# ASSESSING CARBON STOCK IN A SEGMENT OF FOREST

# IN NORTHEASTERN ARMENIA

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ABSTRACT

Estimation of carbon storage by forests is an essential step for assessing the potential of forest ecosystems to offset fossil fuel emissions and following on the commitments under the Kyoto Protocol. A sample of 147 trees from a predominantly deciduous forest segment in the vicinity of the town of Vanadzor, Northeastern Armenia, was used to estimate the above-ground carbon stock of the forest. On-site carbon stock assessment was integrated with Geographic Information Systems (GIS) analysis. From recent satellite imagery data (resolution=32m/pixel), the study area was classified into Forest and Non-Forest classes using image processing software, and the total carbon stock for pixels of the Forest class was quantified (49,110 metric tons[1] of carbon, corresponding to 98 metric tons of carbon per a hectare of forest). ArcGIS 8.1 application (ESRI, Redlands, CA, USA) was used to map the area and to produce interim and final maps of the study area.

Keywords: Deciduous forests, carbon stock, above-ground biomass, GIS and remote sensing, carbon calculator.

INTRODUCTION

The association of the insidious climate change and the commensurate changes in the Earth's biosphere with human activity have been recognized. While the deterioration of the global habitable environment poses a serious challenge to the humanity, measures are long due to study, protect and capitalize on the inherent but largely overwhelmed compensatory mechanisms of the biosphere to offset the ever-rising carbon dioxide emissions. Perhaps the most obvious of these is the significant capability of the forests to reclaim carbon from the atmosphere. The total value of carbon stored in the world's forests has been estimated at 1146 gigatons (Gt)[2], of which 359 Gt is stored as living biomass and about 787 Gt as organic matter in the soil (Bodegom et. al. 2000). According to the Global Forest Resources Assessment (2005), the world's forests store 283 Gt of carbon in their biomass. The amount of carbon stored and the ratio between living biomass and soil carbon depend on

[1] 1 metric ton = 1000 kg = 1 Mg
[2] 1, 000, 000, 000 (1 billion) metric tons =1, 000, 000, 000, 000 (1 trillion) kg = 1 Gt

the climate and the forest type. Undisturbed natural forests possess the highest amounts of both biomass and soil carbon (Bodegom et. al. 2000).

Deforestation and use of forest lands for crops and pastures, harvesting, forest ageing and degradation, disease and pest outbreaks, and fires reduce or eliminate the contribution of the given segment of the global carbon-trapping capacity and disturb the balance of carbon circulation (Brown 2001). In the last two decades, Armenia has suffered alarming rates of forest degradation reducing the carbot sequesteration capacity of a substantial area. According to the United Nations Development Program (UNDP) “Armenia – Country Study on Climate Change” project report (2003), the sequestration of carbon dioxide in forest ecosystems of Armenia had reached 697 Gg in 1990 but has since shrunk to 523 Gg in 2000 (a 25% reduction) (UNDP “Armenia – Country Study on Climate Change” project report 2003).

In the first millennium B.C. about 35 % of the territory of present Armenia was covered with forests (First National Communication of the RA 1998). Now only 7-8 % is left from that forest cover, of which 62 % is concentrated in the northeast of Armenia, 2 % in the central part and 36% in the southeastern marzes (districts) (Moreno-Sanchez and Sayadyan, 2005). About 97% of forests in Armenia are broad-leaved consisting mostly of oak, hornbeam and beech (Chorbajian, 2006). There are also other species such as birch, juniper, pine and yew. Although climate has had a considerable impact on the forest cover, this influence pales in comparison with human interventions (primarily illegal logging of mass proportions and poor-to-none forest maintenance), which have yielded a devastating impact since early 1990’s. About 600000 $m^3$ of forests were cut each year in 1991-1996 (Moreno-Sanchez and Sayadyan 2005). The mass degradation of forest conditions has led to soil erosion, desertification, landslides, diseases caused by air pollution, etc. They continue today, deepening environmental losses even further (Moreno-Sanchez and Sayadyan 2005).

Clearly, Armenia is in urgent need of sustainable forest management as a high-priority component of efforts to overcome the ecological crisis facing the country. The purpose of this study is to consider the capacity of Armenian forests to contribute to the reclamation of carbon dioxide from the atmosphere, combining field assessment methods with GIS technologies. As a non-Annex I country, Armenia can participate in the Clean Development Mechanism (CDM) of the Kyoto Protocol

(Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC); Climate Change Information Center of Armenia, 2007). This participation will allow the country to cooperate with developed countries and increase the area of new forests through investments in afforestation and reforestation (AR) (Climate Change Information Center of Armenia, 2007).

The CDM projects that have been carried out in Armenia and have been registered by the CDM Executive Board are the following: Nubarashen Landfill Gas Capture and Power Generation Project in Yerevan, Argichi Small Hydroelectric Project, Yeghegis Small-Scale Hydro Project and Lusakert Biogas Plant project. Though no CDM project in the field of afforestation/reforestation (AR) has been registered so far, a Community Small Scale AR Project in Lori marz is currently under development (Climate Change Information Center of Armenia, 2007). The methodology for this project is based on the Good Practice Guidance for Land Use, Land-Use Change and Forestry of the Intergovernmental Panel on Climate Change (IPCC) 2003.

A comprehensive calculation of carbon sequestration of tree and bush vegetation (forests, different types of protective plantations, greenery, orchards, etc.) in Armenia was carried out in the period of 1996-1998 within the frame of the preparation of the First National Communication of Armenia, when the annual quantity of carbon stored during the vegetation growth and annual $CO^2$ emissions were calculated for a number of years between 1985 and 1996. These calculations were carried out by the National Greenhouse Gas Inventory and were based on the methodology of Greenhouse Gas Inventory Workbook of IPCC 1996. Currently the Second National Communication to the UNFCCC is in the process of development, where the same methods will be used for calculating carbon sequestration of bush and tree vegetation in Armenia (Climate Change Information Center of Armenia, 2007).

The above mentioned cases are the only cases of carbon sequestration calculation of forests in Armenia. However, none of them have used Geographic GIS and remote sensing technologies. Besides, no individual studies have been carried out in the field of carbon sequestration and carbon stock assessment in Armenia. With the exception of Climate Change Center of the Ministry of Nature Protection, awareness and research on carbon sequestration and carbon stock of Armenian forests and on AR activities in the framework of CDM are almost non existent.

Although AR CDM project opportunities exist in all regions of Armenia, a comprehensive feasibility study would be necessary to assess the real potential of AR projects in Armenia in the framework of CDM (Climate Change Information Center of Armenia 2007). A large need exists to expand research in the field of carbon sequestration and carbon stock assessment in Armenia, to further explore the opportunities of AR activities in terms of mitigation of climate change. So far methodology used in this field has been quite limited. New research should focus on different methodologies that exist for carbon sequestration and carbon stock assessment in forestry sector. Simple methodologies similar to the one used in this study can be used for assessing carbon stocks for small forest patches.

This pilot study is the first individual research in this field. It aims to measure the carbon stock of a small forest segment in the north-eastern part of Armenia, in comparison to other studies that target all tree and bush vegetation of Armenia or a whole region in the country. Our study of carbon stock assessment of Armenian forests is also the first one in Armenia to use GIS and remote sensing methodology. This study sets the precondition for further periodic GIS-based carbon assessment studies assisted with the simple method of tree carbon calculator. This method can be an effective way of measuring carbon stocks in countries with limited resources for other methods of carbon stock assessment. The method is also very effective for individual trees as well as small forest patches. However, further carbon assessment studies will be applied to larger forest areas of Armenia and will use more developed and accurate approaches and methods.

## METHODS

### *Assessing Carbon Stocks*

This study focuses on a forest patch in Lori marz (northeastern Armenia, near the city of Vanadzor) (Figure 1). The patch is dominated by deciduous-type trees, including oak, beech, hornbeam, lime, ash, maple, apple, pear, and pine. Primary and secondary data have been used for the study. Primary data in the form of tree measurements were collected during field work. Secondary data were based on literature sources about forests near the city of Vanadzor. Primary data were collected from a sample of trees (total sample size = 147) during two field trips conducted in September 2006. Tree sampling was performed by first stratifying the study area into three sites (strata) based on an aerial photograph where the boundaries of these sites (strata) showed an apparent delineation and could be clearly identified at the ground level. About 50 trees were sampled in each sampling site through a systematic proportionate sampling technique (Babbie 1983).

Record sheets were prepared to input information collected during field work (Table II). Tree parameters such as height (using a clinometer), diameter at breast height (dbh), and the average distance among the trees in specific areas were gathered. Location coordinates were collected using a hand-held Global Positioning System (GPS) device. In addition, descriptive data were acquired about the study area from the local forestry officials. Recent satellite imagery (July, 2006) was used for delineation of the forest and classification of land cover for subsequent assessment of carbon stock.

There are a number of models and analytical methods to calculate the terrestrial carbon stocks and fluxes, varying greatly from sophisticated ecophysiological models to simple calculators of carbon accounting (Masera 2001). Because of limited resources for other more comprehensive methods, the simple tree carbon calculator provided on the website of the Cooperative Research Center for Greenhouse Accounting (CRC) (1999-2006) was used to estimate the average carbon stock in the forest segment. The use of this kind of model does not have any precedent studies. It is also an effective way of measuring carbon stock in individual trees or in small forest patches.

Using this model, it is possible to estimate the amount of carbon stored in a tree by entering the tree circumference at breast height or 1.3 meters from the ground and the tree type (hardwood/deciduous tree or softwood/conifer) into the calculator. The calculator gives a reliable estimate of the stored carbon in softwood trees up to a circumference of 157 cm (dbh 50 cm) and hardwood trees up to a circumference of 408 cm (dbh 130 cm).

The tree carbon calculator works by first estimating above-ground biomass of the tree—using general allometric relationships—and then the biomass of the tree roots—using the root:shoot ratio. Afterwards, the total values of the above-ground biomass and of the tree roots are converted to carbon. It is assumed that 50% of the tree biomass is comprised of carbon. As inferred from above, the forest segment selected for this study is dominated mostly by hardwoods, deciduous broad-leaved trees. The above-ground biomass (kg) for hardwood is calculated through the following empirical formula: 1.021a x e (ln dbh x 2.589 - 2.733) (CRC for Greenhouse Accounting 1999-2006).

The CRC, IPCC has set default values for the estimation of root biomass when the value for the above-ground biomass is known. These values are used in the carbon calculator for estimating the root biomass. For hardwoods, the root: shoot ratio is 0.25.

***GIS and Image Processing Methods.***

Recently acquired 3-band (Green, Red and Near-Infrared channels of the spectrum) satellite imagery by Disaster Management Constellation (DMCii) was used for the analysis. The images were acquired by the DMCii on behalf of Environmental Conservation and Research Center (ECRC) at the end of July 2006.

ArcGIS 8.1 application (ESRI, Redlands, CA, USA) was used to map the study area and produce interim and final maps. MultiSpec© Multispectral Image Data Analysis System software (Purdue University, West Lafayette, IN, USA) was used for the land cover classification into Forest and Non-Forest classes. Image classification and analysis included (1) image preparation (cropping the study area from a larger image for faster processing time) (Figure 2) , and (2) selection of pixel samples drawn as polygons (39 groups in total) for further classification. Two distinctive groups of pixels were selected representing Forest and Non-Forest land cover (Figure 3) with their respective spectral characteristics (i.e. pixel values for each of the three spectral channels) to “train” the MultiSpec© classification algorithm. Subsequent steps were (3) classification of the image and (4) integration of results (classified maps) within the GIS environment for the preparation of the final maps (Figures 4 and 5).

RESULTS

For the purpose of this study, the overall sample of trees was divided into eighteen sub-groups based on location and tree species. The average circumference was calculated for each sub-group of trees. The maximum and minimum circumference for each tree sub-group was estimated as well. The number of trees per one pixel of the satellite image (1 px =32m – the resolution) was calculated using the value of the average distance among the trees for each group. Using image processing software, the study area was classified into Forest and Non-Forest classes. Given that the classification resulted in an image with only two types/classes of values, it was possible to calculate the number of pixels for each class, and, as a result, calculate the areas under each class based on the area of a single pixel i.e. 1024 sq.m or 0.1024 ha. Finally, the carbon (kg) value for the trees per one pixel was estimated for all tree groups. The GIS analysis showed that the forest in the 1,013 ha study area covers 4,909 pixels, which corresponds to 503 ha of forested area. Given the carbon values per pixel for all groups of trees, the average carbon stock for one forested pixel is 10,004 kg excluding the outliers, that is minimum and maximum values (1700 and 72576) corresponding to group “a” and “r” for the purpose of statistical accuracy. Thus, the total carbon stock for all the pixels of the forest area is 49,109,636 kg (4,909 X 10,004), which is equal to 49,110 metric tons of carbon. It follows that there are 98 metric tons of carbon per forest ha (49,110/503). See Table 2.

## DISCUSSION AND CONCLUSIONS

Recently much attention has been paid to temperate deciduous forests as carbon sinks since they amass on average twice to twenty times more carbon above ground than desert, shrub, or grasslands (Curtis et.al. 2002). According to Dahlman et.al. (2001), all deciduous forests on the planet could store up to 3 Gt of carbon. Goulden (1996) states that in New England (USA), deciduous forests sequester 1.4-2.8 metric tons of carbon per ha per year. Birdsey, in Curtis et. al. (2002), estimated from forest inventory data that an average net accrual of carbon in the eastern deciduous forest region of North America is from 1 to 2.4 metric tons per ha per year, which makes 45% of US forest carbon sequestration. Armenia has good potential for carbon sequestration because of the predomination of deciduous-type forests, particularly oak and beech; however, these forests continue suffering extensive damage bordering extinction in many areas.

The results of this study show that the carbon stock of the forests in the north-eastern part of Armenia is about 98 metric tons of carbon per forest ha. Given the comparison with estimates of carbon stock for other deciduous forests and the predominance in Armenia of such broad-leaved trees (oak, beech, etc.) that have, in general, the highest potential for carbon sequestration, it becomes more than clear that Armenia could have a strong position among small countries in carbon offsetting. The geographical area of Armenia is quite small (29,800 sq km); however, the rich landscape and climatic diversity offer good prospects for afforestation and reforestation activities to mitigate the adverse effects of climate change and to contribute to economic development through the implementation of the CDM.

The importance of this limited study can be measured by its potential for further expansion. Future research can cover a larger area, higher level of spatial and temporal detail, and could engage stakeholders in collaborative efforts. The expanded project might include several stages addressing the preconditions for the achievement of the most vital goal: the initiation of the CDM in Armenia. Before undertaking subsequent surveys and measurements, and planning for monitoring and trending activities,, accurate methods of monitoring, measuring and modeling need to be developed and reliable sources for grounds and satellite data established. These methods should serve as an inseparable part of any AR project and should be used to consistently assess the terrestrial carbon stocks and carbon fluxes at the forest ecosystem level, and to determine the actual carbon sequestration and the potential for carbon sequestration of specific forest types grown in specific geographic areas of the country.

## LIMITATIONS

This study has a number of limitations. The existing means of measuring and modeling terrestrial carbon stocks and carbon fluxes entail the prerequisite of extensive field work for data collection. Well-designed site inventories can result in rather precise estimates of carbon stocks. The higher the desired level of accuracy of the carbon stock estimates, the more complex the measurement and modeling techniques. Due to the lack of resources for destructive measurements, we used a limited number of easily obtainable parameters and calculated the carbon stock with the CRC tree carbon calculator that introduces a substantial error by using only the tree type and tree circumference.

Another serious limitation of this study is the low resolution of satellite imagery. Finer resolution is required to effectively differentiate between tree species. The use of multispectral IKONOS imagery with a spatial resolution of 2.5m will be pursued for subsequent studies and for carbon stock monitoring and trending purposes.

In spatial terms, the study area of the future project will include all of the forested areas of Armenia. Sampling, measurement, modeling, and monitoring for carbon stock and flux estimates will be implemented using a methodology to achieve the highest possible level of accuracy and reproducibility of the results, while still respecting manpower and other budgetary constraints. GIS and Remote Sensing data will be used for the accurate assessment of the carbon sequestration trends in Armenian forests, and for a full evaluation of the realistic potential in different forest management scenarios.

ABBREVIATIONS

AR – Afforestation/Reforestation

CDM – Clean Development Mechanism

CER – Certified Emission Reductions

CRC - the Cooperative Research Center for Greenhouse Accounting

DMC – Disaster Management Constellation

ECRC – Environmental Conservation and Research Center

IPCC - Intergovernmental Panel on Climate Change

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