,832	5,645	10,507
11	Licurana	53.6	24.0	3,114	1,775	2,766
12	Licurana	52.8	23.0	2,545	1,717	2,665
13	Machaerium	54.5	24.5	3,778	1,840	2,883
14	Myrcia	28.0	24.0	897	407	547
15	Pseudopiptadenia warmingii	84.0	31.0	10,570	4,659	8,400
16	Ocotea catharinensis	81.0	31.0	6,865	4,313	7,680
17	Myrtaceae	50.9	20.3	2,876	1,585	2,433
18	Calycorectes australis	33.0	27.4	844	598	826
19	Bauhinia forficata	25.6	13.0	231	328	437
20	Calyptranthes sp	64.0	21.0	4,058	2,607	4,293
21	Talauma ovata	48.0	23.0	1,663	1,393	2,103
22	Calyptranthes sp	35.4	17.0	1,133	702	984
23	Matayba guianensis	58.5	17.0	2,094	2,147	3,436

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

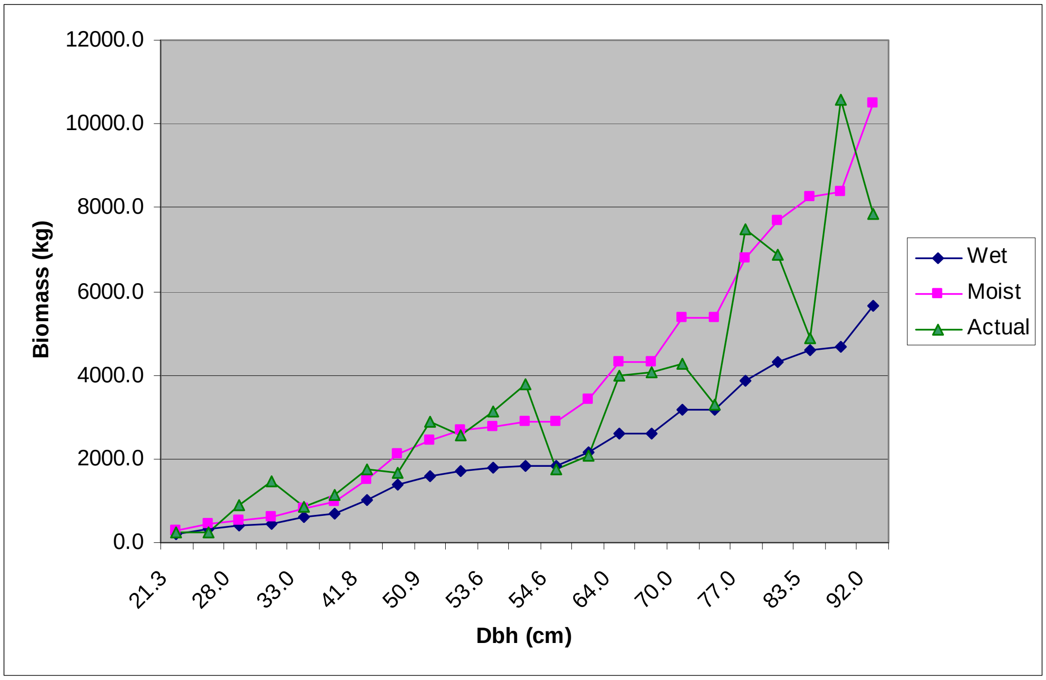

Figure 1A. Comparison of estimated biomass with general moist and wet equations compared to actual measured biomass.

Also the biomass of 26 lianas, bigger than 4 cm of DBH, were measured as an objective to develop a new allometric equation (Figures 1B and 1C)

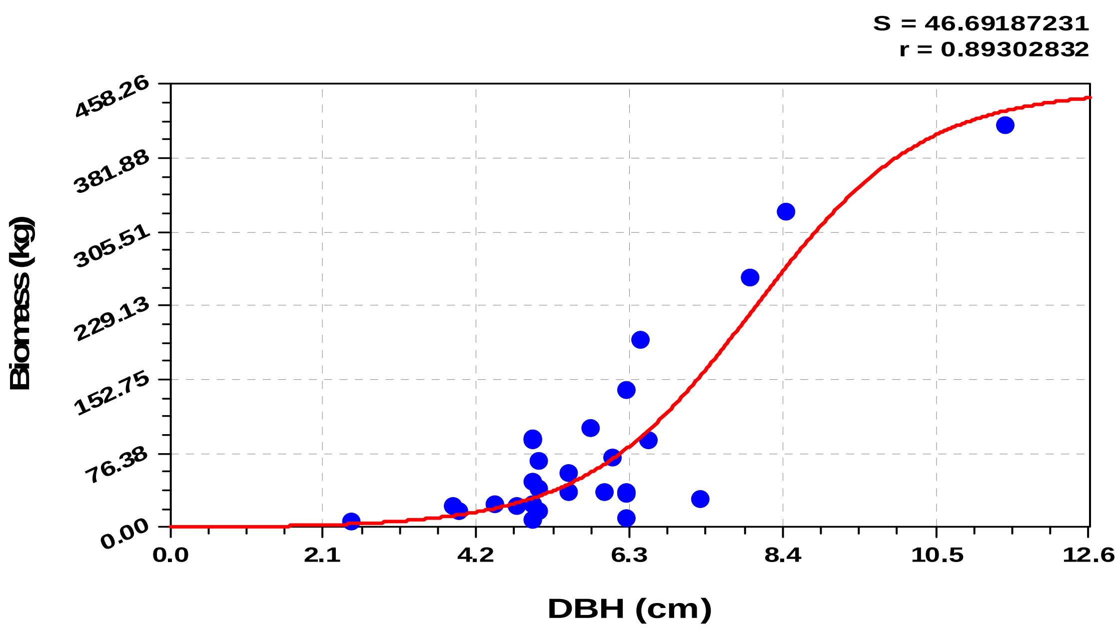

Figure 1B. Relationship between height and biomass for fern trees

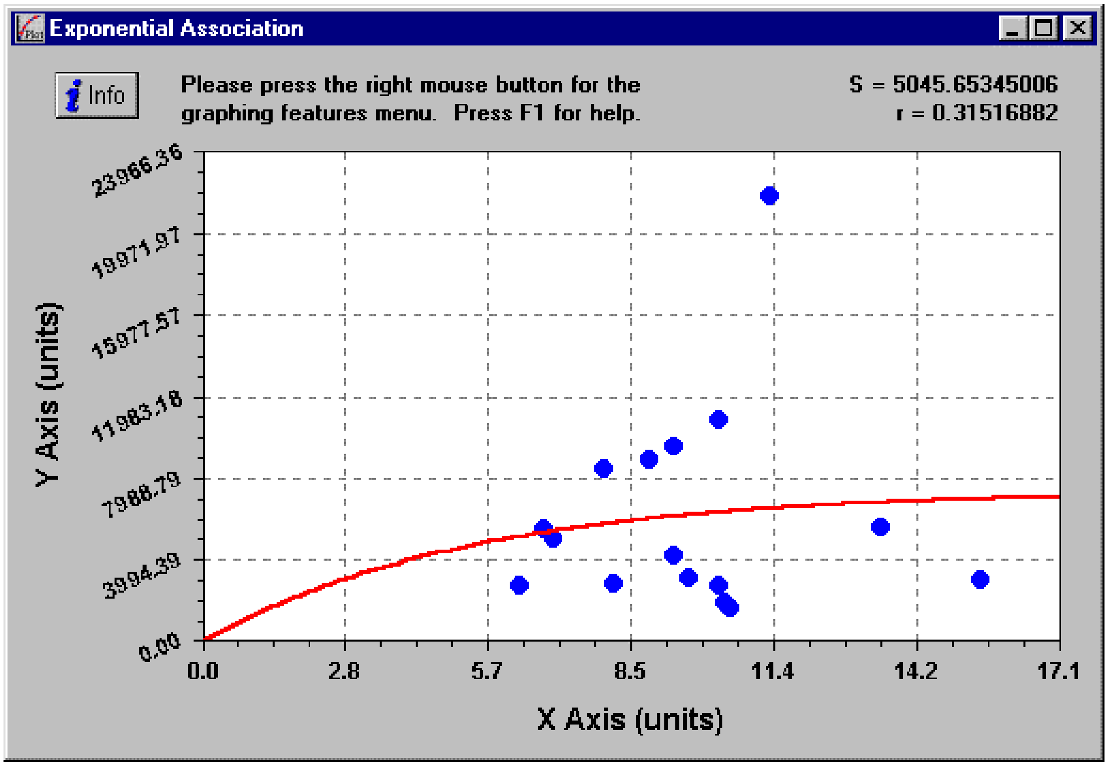

Figure 1C. Allometric regression equations for fern trees

3. *Vegetation Mapping*

A vegetation map for the General Motors project area in the Cachoeira River Basin was completed in Year 1. To leverage the benefit of the vegetation map to the research, a soil map was completed for the General Motors project using internal funding. Eleven forest strata were distinguished by combining soil classes (Argissolo, Cambissolo, Gleissolo and Neossolo Flúvico) and vegetation types (Submontane Forest, Wetland forest, advanced/medium secondary forest, medium secondary forest, and young secondary forest).

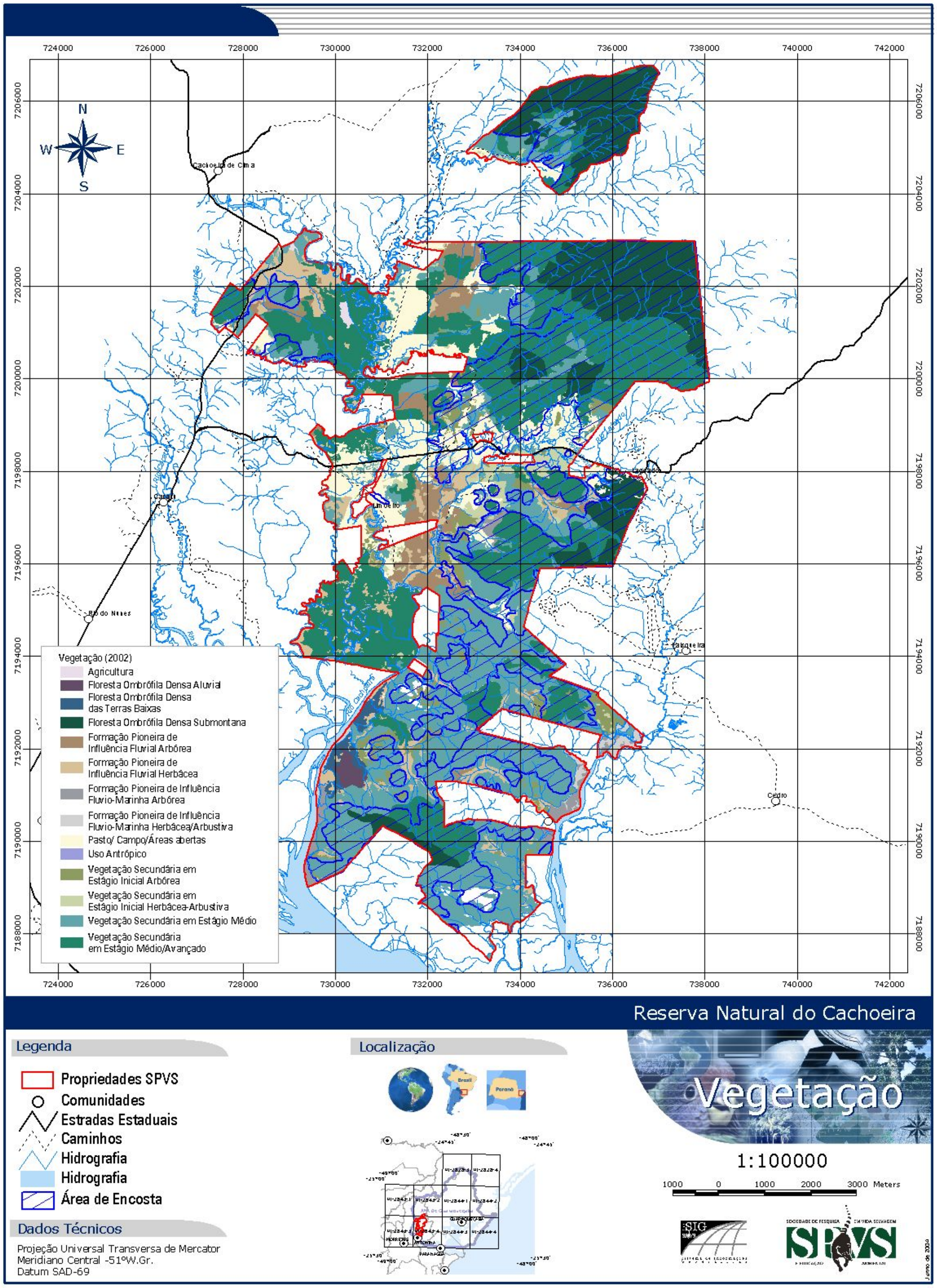

Figure 1D: Vegetation map from Reserva Natural Cachoeira, Antonina, Paraná, Brasil

In order to refine the vegetation maps, aerial photos from 1952 and 1980 were obtained. These maps helped to generate a better estimate of biomass increment at the different forest strata, by determining the age of the forest. The age of the forest and carbon stock were used to build the growth curves for the forest and soil types. One of the most reliable ways to determine age is by going back in time and identifying areas that were non-forest at a given time and regenerated to forest at a later period.

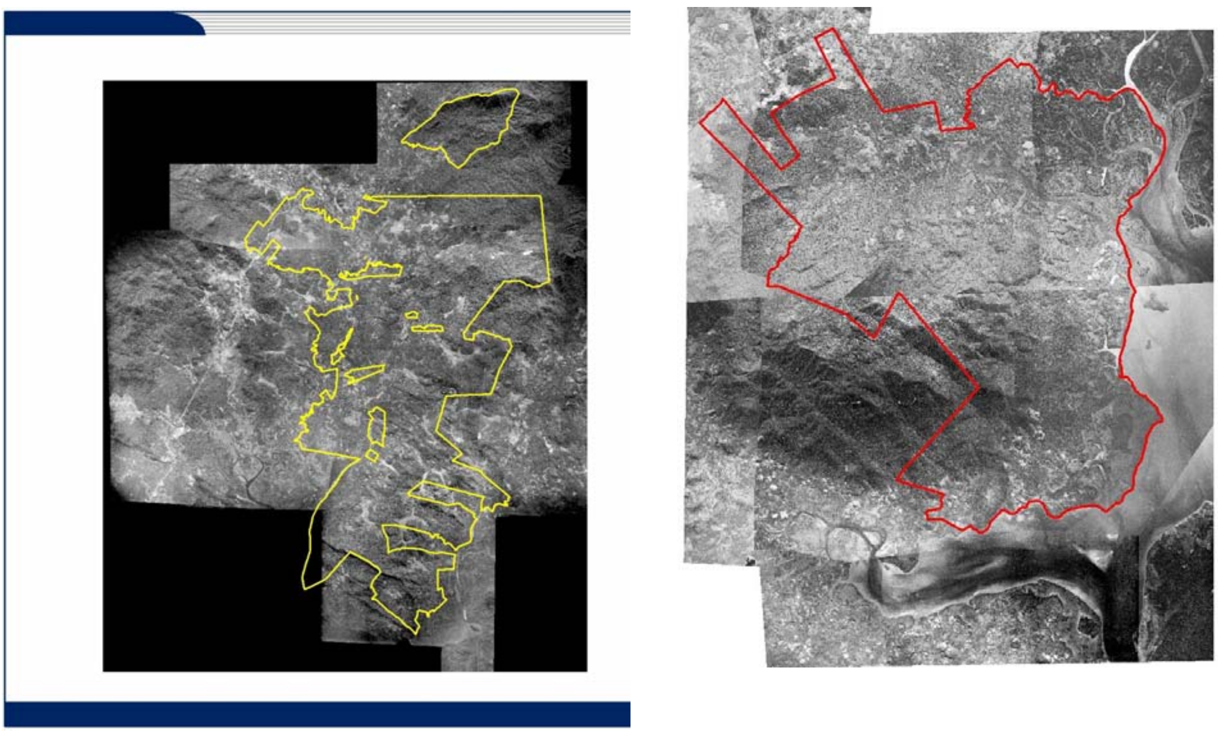

Figure 1E. Mosaic of aerial photos (1952) from GM and Itaqui Project

4. LIBS

The LIBS workshop occurred May 31st to June 1st. During the workshop, soil samples from various areas of the project were collected and sent back to Los Alamos National Laboratory for analysis.

Several additional presentations on advanced soil measurement technologies were given. These included a presentation by Lucian Wielopolski from Brookhaven National Laboratory on In Situ Non-Invasive Soil Carbon Measurement, and a presentation by Jim Reeves of AMBL and EQL, BARC, on the potential of spectroscopic methods for rapid analysis of soil samples.

In addition, the results of the soil survey conducted at the projects were presented by TNC and SPVS. The workshop presented a great opportunity to discuss and provide input into the methodologies used to conduct soil sampling on the projects, resulting in a protocol to measure and monitor soil carbon. A proceedings report of this work was written and submitted to DOE.

Task 2: Remote Sensing for Carbon Analysis

Summary of Objectives

Reducing carbon inventory costs can help to ensure cost-effective production of offsets in the land-use change and forestry sector. One method of reducing carbon inventory and monitoring costs is through the use of remote-sensing technologies. However, there are distinct limitations to satellite imagery when used in tropical environments to monitor fine-scale, or project level land-use change, especially on heterogeneous landscapes. Selective logging, small road development, and appearance of small farm holdings (¼ hectare or less) that indicate colonization of a region or intrusion into a reserve are usually too small to be picked up by the coarse resolution of Landsat or Spot images. Also, the persistent cloud cover in these areas often makes it difficult to obtain satellite coverage on a time scale that is useful for local monitoring.

The Nature Conservancy and its partners are working together with Winrock International to develop low-cost digital camera systems to support large-scale aerial surveys of remote regions. Since this research project launched last year, additional applications of M3DADI have been identified and the research objectives have been expanded accordingly. The expanded objectives of this research are to:

- Find out whether measurements of crown diameter or vegetation area and height made from the air can be sufficiently correlated to biomass to accurately calculate the carbon storage in vegetation;.
- Determine how well M3DADI can monitor carbon inventories on heterogeneous landscapes, such as open forest pine savanna or patchy natural regeneration;
- Assess the effectiveness of M3DADI in measuring carbon storage in closed canopy systems;
- Assess M3DADI as a stratification tool; and
- Compare the costs of M3DADI to traditional inventory approaches.

Some regression equations for calculating above-ground biomass based on crown diameter measurements and height obtained from digital imagery have already been developed, however, it is necessary to improve these equations in order to better describe the correlation between carbon storage measured through ground sampling and carbon storage calculated using digital imagery. Furthermore, these equations were developed for relatively homogenous landscapes and for a specific type of vegetation, closed forest. This research applies digital imagery to the measurement of carbon in heterogeneous landscapes composed of shrub, tree, palm, hardwood, and conifer mixtures, and in forests of varying ages in the Mississippi Delta.

A comparison of the results of typical inventory methods and digital imagery shed light into which of the two techniques gives the most accurate results at the lowest cost.

M3DADI Results

<u>Mississippi Delta</u>

The final report entitled "Field Measurements and Analysis from Delta National Forest" was completed by Winrock International in September 2004. A summary of key points and findings follows below.

In October 2003, a 1.5 kilometer spaced-grid of the Delta National Forest in Mississippi was flown. Field data was also collected during the reporting period to accompany the imagery. A total of 330 trees in 26 plots were measured. Additionally the dimensions of 44 trees, spanning a dbh range from 5 to 113.5 cm and a height range from 3 to 42.6m were measured. This provided an adequate database for preliminary calibration of M3DADI for use in the region. It is not possible to measure dbh from aerial imagery, therefore alternative facets of the trees have to be used to determine biomass. Two components that can be measured are tree heights and crown area. To relate biomass to these two factors would require the harvest of at least 30 trees. As this was not feasible the biomass of each tree was estimated from the dbh and height gathered from the DNF, and then estimated biomass was modeled against crown area, multiplied by height. The study has produced two equations relating vegetation facets measurable in M3DADI imagery with biomass:

Biomass carbon (t C/ha) = 0.0001*(Crown*Height)$^{1.1212}$
Biomass carbon (t C/ha) = 0.0006*Crown Area$^{1.6053}$

Greater precision results from using the equation incorporating height but the option of not measuring height is preserved with the alternative equation. The study also allowed the number of measurement plots that would be required to calculate biomass through field measurement for comparisons with the efficiency and cost effectiveness of M3DADI. This study estimated that carbon density in live aboveground tree vegetation in mature forest to be 115 t C/ha +- 15.8 (mean +-95%confidence interval), and that 39 plots would be required to produce estimates precise enough for carbon reporting (to within 10% of the true mean with 95% confidence)

<u>Belize</u>

<u>*Savanna Forest*</u>
The final report on the M3DADI analysis for the pine savanna in Belize was completed and submitted to NETL. The results given in the complete report are excerpted below:

<u>Allometric equations</u>
The highly significant allometric equations of biomass carbon versus height and crown area for all tree groups were linear in shape, went through the origin, and had high r^2. On average the biomass carbon per tree for the broadleaf species is higher than for the pine species, most likely caused by the higher wood density and more branching for the broadleaf species. However, when we combined both data sets, the resulting equation maintained its high significance and high r^2. The form of the equations for trees is very similar to those based on basal area and tree height, as might be expected. These are the first set of such equations to our knowledge.

The equations for the palmettos and shrubs were also linear but with lower r^2 than for trees. The biomass carbon of the palmetto clumps and thickets are markedly different from each other although their height range is very similar. On average the palmetto clumps contain about 4.5

times more biomass carbon per meter of height than the palmetto thickets. Compared to the shrubs, palmetto clumps contain about 20 times as much biomass carbon per meter of height and palmetto thickets about five times as much.

Patches of dense grasses contained about twice as much biomass carbon as sparse grasses.

Estimated carbon stocks

The mean total aboveground biomass carbon density for the 77 plots was 13.1 Mg C ha^{-1} with a 95% confidence interval of 2.2 Mg C ha^{-1} or ±16% of the mean. Fifty-one percent of the total carbon density was contributed by the trees, 21% by palmettos, 4% by shrubs, and 25% by grasses. Pines were present in 74 % of the plots and on average accounted for 35 % of the total carbon density.

Although trees account for a large proportion of the carbon stock in aboveground biomass, it is clear that at low tree densities, the palmettos and shrubs are a significant carbon pool. More than half of the sample plots contain less than 5 Mg C/ha in trees, and their total carbon stock is up to 2 to 10 times more than in trees.

The coefficient of variation (CV) was high for all vegetation types, reflecting the heterogeneous nature of the system. The CV was 72 % for all components combined with shrubs being the most variable (CV of 303%) and grasses the least (CV of 31%). By examining the mean and the standard deviation for the 77 plots studied, it is possible to calculate how many plots would have to be examined in order to attain the desired ± 10 % of the mean with 95 % confidence. The estimated number of plots required is 202, or about 2.5 times more than already measured.

Error analysis in image interpretation

Across the seven plots examined by two independent image analysts, there was no significant difference in the resultant biomass carbon estimates (ANOVA, df = 1, F = 1.83, P = 0.201). Differences emerged through variation in the classification of vegetation types as well as variation in heights and crown areas. Twenty-eight trees and 12 palmettos were randomly selected for further examination. On average, crown areas measured by the two analysts differed by 22 %. Ground height differed by 0.75 m and crown height by 1.44 m leading to a mean height difference of 1.70 m (or 28% error). The absolute error in tree height was greater than for palmetto height, whereas the absolute error in tree crown area was less than for palmettos. However, on a percentage basis, height and crown area measurements of trees were less than the error for palmetto height and crown area as might be expected given the smaller stature of the palmettos compared to trees.

Time analysis

The M3DADI approach has two time-expensive steps missing from the conventional field approach—the time to prepare and load the equipment on the plane and collect the imagery and the time to process the imagery ready for interpretation. In the case for Belize, the amount of time in the air for data collection was a relatively large component of the 24 hours estimated for this step because of the time it took to fly from the closest airport to the study area and the limited air-time the plane could manage given the amount of fuel it could carry. However, there is a trade off between a larger plane with a larger fuel capacity and cost. If the airport had been closer to the study area, less time would have been needed for this step.

The largest single unit of time for the M3DADI approach is the processing and preparation of the imagery ready for interpretation—the 65 person hours it took for this step resulted in the complete processing of all the transects and the preparation of all 3D image block files. As the block files are prepared in just a few operations, essentially little time is saved by processing parts of the transects. The time needed for this step would not vary whether 30 or 230 plots were interpreted. For the field approach, the time for processing the field data is on a per plot basis for drying and weighing vegetation (usually grasses, palmettos, and shrubs) harvested in small sub-plots within the standard main plot.

The interpretation of the imagery plots, including setting up the plot circles on the imagery and establishing the attribute file in which the data are collected, took between 17 (only grasses present) to 155 (the full compliment of vegetation types) person-minutes, with an average time of 42.8 ± 6.6 person-minutes (mean ± 95 % confidence interval) or 0.71 person-hours per plot. In contrast, the field plots took on average 3.0 person-hours per plot. Transfer of the data from the imagery ERDAS attribute file to an excel spreadsheet took an additional 0.25 person-hours and transfer from the field sheets to excel took 0.75 person hours.

Using these results, Winrock estimated the total person-hours needed to collect and prepare the data for the final step in estimation of the carbon stocks (the final step is estimated to take the same length of time) for 202 plots, the number of plots needed to attain a 95% confidence interval of ±10% of the mean, is 283 for the M3DADI and 865 for the conventional field approach. The level of skill needed for the M3DADI approach is likely higher than for the conventional field approach and thus likely to command a higher pay scale per hour. However, given that the person-hour difference is about a 3-fold factor, salaries for the M3DADI approach would have to be about three times higher than for field foresters to have total cost to be about the same. From their experience, this is not the case.

1. Belize – Closed Forest

Field data collection methods were developed for the closed forest and sent to Programme for Belize. The only additional data that was necessary to collect were for developing a relationship between crown area and dbh, in order to be able estimate biomass from the imagery data.

- Data collected on dbh, total tree height, and crown diameter for a range of trees (minimum 40) that encompass the smallest to the largest diameter trees and represent most species.

- Developed procedures to get as accurate measurements as possible

Imagery for the closed forest is being processed into 3D block files

2. Cost Comparison

For comparing the cost-effectiveness of the M3DADI approach with conventional field methods in the pine savanna, Winrock collected data only for the time (in person-hours) involved in each of the various steps. Different steps in both approaches require different skill sets –e.g. an M3DADI image processor will require a background in GIS and image software whereas someone working in the field as an assistant will require fewer skills. Although Winrock only compared the time components in this analysis, they will discuss the implications to the total cost with respect to the kind of skills needed. They also focus only on the variable costs of collecting the data and performing the analyses, and did not include for example the cost of renting the plane (with fuel) with a pilot nor the cost of renting a vehicle (with fuel) for the field work. It was assumed that the fixed costs involved would be the same for both methods. The overall goal is to compare the total person-hours needed by both approaches to collect the same set of data to achieve a 95% confidence interval of ±10% of the mean based on the sampling error only (this will be a function of the number of plots).

For the M3DADI approach, Winrock collected the following time data for the 77 imagery plots: collection of the original imagery data (time to prepare the equipment and load onto the plane, the flight time, and downloading data time), processing the imagery into the 3D block files, selecting the images to interpret, setting up the images with the nested plots and the GIS attribute files, collecting the data from the images, and converting the imagery data into excel files ready for combining with the allometric equations. For the conventional field approach, Winrock collected the following time data for establishing 32 plots: travel to and from the study area and between plots, collection of all field data in each plot, drying and weighing plant samples (mostly grasses from sub-plots), and entering the data into an excel file for combining with allometric equations. The two sets of time data for these two approaches is the time needed to accomplish the same task—collect all field data for estimating the carbon stocks in live vegetation and prepare it for the final step in the analyses.

<u>LIDAR and Quick bird in Northern California</u>

Our landscape-scale remote sensing test showed that Lidar-derived forest carbon estimates show lower uncertainty than QuickBird-derived estimates and that local field measurements are essential for both systems. We found forest carbon densities higher than Amazon rainforest. In addition, we developed equations that other organizations can use to calculate forest carbon from Lidar data in similar forests elsewhere in California. Analyses of the transect data indicate that certain species are shifting upward in elevation in response to warmer temperatures. These shifts are changing habitat, fires regimes, and forest carbon patterns. We presented results of the research at the California Climate Change Conference and to the USDA Forest Service Regional Leadership Team. We distributed the data to staff of the Nature Conservancy and the USDA Forest Service. Manuscripts for scientific publication are in progress.

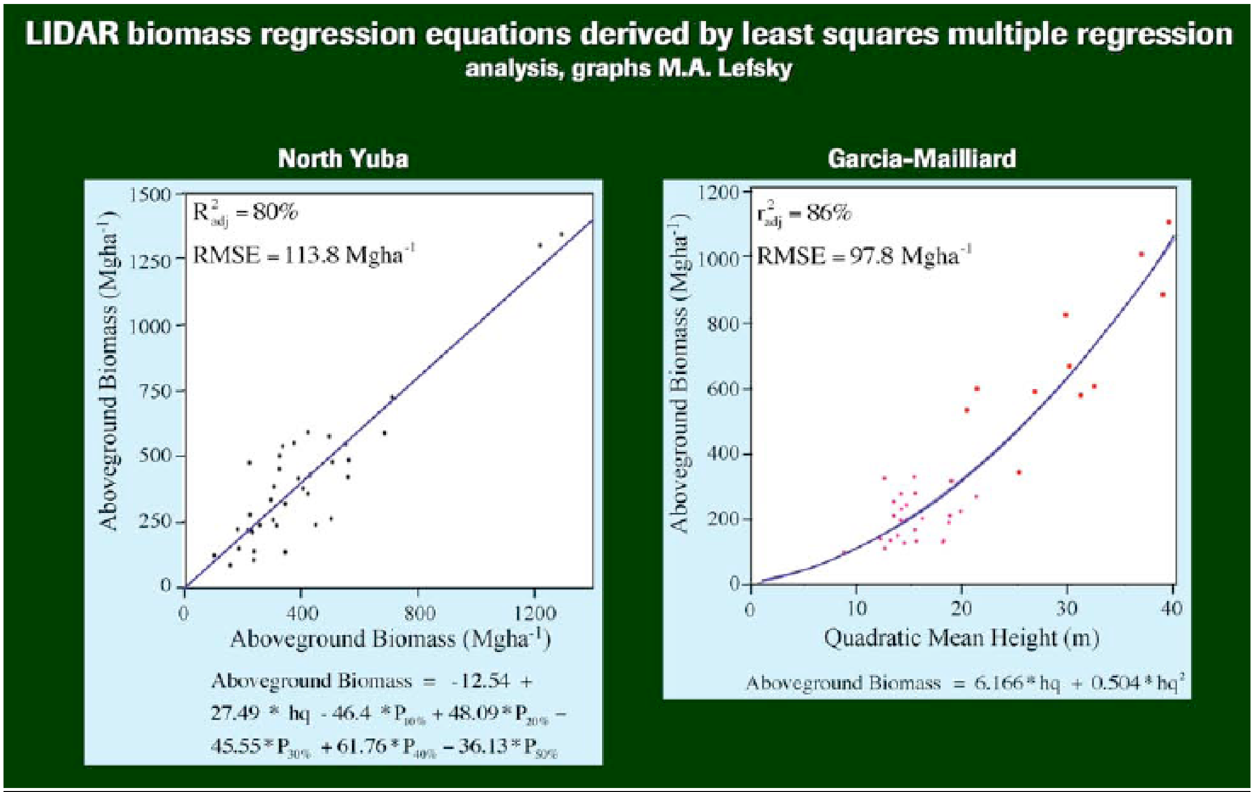

Figure 2A. Lidar biomass regressions

Task 3: Baseline Method Development

Summary of Objectives

To quantify the CO_2 emissions reductions resulting from the protection of forests you must be able to quantify the environmental damage that would have occurred had the forest not been protected. This is a challenging task, demanding that the probable future management of a land area be predicted so that changes from the anticipated use can then be measured and the difference between the two quantified.

Emissions avoidance projects preserve carbon stocks (in soils, forests, etc.) in areas that are demonstrably threatened with land conversion or degradation (e.g. high-grading). Methods to estimate the timing and location of deforestation or other management activities that lead to land use are not yet well-developed.

Predicting land-use trends is one of the most challenging components of baseline assessment in forest-based carbon offset projects. An appropriate method for making these assessments is critical for producing accurate and precise carbon estimates. Spatially explicit models are a sound way of projecting baselines. Deforestation or land-use emissions trend models – GIS and software-based analyses that allow a more accurate estimation of the "without-project" baselines – need to be refined and applied to project sites in order to evaluate their effectiveness.

The overall goal of this task is to develop and refine land cover change models and to test them by applying them to a diverse suite of project sites within The Conservancy's portfolio. We originally proposed applying models to five international and three domestic sites where The Conservancy and its partners are developing and implementing projects. Though the sites have changed, we still plan on conducting five international and three domestic baseline studies. The models will asses the risk posed to these forests and analyze expected carbon storage trends.

Two different models are being used: GEOMOD, a computerized geographic model requiring a spatially referenced set of equally dimensioned digital grid (raster) maps as inputs, and The Conservancy's FRCA model. The models determine rates of deforestation, identify the location of areas converted from forests, calculate the percentage of the total study area deforested, and determine existing forestation rates. At two sites, both approaches will be used in order to compare them. Specific objectives under this task include:

- Identify sites for study by screening their potential contribution to the protection of biological diversity and carbon sequestration.
- Gather information on raster maps, or digital coverage of roads, hydrography, population data, and climate difference over the project area.
- Determine rates of deforestation, identification of the areas converted, calculation of the percentage of the total study area deforested, and rates of forestation.
- Convert GEOMOD or other output maps and data into time-series display module called ECOPLOT or into summary table format.
- Test variations of the spatial modeling approach, including FRCA.
- Assess variations in terms of credibility, transparency, portability, and cost-effectiveness.
- Explore how baseline uncertainty might be quantified and treated.

Results

Topical reports on these baseline studies were completed for seven sites. Specifically the were completed for sites in coastal temperate Chile, the central Peruvian Amazon, two regions of the Atlantic forests in Brazil, the Albemarle Peninsula of North Carolina, Northwest Florida longleaf pines, the Clinch and Powell River Valleys of Virginia.

Both of the primary methods used, GEOMOD and FRCA detect and measure the rate of land cover change in a time series of satellite images, and use regression analyses to determine which areas are most likely to be deforested in the future. However, FRCA may be more portable than GEOMOD because it can be conducted using both ARC and IDRISI software, whereas GEOMOD depends upon IDRISI. Below are examples, not comprehensive of the baseline work that was conducted.

<u>Brazil</u>

<u>Guaraqueçaba</u>

In the Guaraqueçaba Environmental Protected Area and ARRP GEOMOD was applied, using land use change data from 1986 to 2002 to determine "without project scenario" (baseline) or "the business as usual" scenarios. (Table 5)

Table 5. Possible scenarios for projects

Without project scenario	With project scenario
Deforested areas, where economic activities are already taking place, tends to stay deforested.	Restoration in deforested areas
Areas close to roads and rivers are under high risk of deforestation	Establishment of private reserves to protect in perpetuity areas with high risk of deforestation
Lack of economic alternatives contributes to the deforestation and degradation of forests and soils.	Development of economic alternatives compatible with environmental conservation
Acceleration of degradation process in private areas and consequent exhaustion of natural resources	Monitoring of land use change and promotion of conservation practices and sustainable use of natural resources

Only part of the Guaraqueçaba environmental protected area was used in the regional analysis. A clear tendency of deforestation was observed in the study area. A total deforestation of 7,120.8 hectares (average of 178.02 ha per year) and a natural regeneration of 2,958.0 ha were projected during the 2000 - 2040 period, resulting in a predicted net forest loss of 4,163.1 ha during 40-year period, or an average of 104 ha per year.

In the projects, the annual deforestation rate was 0.17 % for the Itaqui Project, 0.12 % for the Cachoeira Project and 0.05 % for the Morro da Mina Project, and 0.06 %, 0.05 % and 0.001 % for the regeneration annual rate, respectively.

In a 40-year period, the projects would generate the following additional carbon benefits (above the 'without project baseline'):

- For the Itaqui Project, a total of 86.303,3 t C would be generated, along a 40-year period, resulting from the planting of native species and natural regeneration of 37,554.7 t C due to preservation of forests (deforestation avoided), totaling 120.120,5 t C or 440.481, 7 T CO2.

- For the Cachoeira project, a total of 46,543.1 t C would be generated, within a 40-year period, through measures applied to avoid deforestation and 120,918.5T C for the regeneration of pastures (planting and assisted regeneration), totaling 167,461.6 t C or 614,081.7 t CO2

- For the Morro da Mina Project, a total of 27,531,2 t C would be generated, within a 40-year period, resulting from the planting of native species and natural regeneration and 17,850.0 t C through measures applied avoid deforestation, totaling 45,313.1 t C or 166,163.1 t CO2.

Besides the carbon benefits, the projects are also expected to generate several additional benefits. These include biodiversity conservation, forest restoration in degraded areas, protection and enrichment of secondary forests, protection of remnants of pristine forest, protection of fresh water resources, soil erosion control and generation of income for local communities around the project area, through sustainable rural and use of economical models compatible with biodiversity conservation.

La Selva Central, Peru

The Nature Conservancy and a local organization in Peru, the Fundación Peruana para la Conservación de la Naturaleza (ProNaturaleza), are planning a project to restore moist tropical forest at the transition from Amazon rainforest to the Andean Highlands in the Selva Central area of Peru. We have defined a 4800 km^2 area of primary and secondary forest, agricultural land, and pastures that lie in a buffer zone around the Yanachaga-Chemillén National Park, the San Matías-San Carlos Protection Forest, and the Yanesha Communal Reserve, three protected areas at the heart of the Ucayali and Yungas ecoregions. The area hosts unique landscapes, such as montane cloud forest, unique flora, including a myriad of orchids, and threatened bird species.

Staff from the Nature Conservancy, ProNaturaleza, and the Universidad Nacional Agraria La Molina, led by Nature Conservancy scientist Patrick Gonzalez, have developed an improved forest restoration carbon analysis (FRCA) method. Building on the lessons of past Nature Conservancy experience, FRCA constitutes an integrated spatial analysis of biodiversity, forest inventory, and remote sensing data that quantifies land use change and estimates the carbon sequestration baseline of a forest restoration project in a biologically important area.

We completed the FRCA for La Selva Central in June 2004. Patrick Gonzalez presented preliminary results May 5, 2004 at the DOE Third Annual Conference on Carbon Capture and Sequestration. In August 2004, Dr. Gonzalez presented the final results to the 89th Annual Meeting of the Ecological Society of America (ESA) in Portland, Oregon (Gonzalez et al. 2004) and to collaborators in Peru. A manuscript for publication in a scientific journal and a DOE topical report are in progress.

The following abstract summarizes the FRCA Peru results:

Conversion of tropical forest to agricultural land and pasture has reduced the extent of tropical forests and the provision of ecosystem services. Deforestation releases carbon to the atmosphere, contributing to climate change. At the same time, climate change is changing the potential distribution of vegetation zones. Research in the Selva Central region of Peru, a transition zone extending from Amazon rainforest to the Andean Highlands, has quantified the pattern of past land use change and has projected possible future patterns. In a 4800 km^2 area of moist tropical forest and other land that forms a buffer zone around a national park, a national forest, and a communal reserve, analyses of Landsat data show that net deforestation from 1987 to 1999 exceeded 200 km^2.

Forest inventories of 24 sites covering 39 ha identified trees of 512 species in 69 families, with 86% of the trees in the primary forest sites representing old-growth species and 76% of the trees in the secondary forest sites representing successional species. The fraction of trees representing old-growth species is a measure of success in the site conservation plan. The density of trees of diameter > 10 cm was 366 trees ha^{-1} in primary forest and 533 trees ha^{-1} in secondary forest, although the average diameter was 24 ± 15 cm in primary forest and 17 ± 8 cm in secondary forest.

Local volume equations applied to the field data and species-specific wood density measurements show an above-ground live standing biomass density of 240 ± 30 t ha^{-1} in the primary sites and 90 ± 10 t ha^{-1} in the secondary sites. Biomass accumulation over time followed a convex trajectory (Figure 3A). Net deforestation caused the emission of 1.2 million t carbon (min. 1 million, max 1.3 million t) in 12 years.

Multivariate statistical analysis permitted determination of the relative weights of six different factors in explaining observed deforestation and reforestation patterns. The six factors include: distance to cleared area, elevation, distance to river, distance to road, slope, and distance to towns. In addition, bivariate statistical analysis of the relationship of 1987-1999 observed deforestation and reforestation patterns to each of the six factors generated probability functions of deforestation and reforestation for each factor (Figure 3B). The weighted sum of probabilities yielded a pixel-by-pixel quantification of the 1999-2011 probabilities of deforestation and reforestation (Figure 3C). The analyses projected a 1999-2011 net deforestation rate of 0.3%±0.05% (Figure 3D).

Restoration of 7000 ha of forest through the natural regeneration and plantation of native species could sequester 230 000 t carbon (min. 140 000 t, max. 310 000) above baseline reforestation in the period 2006-2035 (Figure 3E). Under the U.N. Framework Convention on Climate Change, carbon emitters may possibly provide funds to the reforestation project in order to gain the rights to this carbon. Conservation of 10 000 ha of municipal forests could prevent the emission of another 10 000 t (min. 8 000 t, max. 14 000 t) carbon. Research in progress is examining the altitudinal migration of vegetation zones due to climate change. This data will allow the Yungas ecoregional plan to set priorities that account for climate change.

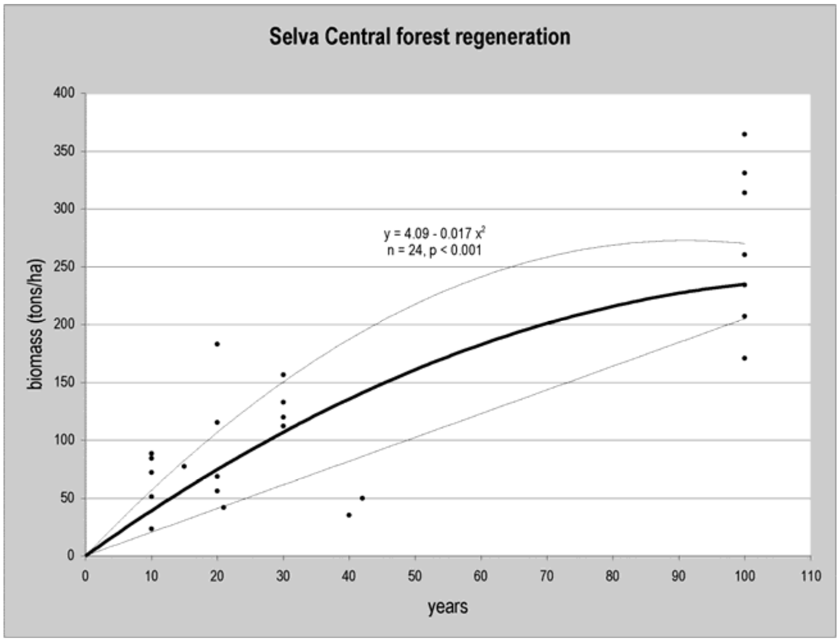

Figure 3A. Biomass accumulation curve based on 24 inventory plots in primary and secondary forest at La Selva Central, Peru (Gonzalez et al. 2004).

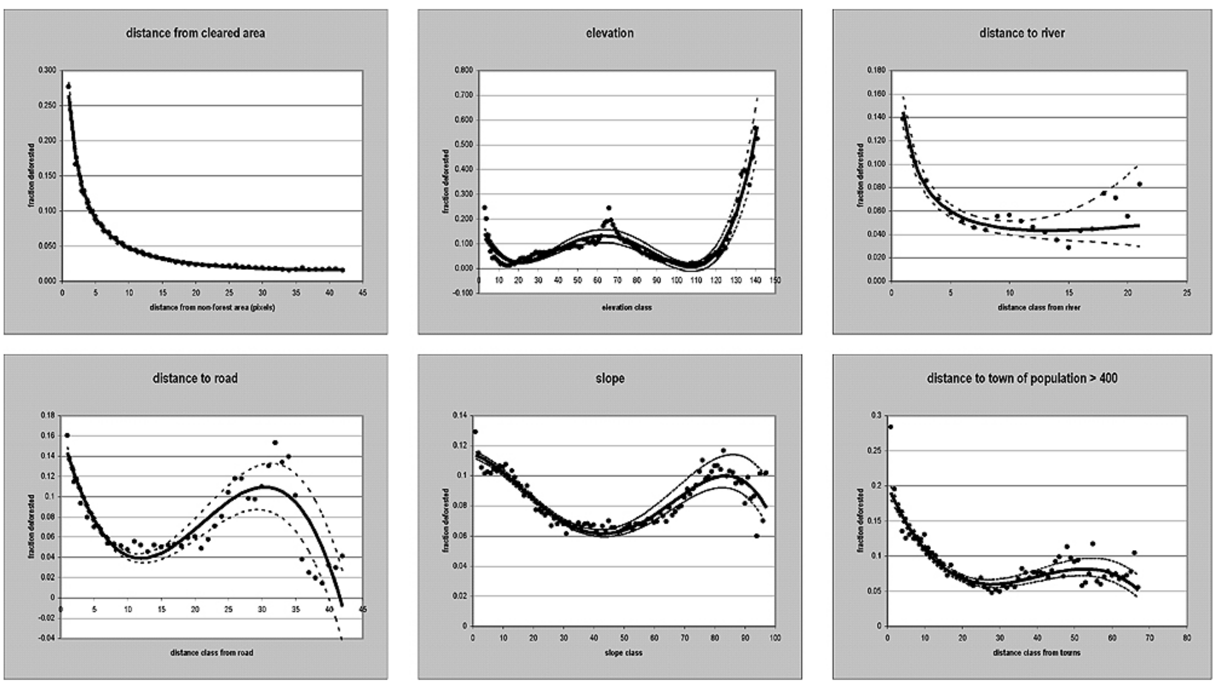

Figure 3B. Relationship of 1987-1999 deforestation probability to six factors: distance to cleared area, elevation, distance to river, distance to road, slope, and distance to towns (Gonzalez et al. 2004).

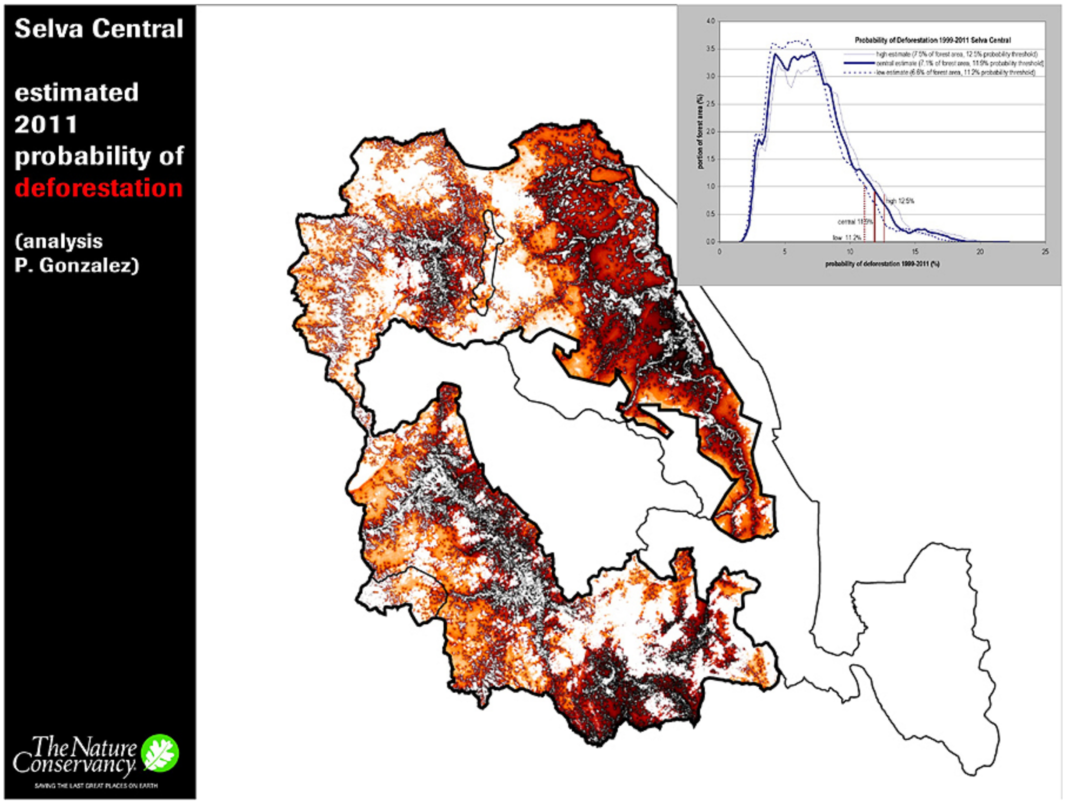

Figure 3C. Probability of 1999-2011 deforestation, based on analysis of observed 1987-2011 deforestation and multivariate analysis of six explanatory factors. The graph shows the probability distribution (Gonzalez et al. 2004).

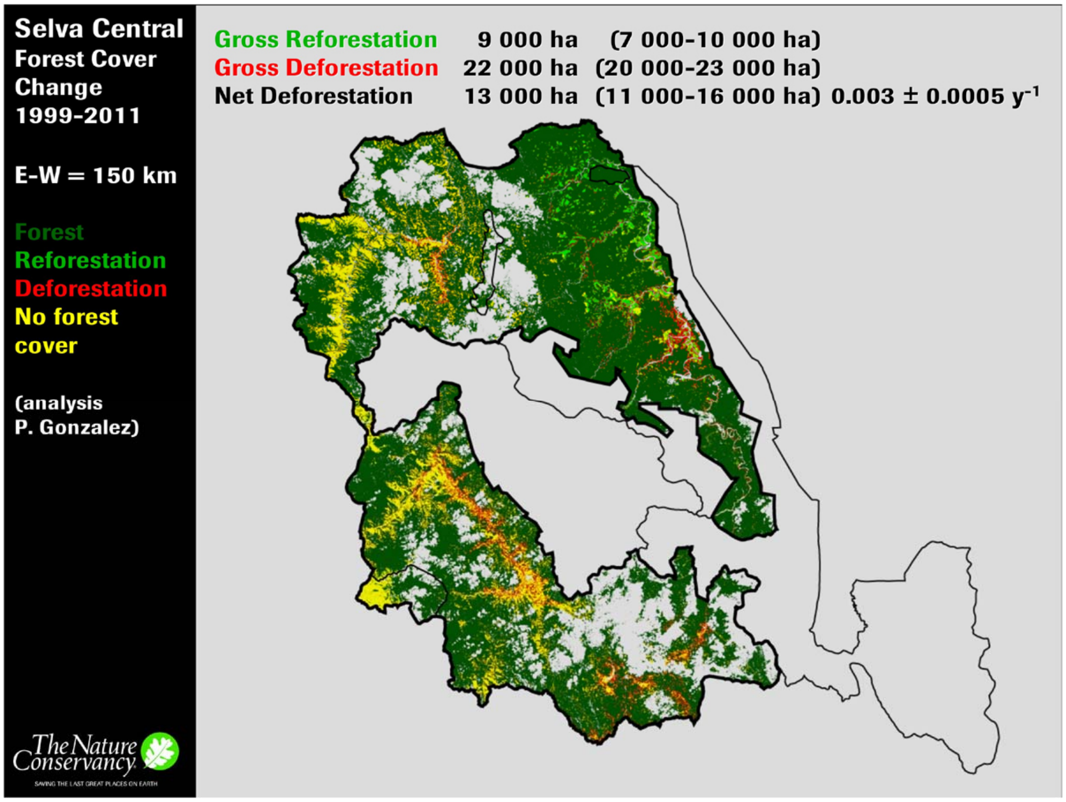

Figure 3D. Projected forest cover change 1999-2011, based on FRCA. Red = deforestation, yellow = no forest, light green = reforestation, dark green = forest (Gonzalez et al. 2004).

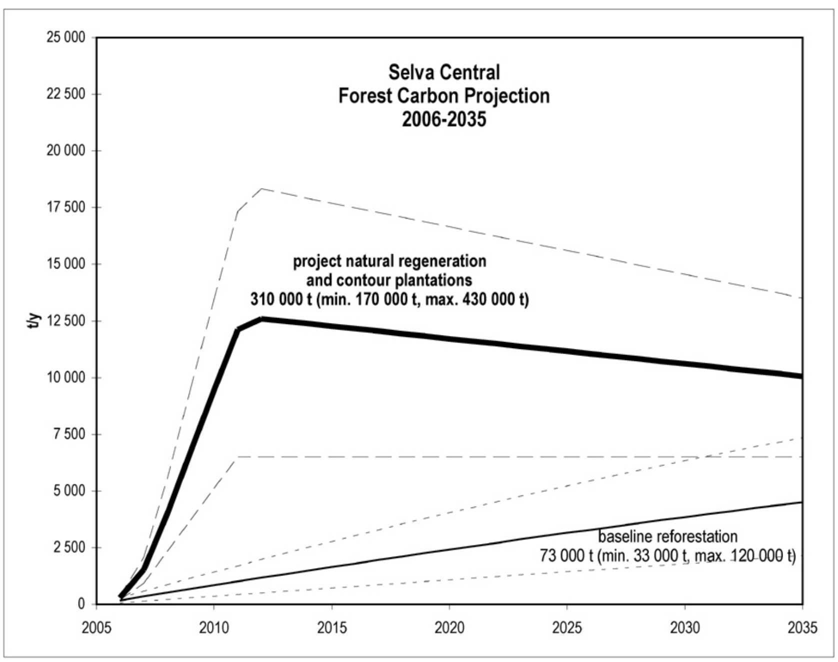

Figure 3E. Forest carbon baseline for the planned 7000 ha reforestation project for 2006-2035, based on FRCA. The dark line shows the net project carbon sequestration in addition to the baseline reforestation. Dashed lines indicate the maximum and minimum estimates (Gonzalez et al. 2004).

Sul da Bahia, Brazil

A consortium of conservation organizations, including The Nature Conservancy, Conservation International, and the Instituto de Estudos Socio-Ambientais do Sul da Bahia (IESB), are developing a project to restore moist tropical forest in Sul da Bahia, Brazil. The region contains some of the last remaining fragments of Mâta Atlântica, a threatened forest type along the coast of Brazil that harbors significant floral and faunal biodiversity. The project proposes to work with local landowners in the buffer zones of the Serra do Conduru State Park and the Una Biological Reserve to reforest degraded land and to conserve threatened parcels.

We have completed an analysis of forest cover change using Landsat images from 1986 and 2001 (Figures 3F, 3G). The remote sensing analyses show net deforestation of 4% of the 1000 km^2 project area (Table 1).

We are planning forest inventories to quantify forest species richness and forest carbon in the project area. We are also planning to develop allometric equations for Mata Atlantica in Sul da Bahia. These will permit us to project a future forest carbon baseline for the planned project.

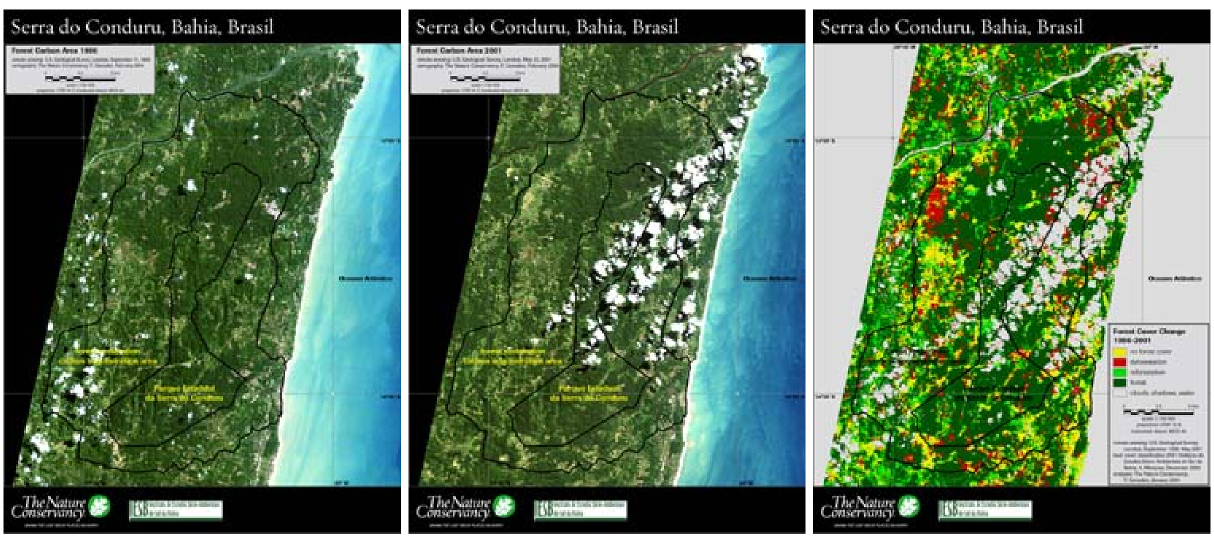

Figure 3F. Serra do Conduru, Bahia, Brazil. Left: Real-color 1986 Landsat image. Middle: Real-color 2001 Landsat image. Right: Forest cover change 1986-2001 (data USGS, IESB, analysis P. Gonzalez, A. Marques).

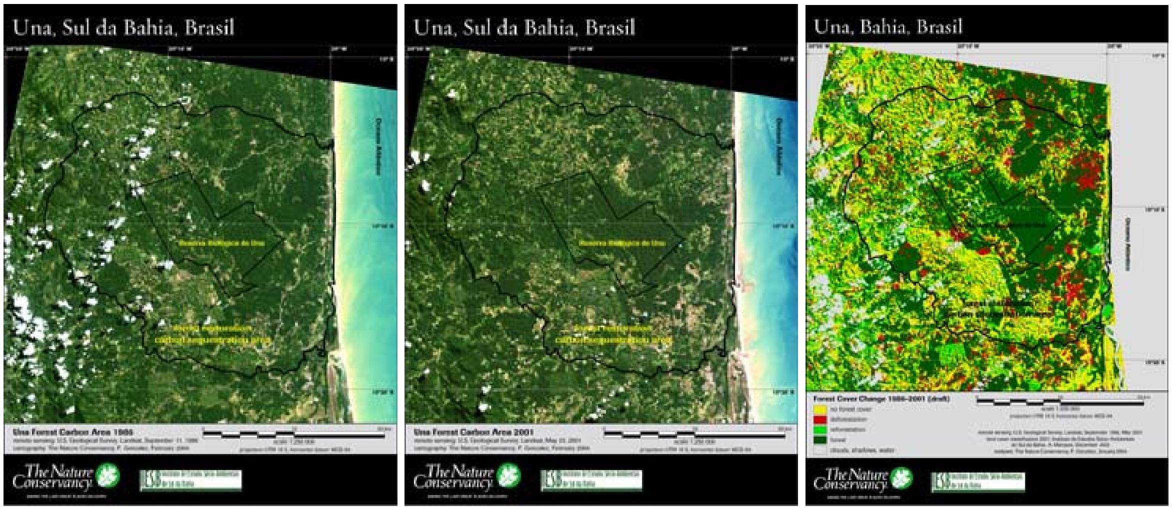

Figure 3G. Una, Bahia, Brazil. Left: Real-color 1986 Landsat image. Middle: Real-color 2001 Landsat image. Right: Forest cover change 1986-2001 (data USGS, IESB, analysis P. Gonzalez, A. Marques).

Table 6. Forest cover change, Sul da Bahia, 1986-2001 (data USGS, IESB, analysis P. Gonzalez, A. Marques).

	Conduru area		Una area	
	ha	fraction	ha	fraction
forest	13 000	0.59	28 200	0.46
reforestation	3 300	0.15	9 100	0.15
deforestation	2 400	0.11	7 100	0.11
no forest	3 100	0.14	17 500	0.28
clouds	3 800	NA	3 300	NA
total	25 700	1.00	65 200	1.00

Valdivia, Chile

The Nature Conservancy and the Universidad Austral de Chile are working to conserve and restore temperate rainforest in the Valdivia area of Region X in Chile. In September 2003, Jorge Gayoso and colleagues Universidad Austral de Chile completed a comprehensive compilation of forest biomass measurements and species-specific allometric equations for Southern temperate evergreen forest in Chile, much based on original measurements (Gayoso and Schlegel 2003). In June, two of our Universidad Austral de Chile collaborators published their research on growth patterns of Southern Beech in Valdivia (Echeverria and Lara 2004).

Table 7. Above- and below-ground carbon in the major forest types of Region X in Chile (Gayoso and Schlegel 2003).

Tipo Forestal	**Estructura**	**Parcelas**	**Carbono (tonC/ha)**		**Desv. estándar**	
		(n)	**aéreo**	**raíces**	**aéreo**	**raíces**
Alerce	Adulto	28	214,3	47,5	91,6	20,1
	Adulto-Renoval	6	132,5	31,6	47,4	11,9
	Renoval	9	166,3	37,4	78,1	18,7

Tipo Forestal	Estructura	Parcelas	Carbono (tonC/ha)		Desv. estándar	
		(n)	aéreo	raíces	aéreo	raíces
Ciprés Cordillera	Adulto	-	-	.	-	-
	Adulto-Renoval	-	-	-	-	-
	Renoval	2	61,3	12,0	-	-
Lenga del Norte	Adulto	44	175,5	42,9	106,5	27,2
	Adulto-Renoval	4	160,9	30,6	53,1	10,1
	Renoval	12	109,5	23,5	85,5	18,9
Coihue de Magallanes	Adulto	12	176,6	40,1	89,5	28,1
	Adulto-Renoval	2	89,3	17,1	-	-
	Renoval	8	58,8	12,2	41,5	7,9
Roble-Raulí-Coihue del Sur	Adulto	16	159,8	35,7	74,0	16,4
	Adulto-Renoval	16	95,2	21,1	60,6	13,4
	Renoval	86	79,4	17,9	50,1	11,8
	Renoval BOMASIL	37	93,2	20,4	36,8	8,1
Coihue-Raulí-Tepa	Adulto	98	178,1	41,0	104,6	24,5
	Adulto-Renoval	28	156,2	35,5	78,5	17,8
	Renoval	-	-	-	-	-
Siempreverde (SV)	Adulto	-	-	.	-	-
Subtipo	Adulto-Renoval	-	-	.	-	-
Renoval de Canelo	Renoval	72	76,6	17,5	47,3	11,3
	Renoval Hueicoya	12	129,5	27,6	14,1	3,5
	Renoval Lenca	15	114,5	24,1	17,8	4,4
Siempreverde	Adulto	4	67,3	15,5	45,2	10,9
Subtipo Tepu	Adulto-Renoval	-	-	.	-	-
	Renoval	1	110,7	21,9	-	-
Siempreverde	Adulto	-	-	.	-	-
Subtipo Mirtáceas	Adulto-Renoval	-	-	.	-	-
	Renoval	6	130,0	26,9	110,9	21,7
Siempreverde	Adulto	161	140,9	35,2	90,4	22,7
Subtipo	Adulto-Renoval	48	106,7	28,8	61,2	18,6
Coihue de Chiloé	Renoval	37	106,0	26,3	55,7	15,3
Siempreverde	Adulto	177	141,9	31,9	87,6	19,7
Subtipo Siempreverde	Adulto-Renoval	25	121,0	26,7	65,5	14,1
	Renoval	43	103,8	23,0	83,3	18,0
Siempreverde	Adulto	26	217,6	48,6	96,7	22,0
Subtipo Coihue	Adulto-Renoval	8	90,0	21,5	40,7	10,7
	Renoval	38	101,2	22,3	54,7	11,8

Antonio Lara and colleagues finished a report (Neira et al. 2004) of the results of analyses of land cover change in a 2300 km^2 area based on Landsat images from 1986 and 1999 (Figure 3H). The results show a loss of 11% of native forest area in 14 years. They also used the GEOMOD software to project future deforestation of a 500 km^2 subset of the area.

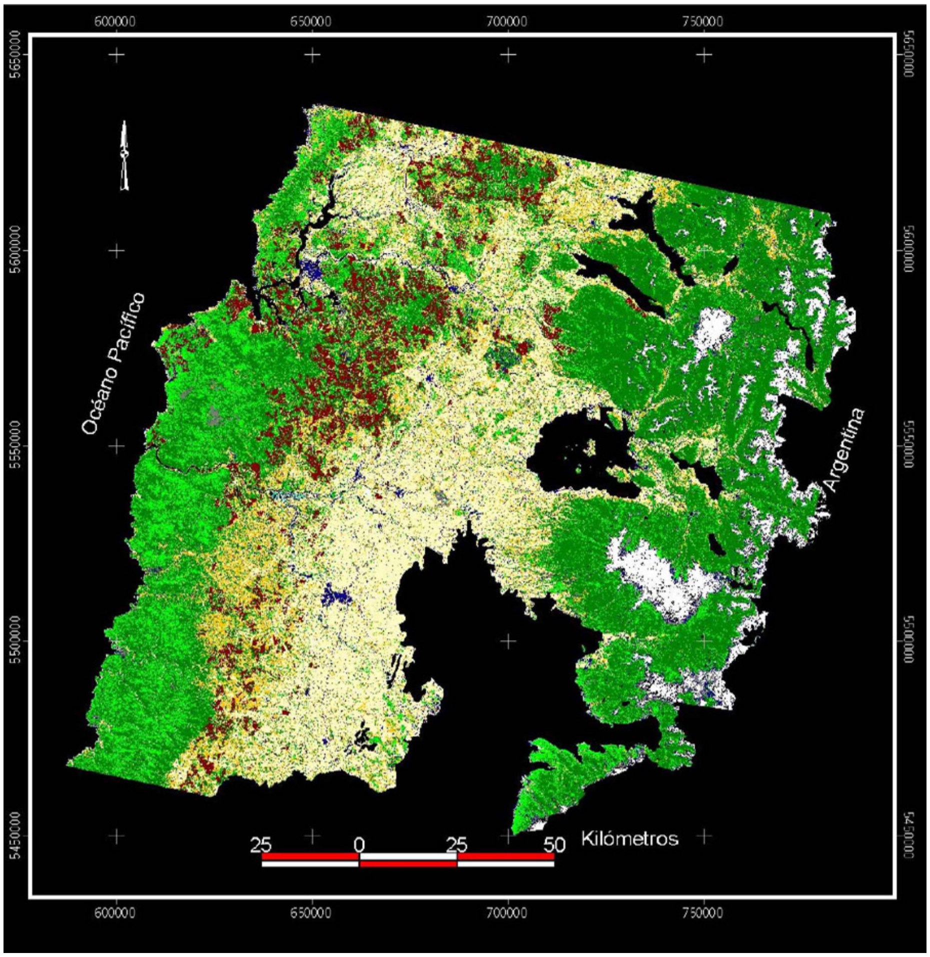

Figure 3H. Land cover 1999, Valdivia, Chile (Neira et al. 2004).

Task 4: Third-party technical advisory panel meetings

Results

The report on baseline and leakage methodologies that was based on research presented during the first TAP meeting in 2002 was completed and was presented to DOE as a topical report.

The 2003 TAP meeting took place on Sept. 11th and 12th at The Nature Conservancy's office in Arlington, Virginia. The meeting focused on presenting the results of the Cooperative Agreement so far, and on evaluating specific carbon inventory and baseline methods. The panelists who participated were: Dr. Richard Birdsey from the USDA Forest Service, Dr. Brian Murray from Research Triangle Institute, Ben de Jong from ECOSUR Institute, and our returning panelist, R. Neil Sampson from The Sampson Group. Presentations were submitted to DOE. Abstracts from the research presented have been collected and were put together in a report and submitted to DOE.

The Nature Conservancy centered discussion around key questions for each research topic.

Carbon Inventory Key Questions

1. For forest inventory sampling areas, what are the advantages and disadvantages of systematic sampling and other methods? How do the various methods vary in scientific accuracy, cost, and the ability to quantify uncertainty?
2. What cost-effective methods would you suggest for developing taxon-specific or ecoregion-specific volume equations for tropical areas?
3. To what extent can aerial videography, IKONOS, and other remote sensing technology reduce the time and money required for continuous monitoring of forest inventory plots? What are other emerging alternatives?

Discussion

Discussion centered on the cost and accuracy of M3DADI compared to other inventory methods. Questions were raised on whether simply using the USDA Forest Service's Forest Inventory and Analysis data on carbon sequestration, which is regularly collected and compiled in look-up tables, would be a more efficient methodology. While using FIA data may be cheaper, panelists agreed that M3DADI is much more accurate than the look up table.

Remote sensing technologies will be able to reduce time and money spent on forest inventory plots, but they will not be able to completely eliminate on-the-ground work. Field work will always be critical to validate information. New methods such as M3DADI can be integrated with traditional sampling methods.

There was no consensus on whether taxon-specific or species-specific equations are needed. Lumping all species together may not be right in all cases, but panelists mentioned that there is a big opportunity to mine research that already exists. It may not be necessary to do destructive sampling in all cases, and it could be limited to just filling in some missing data points, such as for large trees.

One significant advantage of M3DADI was identified during the meeting. Because data for M3DADI is collected digitally, it is essentially a snapshot of the project frozen in time. It is easy to go back at a later point in time to reanalyze the data, whereas you can't go back in time to re-measure field data because the "field" will have changed.

While M3DADI may not be significantly cheaper than traditional options at the moment, current costs include many "learning curve" costs, which should be reduced when the technology is fully developed. As cost comparison is being undertaken under Task 2, and will soon be complete.

Less accurate remote sensing methods, such as satellite imagery could be used on an annual basis for basic monitoring of the project. Such methods could also be used to measure certain carbon pools or areas where there is not expected to be large increments of change and the project does not want to spend money on more rigorous methods.

Another general comment made by the Panel was that no one approach to carbon inventory is the best. When deciding what method to use, one must look at accessibility, what knowledge people in the field have, ecosystem characteristics, status of investment, and if someone has already researched data that can be used. The Panel also reaffirmed that the carbon inventory methods, such as nested plots, that Winrock and TNC partners use are accurate and efficient.

Soil carbon emerged as an area that needs further research. The general equations for soil are not as well-developed as the general equations for standing biomass. Panelist suggested that while it is expensive to measure soil carbon, it may be worth it to measure as part of baseline. If cost-effective methods emerge later to monitor soil, the project can choose to monitor and claim credit for this pool. In addition, while soil carbon is seen as a negligible carbon pool in many projects, policy may require data to prove this. As part of this Cooperative Agreement, The Nature Conservancy will be hosting a soil carbon sequestration workshop in Brazil. This workshop will focus primarily on testing LIBS in the field in study areas near Curitiba, Paraná, Brazil. In addition, TNC is exploring with NETL the possibility of further testing and comparing soil carbon measuring technologies if the agreement is expanded.

Baseline Questions

1. How should the boundaries of baseline analyses be drawn? Are regional approaches appropriate given variations between different areas within a region?
2. For reforestation, should ongoing regional reforestation be included in the baseline, or should the baseline simply be indicative of what has happened at the actual project site over the last decade or so?
3. What is your vision of how baselines will be developed in the future? What place does the research being discussed today have in this future program?

Regional approaches to baselines may be appropriate, but panelist believed that it would be more relevant to define regions by ecological characteristics than by political boundaries. There is a need to do this in a consistent way however, and research on ecological boundaries may not be uniformly available. Default rates for regional baselines could also be developed by some central research authority.

Furthermore, boundaries do need to be wide enough to understand what is happening outside the project area and to capture relevant regional trends. Ongoing regional reforestation should be relevant in developing reforestation baselines, since this is indicative of regional trends in land use, and cannot be ignored.

Spatial models answer where and how land use is changing, and in this way are fairly objective. However, these models ignore the question of why land use change is happening in certain areas. Panelists emphasized that understanding why is important. The most probable future course for a project area is usually dictated by who is on the land and why. It is more difficult to model in an objective way, but it is still very important to take into consideration. Furthermore, if we can understand the causes of land use change it will be easier to incorporate leakage into the baseline analysis and design mechanisms to avoid leakage. Further research into how to factor non-spatial variables into drivers may be needed. The other challenge for spatial models is the spatial scale. As discussed during the last TAP meeting, widening or narrowing the boundaries of the spatial analysis can affect the results.

One advantage to spatial methods such as GEOMOD is that they can also be used before a project area is selected to develop a risk map. This would identify high, medium, low risk areas in the region, which would enable project developers to target projects where they would have the most likely effect.

Regarding temporal scale, there was a widespread conclusion among the panelists and the audience that projecting baselines past 10 or 15 years is difficult. However, no guarantee of the baseline beyond 10 years creates greater uncertainty for project investors and would create an additional barrier to these projects.

Baseline methodologies also face tradeoffs between cost and accuracy. For example, for the GEOMOD research in Brazil, accuracy was affected by a lack of updated road information in the north. However, such information is difficult to obtain and digitize. For research purposes, it may be worthwhile, but it would not be feasible to develop a new road map for each project.

The final word on baselines remains with policy makers. There is currently no consensus on how much data needs to be collected for a project, or on how to prioritize between essential and non-essential data when cost is an issue. In the past, TNC has discussed discount rates for less rigorous baselines, and still believes this could be an attractive solution.

Policy will likely require some sort of standard, easily replicable and transparent methodology. Policy makers in the audience expressed that regulatory agencies will not likely consider the individual reasons behind land use change in each project. While understanding the “why” can lead to more accurate baselines, and was considered an important issue for panelists, as a methodology, it is more subjective, more complicated, and more open to gaming, and therefore less favored by policy makers.

Furthermore, Industry representatives present at the meeting cautioned that if baselines are made too complicated, there will be less and less incentive to invest.

Project Finance Questions

1. The emerging carbon market will not fund up-front project costs, and current carbon prices are not high enough to pay for full project costs. Is the new finance model The Nature Conservancy is considering, i.e., using philanthropic dollars to help co-finance projects, a valid approach to securing project financing? For example, given that carbon funds may only cover 10-50% of the costs of many projects, how can projects show that they are additional, that is that they wouldn’t have happened without the carbon financing?
2. How do you see financial additionality being treated in a future policy regime?
3. Does it make sense for TNC to build revenue generating components into conservation projects, either as an alternative to philanthropic dollars or in addition to them? E.g., timber production, fruit production? Keep in mind the nature of the organization and the fact that many of our members and the broader public are uncomfortable with The Conservancy engaging in resource extraction.

The carbon market is evolving from a testing period into a market period. Panelists agreed that the value of carbon is not driving decisions on projects, and that carbon in combination with other sources of income (hunting, resource extraction) is often necessary to overcome investment barriers. They were supportive of using carbon to "tip the scale" rather than to fund full project costs.

Concerns were expressed that there is a limited window to bring the price of carbon down, otherwise a market for these projects will never get off the ground. Forestry offsets are in direct competition with technology. This makes it all the more important to market the multiple benefits of projects and pursue other revenue streams. Panelists suggested another way to make a project more attractive to investors is by only selling part of possible assets up front, so the project itself can take on part of the investment risk.

Another possibility mentioned for complementary sources of project funds were development and environmental funds such as the GEF. Co-financing from these funds could enable projects to have money upfront and not violate additionality requirements. However, international projects are mainly driven by the CDM market, which does not allow for Overseas Development Assistance (ODA) to fund projects.

The Nature Conservancy presented work it is undertaking with other NGOs and businesses on the Climate Community and Biodiversity Standard (CCBA). The CCBA standards are designed to identify projects with multiple benefits – to local communities, to the environment and to the atmosphere. Panelists and audience members remarked that the CCBA standards provide value in that they can:

- Improve success of carbon project portfolio (i.e., through better design, implementation, measurement)
- Enhance project credibility (standards are developed by respected NGOs and peer reviewed)
- Manage risks (less opposition, implementation road blocks if standards are met)
- Improve initial project screen (screen out projects w/ negative impacts, identify needed project design improvements)
- Meet multiple objectives (sustainable development, climate change mitigation, biodiversity conservation)
- Have applications beyond carbon projects

However, panelists familiar with the forest certification process noted that there is little evidence of a price premium for certified wood. Therefore, carbon generated from CCBA projects may have trouble reaping a price premium for multiple benefits. Meeting standards represents a real cost, and if there is no added value, there is little incentive.

Task 5 New Project Feasibility Studies

Feasibility studies were completed for six U.S. locations. These locations include the Apache Highlands Grasslands of Arizona, Kankakee Sands Prairie of Indiana, the Lower Mississippi Valley, the Clinch and Powell River Valleys of Virginia, Chesapeake River region of Virginia, Longleaf Pine Forests of Northwestern Florida, submitted to DOE as topical reports and reported on in previous technical reports. More recently an 11-state feasibility study was completed for the Northeast region of the U.S. and the results are described below.

Northeast Regional Study

Potential carbon increases and costs of changes in various land-use activities were summarized and compared spatially across the region. The analysis of biomass energy potential used different methods and cannot be compared to the other options and is reported. Also, consideration of environmental co-benefits were studied and reported.

The results suggest that —if the options were limited to one strategy only, rather than multiple activities being eligible simultaneously—between 1.2 to 8 million tons of CO2e (t CO2e) could be sequestered on agricultural lands over 20 years through tree planting, the use of no-till or noncultivated crops at a cost of less than $10 per metric ton of CO2e. The greatest increase, up to 8 million t CO2e, would come from afforestation of pasture lands, with no-till agriculture providing the lowest amount of sequestration. With the same carbon payment of $10 per metric ton of CO2e, an additional 143,000 to 11 million t CO2e could be sequestered over 20 years in existing forests by changing forest management practices (restocking understocked stands, 5-year rotation extensions, riparian buffer plantings). The analysis considered the effects of afforesting and changing management activities on all available crop and pasturelands and forest lands—a scenario that is recognized as unlikely and may not be desirable. However, the analysis demonstrates the economic potential of carbon sequestration from these activities at various price points.

Table 8. Summary of potential carbon sequestration and/or emissions reductions and area available at various price points for all land management options (20 year contracts for agricultural land and permanent contracts for forest land)

	Agricultural Lands				Forest Lands		
	Afforestation of Cropland	Afforestation of Pasture	No-Till	Non-Cultivated Crops	Restocking Understocked Stands	Five-Year Rotation Extension	Riparian Buffer
	(Million metric t CO_2e)						
< $7/t CO_2e		8.0		6.6	10.0	8.4	.14
< $10/t CO_2e		8.0	1.2	6.6	10.8	11.0	.14
< $20/t CO_2e		21.0	32	7.6	12.9	11.6	.20
< $40/t CO_2e	.12	215	33	13	14.3	11.8	.49
	(Thousand Acres)						
< $7/t CO_2e		169		550	1,000	1,400	79
< $10/t CO_2e		169	110	550	1,000	1,900	87
< $20/t CO_2e		351	5,700	636	1,300	2,100	123
< $40/t CO_2e	2.0	3,600	5,700	1,000	1,500	2,200	193

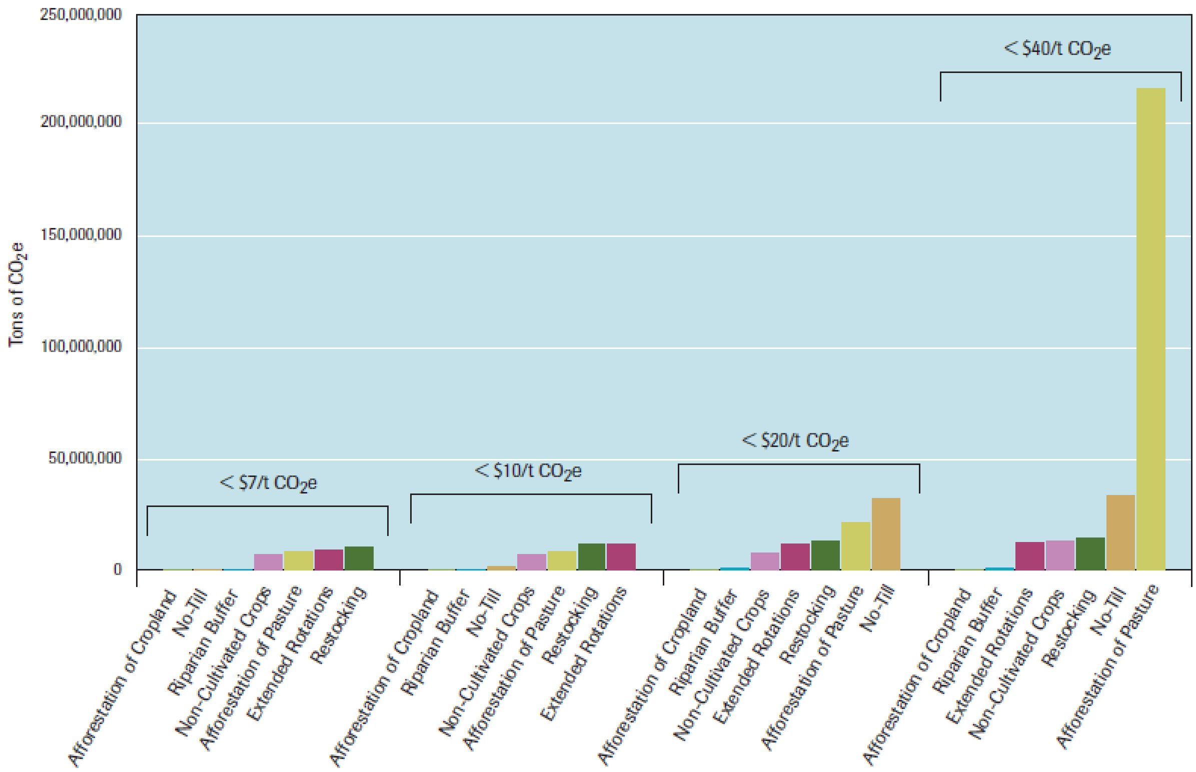

Figure 5A. Total potential CO2e from various land management activities generated at various price points from \$7 per ton up to \$40 per ton.

Task 6: Development of New Project Software Screening Tool

The final product incorporated two components: (1) a carbon monitoring cost spreadsheet to estimate measurement costs for various project types; (2) a carbon sequestration spreadsheet to model total carbon sequestered by a project in different geographic areas. By combining the two models, a project designer is able to quickly calculate whether the value added by selling carbon credits would be more or less than the additional cost imposed by monitoring the carbon over the life of the project.

1. Carbon Monitoring Cost Spreadsheet

The final cost spreadsheet was completed by Sian Mooney, and has been finalized. It is a very useful and accurate tool for calculating monitoring costs. The tool was be submitted to NETL.

2. Carbon Sequestration Spreadsheet

This model was completed, based on Forest Inventory and Analysis (FIA) data on carbon sequestration rates developed by Dr. Richard Birdsey for forest types across the United States. FIA data may be augmented with data gathered through the feasibility studies.

3. Full Tool

These pieces were combined and together resulted in a useful tool for evaluating estimates of carbon storage from reforestation in various forest types in the U.S., along with the likely costs of measuring the carbon sequestration from those activities.

Conclusion

This project, *Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration*, has resulted in over 50 presentations and reports, available publicly through the Department of Energy or by visiting the links listed in Appendix 1.

The following are some of the major accomplishments:

1) New carbon regression equations were created to relate field measurements to carbon storage amounts for new species (fern tree) and vegetation types (pine savanna). These results were provided to DOE and presented and published in proceedings of the International Symposium on Forest Carbon Sequestration and Monitoring.
2) A new airborne technology and method, multi-spectral three-dimensional digital imagery (M3DADI), was successfully used to quantify carbon sequestration in pine savanna and broadleaf forests in Belize and the U.S. Results of these tests were presented at the 2004 Annual Meeting of the Ecological Society of America and published in *Ecological Applications*. This method proved to be more cost-effective than traditional carbon inventory techniques.
3) A new method, called Forest Restoration Carbon Analysis (FRCA), was developed for assessing biodiversity and baseline carbon emissions from forest conservation and reforestation. FRCA results for Selva Central, Peru were presented at 2004 Annual Meeting of the Ecological Society of America.
4) Reports detailing costs of terrestrial sequestration for grassland restoration and reforestation were developed and presented at national conferences and to the DOE. Options for sequestering carbon at the cost of $10 per ton of CO_2 were identified. One of the project concepts evaluated through this work, reforestation of bottomland hardwood forests in the Mississippi Alluvial Valley, was attractive enough to industry investors looking to reduce their CO_2 footprint that they invested in sequestration activities on the ground.
5) A screening tool, available on the internet that allows would-be project developers to input information about their project idea and receive graphical and numerical descriptions of the potential carbon growth from afforestation, along with estimated costs of measuring the carbon growth.
6) A report comparing uncertainties of estimates of aboveground forest carbon from Light Detection and Ranging (Lidar) and from QuickBird high-resolution satellite images, calibrated by field measurements of individual trees in the several different forest types found in northern California.
7) A report with tables and GIS maps showing the current characterization (as well as historical and future predictions) of eleven states in Northeast region in terms of land, climate, land-use, and population. The report spatially depicts the opportunities for improving the amount of carbon storage and management on agricultural lands and forest lands, including both carbon supply and costs for afforestation, improved forest management, and conservation tillage and is being used by policy makers working on the Regional Greenhouse Gas Initiative to identify the best opportunities for abating CO_2 emissions through forestry activities.

More important than the reports themselves, the project has helped to lead to the development of on-the-ground projects in Southwestern Virginia, Louisiana, and Chile while informing policy development in Virginia, the Regional Greenhouse Gas Initiative, the California Climate Action Registry and U.S. and international programs.

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Appendix I

Reports Developed Under Cooperative Agreement

Task 1: Carbon Inventory Advancements

Ebinger, M., Calmon, M. and Stanley, B. (2004). *Application of Advanced Soil Carbon Measurement Methods on Brazil Carbon Project Lands* **Los Alamos National Laboratory and The Nature Conservancy**: Arlington, Va. http://conserveonline.org/workspaces/climate.change/documents/doe-netl-task-1-carbon-inventory-proceedings-libs/view.html

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