NCRC

Building a Carbon Map of Ghana:
Summary Report on Existing Carbon Stock Data

21st January, 2010

David Aitken, Tutu Benefoh Daniel, Asante Winston &
Professor Yadvinder Malhi

Executive Summary

There is a clear need for credible carbon maps that cover a nation which will offer a range of benefits to researchers, decision makers and project developers alike. This presents new opportunities for many tropical nations as a substantial source of finance for ecosystem protection. However, Ghana, like many tropical nations in Africa does not yet have a map of its forests and ecosystem resources, a vital tool in carbon stock accounting.

Therefore, this project has been designed with an overall goal to produce a freely available and accessible carbon map of Ghana by the end of 2010, which will be robust with a fifty metre resolution. Hence, in support of existing capacity building efforts on forest conservation, carbon stocks and REDD in Ghana, a scoping workshop was held in Accra on 2nd December, 2009 to lay the foundation for developing such a map.

Discussions and presentations at the workshop revealed that many useful data sets on carbon stocks already exist in Ghana. These data sets will provide a base to build a carbon map of Ghana if the following key issues are addressed:

- *Data sharing* (in particular, will the data be available to build the carbon map and at what level of disclosure?)
- *Data time frames* (when were the data collected and has the land cover changed since then?)
- *Geolocation* (have the data been accurately located using a global positioning system?)
- *Consistency* (do different data sets use the same definitions, equations and classifications, as well as methodologies)
- *Data quality* (how accurate are the data and can they be used to inform the carbon map project)

There are a number of gaps in the existing carbon stock data in Ghana. In particular: northern areas, coconut and oil palm plantations and some farming types have either not been measured or measured less than other land uses, particularly forests.

A key priority of the carbon map project is to obtain as much of the existing data as possible so that the map analysis structures can be developed and further data collection can commence on the gaps that remain in the available carbon stock data. It was however encouraging to note that many researchers are willing to contribute data under various options of disclosure.

1. Introduction

Mechanisms to protect forest and ecosystem carbon are developing rapidly and are likely to be adopted within an international climate change agreement. This offers new carbon funding opportunities for many tropical nations, but also presents new challenges for these nations in accurately measuring and reporting carbon stocks.

Developing credible carbon maps can help tropical nations meet these challenges and can provide a range of benefits to government ministries, project developers and research organisations. At the national level, carbon maps can improve reporting of carbon emissions and help identify areas where carbon stocks need to be conserved and/or improved. Whiles at the project level, carbon maps can provide a carbon stock baseline. This can help organisations to develop carbon offset projects and get carbon finance flowing to forest and farming communities. For research purposes, carbon maps can identify which land use changes cause significant losses in biomass and/or soil carbon stocks and which systems are more effective at conserving carbon stocks. It can also help investigators determine the main factors driving these carbon stock changes.

However, Ghana does not yet have a map of its ecosystem carbon resources. The Moore Foundation has therefore provided financial support for a project to produce a carbon map of Ghana. The carbon mapping project is being coordinated by Professor Yadvinder Malhi of the University of Oxford, who will be in Ghana for the duration of the project, and it is being managed by the Katoomba Ecosystem Services Incubator (The Incubator) and the Nature Conservation Research Centre (NCRC). The map will be developed in collaboration with Professor Sassan Saatchi at the Jet Propulsion Laboratory at NASA.

The aim of the project is to produce a robust carbon map of Ghana, showing total biomass and soil carbon stocks based on 2009 land cover, with 100 metre resolution by the end of 2010. The carbon map that is produced will be freely available and accessible and will be accompanied by a report detailing the methodology used, whiles noting any limitations in it. One or more scientific papers may also be produced on the carbon map with contributors appropriately acknowledged, including co-authorship for all those who provide data that is used to produce the carbon map.

The project intends to use the latest remote sensing techniques (including ALOS PALSAR and ICESat GLAS data) as well as biomass and soil carbon field data to produce the map. The optical images that are used will predominantly be medium to low spatial resolution images (e.g. MODIS and Landsat) rather than images with high spatial resolution (e.g. IKONOS). However, high spatial resolution imagery may be used in a few focal areas to test the accuracy of the map at finer scales and provide more detailed information at the Incubator pilot project sites. Elevation and texture information will be incorporated when analysing remote sensing data. The project may also develop specific allometric equations for Ghana to convert biomass into carbon stocks if existing allometric equations are not found to accurately represent conditions in Ghana.

The above approach has been adopted in order to produce a cost effective yet accurate carbon map of Ghana at a resolution that is useful to a range of stakeholders. It is

possible that the national carbon map may not provide sufficient quantitative information at a local level for carbon project development purposes in places where high resolution imagery is not used. More detailed local information may be required to inform potential projects to conserve or enhance carbon stocks. However, in such a case a national map can still address other important considerations for local projects (including for example the potential for carbon leakage from one area to another). It is also important to note that the map will provide a snapshot of carbon stocks in Ghana and will not show how carbon stocks have changed in Ghana over time. However, the national carbon map should provide a base for developing relatively inexpensive maps in future projects to show carbon stock changes in Ghana over time.

This summary report outlines existing carbon stock data for Ghana identified prior to and during a scoping workshop on carbon stocks in Accra on 2 December 2009. The workshop was well attended (see participation list in Appendix to this report), and the level of enthusiasm and willingness to engage in this project has been impressive.

The report outlines the key issues discussed at the workshop and suggests where the key gaps in existing carbon stock data are. This report will inform the next stages of the project which involves obtaining existing data on carbon stocks, collecting further carbon stock data on areas where gaps currently exist and holding two capacity building workshops in early 2010 which include international experts (the first will focus on biomass and soil carbon inventories and the second will address remote sensing of biomass and soil carbon).

Subsequent to the workshop, two people have been tasked to work on the implementation of the carbon map, and coordination with the partners.
Daniel Benefoh Tutu will coordinate the database assembly, and implement the remote sensing and mapping analysis in coordination with NASA. Winston Asante will coordinate the compilation and standardisation of existing biomass and soil carbon data, and will implement fieldwork on geolocation of existing plots, and collection of new data from under-sampled vegetation types.

Prof. Yadvinder Malhi and Dr Rebecca Asare will coordinate and oversee the scientific aspects and management of the project.

2. Method

Key informants and literature review of researches on carbon were used to identify all the key people working on carbon stocks and related data in Ghana. A small scoping team was then put in place to engage and link up with as many researchers and scientists as possible to further understand their research, and its applicability to the carbon map project.

Finally, a stakeholder workshop was organised, which convened as many of the researchers and scientists as possible to discuss the existing carbon stock data in Ghana, as well as the availability of their data to the carbon map project. This was to ensure that other existing carbon stock data that hadn't been identified prior to the workshop were included in the database of existing data. It was also to create a unique platform, where key issues relating to carbon stocks and carbon map in the context of Ghana are discussed.

Six presentations were made by key resource people and researchers, in their respective fields. This was to clarify the scope of existing data sets and the status of current research activities:

- Foster Mensah – *Centre for Remote Sensing and Geographic Information Systems (CERSGIS)*
- Kofi Affum Baffoe – *Resource Management Support Centre (RMSC)*
- Dr Stephen Adu-Bredu – CSIR-*Forest Research Institute of Ghana (FORIG)*
- Dr. Edward Yeboah – CSIR-*Soil Research Institute (SRI)*
- Prof. Samuel Oppong – *Kwame Nkrumah University of Science and Technology (KNUST)*
- Daniel Tutu Benefoh – *Environmental Protection Agency (EPA)*

While the project made a concerted effort to identify all existing data on carbon stocks in Ghana, it is likely that some information was overlooked. Any additional information that could be contributed to the map would be much appreciated; as such data would help to improve the accuracy of the carbon map. Contact details of the authors and workshop participants are provided in Appendix 1.

3. Results

The following section summarises the key data on land cover mapping and carbon stocks identified for Ghana. Brief comments are made initially on the current status of national land cover mapping work. Existing carbon stock data is then presented according to land cover type in order to help analyse where the gaps in existing carbon data sets are located.

3.1 National Land Cover Mapping

3.1.1 CERSGIS – Foster Mensah

CERSGIS has produced national land cover maps at 1:250,000 km scale for Ghana based on 1990 and 2000 Landsat images. These maps classify land cover into nine main categories with further subdivisions in each category. More recently CERSGIS has used ASTER images to map land cover changes and has conducted further work in three northern areas in Ghana. However, since 2000, CERSGIS has not been able to update its national land cover maps of Ghana. This was due to funding constraints; hence classifications have not been validated. Following the workshop, CERSGIS agreed to make these 1990 and 2000 land cover maps available for the carbon map project, including the full classification scheme and other supporting data for the maps. On condition that the data is only used for the carbon mapping project.

3.1.2 EPA – Tutu Benefoh Daniel

The EPA has produced national land cover maps for Ghana for 1996 and 2007. The 2007 map draws on Food and Agriculture Organisation (FAO) data

from the Global Forest Resources Assessment 2005 and soil carbon data from the Spatially Explicit Modelling of Soil Organic Carbon (SEMSOC) project. The EPA may be able to make this land cover map available for the Ghana carbon map project in the first quarter of 2010 after meeting its reporting and submission obligations. Ground checking indicates that the maps' accuracy is approximately 58% and that it presents challenges to classifying tree crops, mapping wildfires and reporting on soil carbon stocks based on current data. Information on plantation areas was only available from government plantations and not private plantations for producing the map.

3.2 Forests

3.2.1 RMSC – Kofi Affum Baffoe, Stephen Mensah

Kofi Affum Baffoe noted that the RMSC established 600 one hectare permanent sample plots in forest reserves (FR) in the High Forest Zone of Ghana between 1988 and 1994. Within each plot, all trees with ≥ 10 cm diameter at breast height (DBH) were identified and tree DBH was recorded. All of these plots were measured at least once with 68 plots re-measured after two and a half years and 40 plots re-measured after 5 years. A schedule records the location of these plots using a compass bearing and distance from a boundary pillar. From 1995 onwards the minimum DBH measured in these permanent sample plots increased from 10 cm to 20 cm. A further 160 plots were re-measured by 1999. Since 1999 these plots have not been systematically re-measured. Approximately 63 of the plots have been devastated by fire and encroachment, and logging has affected the condition of some other plots. The RMSC is currently working with the University of Leeds to re-measure a select sample of the plots.

Kofi Affum Baffoe indicated that the RMSC is interested in making its data available for the Ghana carbon map project but that a formal request needs to be made to the CEO of the Forestry Commission of Ghana for this data.

Stephen Mensah has used remote sensing images and GIS to see whether tree height can be used as a way to assess forest degradation for his MSc dissertation. Stephen has provided a copy of his MSc dissertation.

3.1.2 FORIG – Dr Stephen Adu-Bredu, Gloria Djagbletey, Dr Dominic Blay and Francis Dwomoh

Dr Stephen Adu-Bredu has measured biomass and soil carbon stocks in forests in Kakum, Awura FR, Upper Tamne FR, Ejura and Bawku. Dr Adu-Bredu is also trying to develop an allometric equation for moist evergreen forests in Ghana using a sample of 42 trees from 16 different species taken from Boi Tano FR. This work will help in assessing how appropriate existing allometric equations (e.g. Chave *et al.* 2005; Chambers, 2001; Brown *et al*, 1989) are to forests in Ghana. Dr Adu-Bredu is also looking at the impact of selective logging in Boi Tano FR as part of the Carbo Africa project.

Dr Adu-Bredu and Gloria Djagbletey are currently working on a project to measure biomass and soil carbon stocks at a range of logged and unlogged sites in Bobiri FR.

Dr Adu-Bredu has indicated that the data on Kakum, Awura FR, Upper Tamne FR, Ejura and Bawku is about to be published and so he will be able to make this data available shortly. The rest of the work is still in progress, but upon its completion Dr Adu-Bredu indicated that he will be able to make the data available for the carbon map project.

Dr Dominic Blay has measured the biomass of plantations in degraded forest reserves in Pamu Berekum FR and Southern Scarp FR.

Francis Dwomoh has measured biomass carbon stocks in Afram Headwaters FR and used Geographic Information Systems (GIS) and remote sensing techniques in order to calculate carbon emissions from forest fires there. Francis has provided a copy of his MSc thesis summarising this work.

3.1.3 KNUST - Evelyn Asante

Evelyn Asante is measuring biomass carbon stocks in different silvicultural treatments in Bobiri FR as part of her MSc dissertation and will use GIS techniques to help analyse the results. Evelyn's MSc dissertation is due to be submitted in March 2010.

3.1.4 International researchers – Simon Lewis, Matieu Henry and Amy Wade

Simon Lewis at the University of Leeds has worked with Kofi Affum Baffoe at the RMSC to measure biomass carbon stocks in Asenanyo FR, Asukese FR, Cape Three Points, Dadieso and Kade. Simon Lewis has also worked with Gloria Djagbletey at FORIG under the Tropical Biomes in Transition (TROBIT) project to measure biomass and soil carbon stocks in Mole National Park, Kogyae Nature Reserve, Ejura, Boabeng-Fiema Monkey Sanctuary and Asukese FR. Simon has been contacted to see whether this data can be made available for the carbon map project.

Matieu Henry at the University of Tuscia, Italy and AgriParis Tech has collected information on biomass carbon stocks in Bobiri and Boin River FRs and Ankasa as part of his PhD research. Matieu has been contacted to see whether this data can be made available for the carbon map project.

Amy Wade at the University of Reading and colleagues collected information on biomass and soil carbon stocks in Atewa Forest Reserve. Amy has been contacted to see whether this data can be made available for the carbon map project.

3.2 Plantations

3.2.1 FORIG – Dr Stephen Adu-Bredu

Dr Adu-Bredu has collected biomass and soil carbon data on teak plantations in Kakum, Ejura and Bawku. Dr Adu-Bredu has indicated that this data is about to be published so will be available for the carbon map project shortly.

3.2.2 RMSC – Kofi Affum Baffoe

Kofi Affum Baffoe noted that the RMSC has established around 65 0.36 hectare plots in forest plantations since 2008.

3.2.3 International Researchers – Dr Wauters and colleagues

J.B. Wauters from Louvain University and colleagues have collected data on rubber tree plantations at the Ghana Rubber Estate Limited plantation near Agona in the Western region of Ghana. They developed a site specific allometric equation for rubber trees there and published their results in 2008.

3.3 Farmlands

3.3.1 KNUST – Benjamin Gyampoh, Evans Dawoe and Alfred Nkusi

Benjamin Gyampoh has measured soil carbon stocks in Offin Basin Headwaters in a range of land use systems including 10 year old cocoa farms and maize, plantain and cassava areas as part of his PhD research. Benjamin is checking with his supervisors whether this data can be made available for the carbon map project.

Evans Dawoe has published measurements of standing litterfall and litter nutrient dynamics under cocoa systems in Ashanti region as part of his PhD research. Evans has been contacted to see whether this data can be made available for the carbon map project.

Alfred Nkusi is measuring biomass carbon stocks on cocoa farms at Offinso Abofour around Afram Headwaters FR using radar images as well as above ground biomass field measurements as part of his MSc dissertation. Alfred's MSc dissertation is due in March 2010.

3.3.2 FORIG – Dr Stephen Adu-Bredu

Dr Adu-Bredu has measured biomass and soil carbon stocks in cultivated and fallow lands in Kakum, Ejura and Bawku. Dr Adu-Bredu has indicated that this data is about to be published so will be available for the carbon map project shortly.

3.3.3 University of Ghana – Dr Morgan Attua

Dr Attua has measured above ground carbon stocks in fallow vegetation in the Akwapim South area in Densu Basin.

3.3.4 International researchers – Amy Wade and David Aitken

Amy Wade at the University of Reading has measured biomass and soil carbon stocks on cocoa farms around Adjeikrom and Kwabeng in the Eastern region. Amy has been contacted to see whether this data can be made available for the carbon map project.

David Aitken at the University of Oxford has measured above ground carbon stocks on cocoa farms in the Western, Ashanti and Brong Ahafo regions. This data will be available for use on the carbon map project.

3.4 Soils

3.4.1 Soil Research Institute – Dr. Edward Yeboah, Enoch Boateng and Prince Gyekye

The Soil Research Institute of Ghana has collected a range of soil carbon data from across Ghana and expressed this data in percentage terms. However, most of this data does not include bulk density measurements which means it is difficult to calculate soil carbon stocks from this data. However, some soil data collected for irrigation projects has bulk density measurements. A range of other soil data may also be useful for the carbon map project including: data collected for the Sustainable Land Management for Mitigating Land Degradation, Enhancing Agricultural Biodiversity and Reducing Poverty (SLaM) project; Soil Research Institute biochar projects; and reports prepared for consultants (although confidentiality issues may prevent this data being released). For example, the SLaM project found high variation in soil carbon stocks in different agro-ecological zones in Ghana.

Enoch Boateng is checking whether the Soil Research Institute has typical bulk density measurements for different soil types which may allow soil carbon stocks to be calculated for samples where bulk density measurements were not recorded. A formal request needs to be made to the Soil Research Institute Director requesting access to Soil Research Institute data for use on the carbon map project.

3.4.2 University of Ghana – Prof. Abekoe, SEMSOC project

As part of the SEMSOC project, Prof. Abekoe has overseen the gathering and analysis of soil and biomass carbon stock information from Afram Plains, Wenchi and Bawku.

3.4.3 FORIG – Dr Dominic Blay

Dr Blay has worked on soil carbon stocks in the Kintampo area and of the impact of land tenure on soil and biomass in Wassa West district in Western region.

3.4.5 KNUST – Winston Asante

Winston Asante has measured soil carbon stocks to 15cm depth in logged and unlogged areas in Boin River FR as part of his PhD research. Winston is checking with his supervisors whether this data can be made available for the carbon map project.

3.4.4 Published Soil Carbon Papers

A range of published papers particularly on soil and crop management may provide useful data points on soil carbon stocks in Ghana. These authors are being contacted regarding their data and, where useful, whether it would be available to build the carbon map.

3.5 Other

3.5.1 Vitellaria paradoxical (Shea nut tree) carbon stocks – Jakpa Shu-aib (University of Twente)

Jakpa is collecting above ground carbon stock data in areas where the Shea Nut tree is common in Paga, Nyanpala and Kintampo as part of PhD research. Jakpa is checking with his supervisors whether this data would be available for the carbon map project.

3.5.2 Land cover mapping – Opoku Pabi, Kwabena Asubonteng, Benefoh Daniel Tutu and Professor Oppong

Opoku Pabi has assessed land cover change in the northern transition zone in Brong Ahafo region using GIS techniques.

Kwabena Asubonteng assessed land use change in Ejisu Juaben district for his MSc dissertation. Kwabena has provided a copy of his MSc dissertation.

Benefoh Daniel Tutu assessed carbon sequestration in Ejisu Juaben district using remote sensing and GIS for his MSc dissertation. Daniel has provided a copy of his MSc dissertation.

Professor Samuel Oppong, Daniel Tutu and Kwabena Asubonteng have been comparing classifiers in the Western region to try to discriminate between mature cocoa areas.

4. Key Issues Discussed at Workshop

Five key issues with respect to existing carbon stock data sets were discussed at the workshop. This session was chaired by Professor Yadvinder Malhi.

4.1 Data sharing

Prof. Yadvinder Malhi noted that ideally as much existing carbon stock data as possible would be made available for the carbon map project fairly quickly. This would allow the map analysis structure to be developed along with an initial map over the next few months, which would help to identify gaps in available data that need to be filled.

On previous projects in South America, Prof. Yadvinder noted that data contributors have been given the option of sharing their data at different levels in order to encourage scientists and institutions and ensure that as much data is shared as possible. The three main options available for data sharing are:

(a) Data values are provided for producing the map but are not released to a wider audience who would therefore not be able to access the numbers in the data;

(b) Data values are provided for producing the map with plot level data at particular locations made available. This is a useful level which allows people to analyse the map and see whether there are, for example, one or two high data points influencing the carbon stocks in a particular land cover type; and

(c) Freely available raw data. This is the ideal level and data sharing agreements can be put in place for the use of this data.

Prof. Yadvinder noted that, data would ideally be provided at level (c) or at least level (b) for the Ghana carbon map project. The responses of the workshop presenters regarding data sharing were very encouraging and have been noted in section three above. Dr Morgan Attua suggested that waiting until data is published might result in significant delays. Prof. Yadvinder responded that the above tiers are not fixed so, for example, someone could initially provide data to inform the carbon map at level (a) or (b) while waiting for publication and, following publication, this data could then be made more freely available at a higher disclosure level.

Jim Gockowski queried whether disclosure of data would be required for validation and verification purposes on carbon offset projects. The manual that accompanies the carbon map would outline the methodology and data sources used to generate the map. This would allow validators and verifiers to independently assess whether the map met their requirements for carbon stock baseline information. Prof. Yadvinder Malhi intimated that data can always be provided at a low level of disclosure in cases where researchers are concerned about the potential use of their data. Where researchers provide information at a particular disclosure level for the carbon map project, this information would only be disclosed to the level agreed to by the researcher.

Prof. Yadvinder Malhi further explained that a short “fair use agreement” relating to freely available data provided to the carbon map project would be

developed. This agreement would ensure, for example, that any data made publically available by the carbon map project would not be used without first contacting the original data provider and that the data provider would be included as a co-author on any papers that used their data.

4.2 Data Time Frame

Prof. Yadvinder Malhi noted that this is an important issue particularly for older carbon stock data where the land use or ecosystem condition may have changed since the data was collected. For example, some forest plots where carbon stock data is available may still be forests but may be degraded and no longer in the same condition as when the data was collected. Older data of this type may still be useful in determining the carbon loss that results from moving from one condition to another, provided further data is collected to establish the carbon stocks under present conditions. Where the land cover remains similar the soil carbon stocks may change less than the above-ground biomass carbon stocks, although where the land-use changes from one cover type to the next (e.g. forest to farmland) there may also be significant changes in soil carbon stocks in moving from one land cover type to the next.

Prof. Yadvinder Malhi also commented that there are two ways that classification data may be used. The first is in helping to classify land cover during the analysis stage. The second is as an interpretation and validation tool to check the interpolation work to produce the map.

4.3 Geolocation

Prof. Yadvinder Malhi noted that geolocation is an important issue and that the benefits of precise Global Positioning System (GPS) measurements are not trivial. For example, in going from 25 m to 50 m GPS accuracy, the amount of resolution noise triples. Ideally data locations should therefore be identified to 10 m accuracy. Unfortunately, many data sets in Ghana, as elsewhere, were collected before this GPS technology was widely available. It may therefore be worthwhile for the project to invest in a good GPS that can obtain at least 10 m accuracy in forests, and then have someone visit the key carbon stock data sites to ensure they are accurately geolocated.

Kofi Affum Baffoe noted this would be useful as the sample plots maintained by the RMSC are still located by compass and distance measurements from a boundary pillar. Kofi Affum Baffoe also noted that the RMSC sample plots need to be categorised according to their condition so that points within different categories of plots can be picked.

Dr Adu-Bredu indicated that GPS locations have been recorded for his datasets. Daniel Tutu noted that Ghana has adopted the WGS 84 scheme as its standard location system and that this system should be used for any further data collection. Stephen Mensah noted that the WGS 84 system is the one used by the RMSC on the plot locations it has converted into digital format. Dr Morgan Attua noted that if the intention is to build a database then standard

protocols will be needed for data collection, while Jim Gockowski noted it is also important to know when the data was collected.

Prof. Yadvinder Malhi also commented that the map aims to represent the existing land cover in Ghana, therefore, all available datasets will need to be reviewed so as to identify those datasets where the land cover has truly remained unchanged. This will involve working through the available datasets on a case by case basis with the data owner to see whether the land cover has changed. For example, it will involve reviewing the RMSC sample plots to see which plots are still in a similar condition to when the data was collected.

4.4 Consistency and Standardisation of Data

A number of participants including Dr Morgan Attua and Foster Mensah noted that care needs to be taken to ensure that classifications based on data drawn from different sources are consistent. For example, "forest" is classified differently in the national land cover maps produced by the EPA and CERSGIS. Foster Mensah suggested it would be useful to standardise CERSGIS and EPA efforts on land cover mapping. Prof. Yadvinder Malhi noted that systems are generally moving towards ecosystem carbon accounting approaches so different land cover definitions may become less problematic in future but that it is still an important issue. It may not be possible within this carbon map project to harmonise land cover classifications. However, this would be a useful exercise and there may be scope for a mini workshop in 2010 to try to do this.

Care also needs to be taken to ensure that biomass carbon data from different sources is also consistent. For example, Prof. Yadvinder Malhi noted that a number of different allometric equations can be used to convert biomass measurements into carbon stocks (e.g. Chave *et al.* 2005; Chambers, 2001; Brown *et al*, 1989). If various researchers in Ghana use different equations to calculate carbon stocks, then this may adversely affect the consistency of the data. That is, different equations are found to produce different results under the same conditions in Ghana. If raw tree data is made available for the project, these results can be standardised using the most appropriate general or locally developed allometric equations. Jim Gockowski queried how root biomass and tree density would be addressed. Prof. Malhi responded that there are very few actual direct measurements of root biomass. Generally it is around 20% of above ground biomass although in drier systems there is relatively more biomass below ground than this. As root biomass is difficult to monitor it is generally just scaled with above ground biomass and this approach is likely to be followed for the carbon map project. Prof. Malhi noted that where tree data is available then wood density values can be determined from existing databases and factored into the carbon stock calculations. Dr Adu-Bredu noted that they have also done density measurements for different species in Ghana.

Consistency issues are also important with respect to soil carbon data. For example, soil carbon samples may have been taken from different depths (e.g. 10 cm, 15 cm etc) making it difficult to compare the results. In many cases

bulk density or volume measurements have also not been taken for the soil samples making it difficult to calculate the carbon stocks. Dr. Edward Yeboah indicated that the Soil Research Institute generally reports on soil properties from 0 – 15 cm depth and that there are ways to correct for different soil depths. Prof. Yadvinder Malhi noted that the top layers (e.g. 0 – 15cm or 0 – 20 cm) is the most vulnerable layer for soil carbon stocks and indicated that it would be useful to agree on a standard soil sample depth (probably based on the most common soil sample depth for the available data) and then use that soil carbon depth as a standard for the carbon map project.

4.5 Data quality issues

Jim Gockowski commented that they have not been able to distinguish cocoa farms from secondary forest in Cameroon using remote sensing and that, in Cameroon, the typical cocoa system has many large shade trees resembling a secondary forest. Foster Mensah noted that oil palm plantations in the Eastern region of Ghana can be distinguished from rubber plantations in the Western region but so far, they haven't been able to distinguish secondary forest from some cocoa growing areas. Daniel Tutu noted that, mixed pixels are an issue in deciding the scale of the map and that sometimes it is difficult to detect whether the pixel boundaries match a farm or ecosystem boundary.

Kofi Affum Baffoe noted that in the first phase of sampling the permanent sample plots data and methodological problems were encountered, but that following a review in the mid 1990s these problems were ironed out. Dr Morgan Attua queried whether the sample sizes and difficulties in data collection would be pointed out. Prof. Malhi noted that the report that accompanies the carbon map should acknowledge any such issues.

Daniel Tutu noted that the 2007 national land cover map produced by the EPA has an accuracy of 58% based on ground truthing from 42 points and that this is less than the literature average which is normally at least 75%. Prof. Malhi noted that the carbon map project should have > 100 vegetation data points that ground truth the remote sensing interpolation to improve the accuracy of the map.

5. Preliminary Gap Analysis

A considerable amount of useful carbon stock data has already been collected in a range of land cover types in Ghana. This data can provide a base for developing the carbon map of Ghana provided this information is available for use on the project.

However, there also appear to be gaps in existing carbon stock data sets that will need to be addressed in order to build the carbon map of Ghana. The following gaps were identified during a session chaired by Daniel Tutu at the workshop:

5.1 Northern regions

Relatively little carbon stock data is available for the northern regions of Ghana. Prof. Malhi suggested that a small sampling effort in these northern regions could improve the modelling effort considerably. He also commented that not as much sampling is required in the north as remote sensing interpolation will be relied on to fill some of the gaps, particularly as radar images are better able to distinguish lower biomass systems from higher biomass systems.

Gloria Djagbletey noted that the TROBIT work provided carbon stock data for some northern areas (for example Mole National Park). Other data sets for northern regions include Dr Adu-Bredu and Professor Abekoe's work in Bawku and Jakpa Shu-aib's work on shea systems. James Agyei-Ohemeng noted that the Nature Conservation Research Centre has some vegetation sample data for Nyankamba, which was designed as a link between Bia and Mole National Parks, and also in Nkroranza h District between Ejura and Asukese.

It was noted that Dr Mathias Afosu may have data on soil carbon stocks in northern regions and that the Savannah Agricultural Research Institute (SARI) and the University of Development Studies may have useful data. Dr Jesse Naab and Professor Jon Lovett have already been contacted at these two institutions, but any information on other possible contacts particularly at SARI would be welcomed.

5.2 Plantations

There appear to be no carbon stock data sets in Ghana on oil palm or coconut plantations.

5.3 Farms

While some carbon stock data sets exist, particularly for cocoa farming areas, there has generally been less work conducted in off-reserve areas compared to forest reserves. Jim Gockowski noted that COCOBOD and the Ministry of Food and Agriculture may have statistics on how much area is under different land use types and Rebecca Ashley Asare noted that the Cocoa Swollen Shoot Virus Disease unit has some maps of cocoa areas.

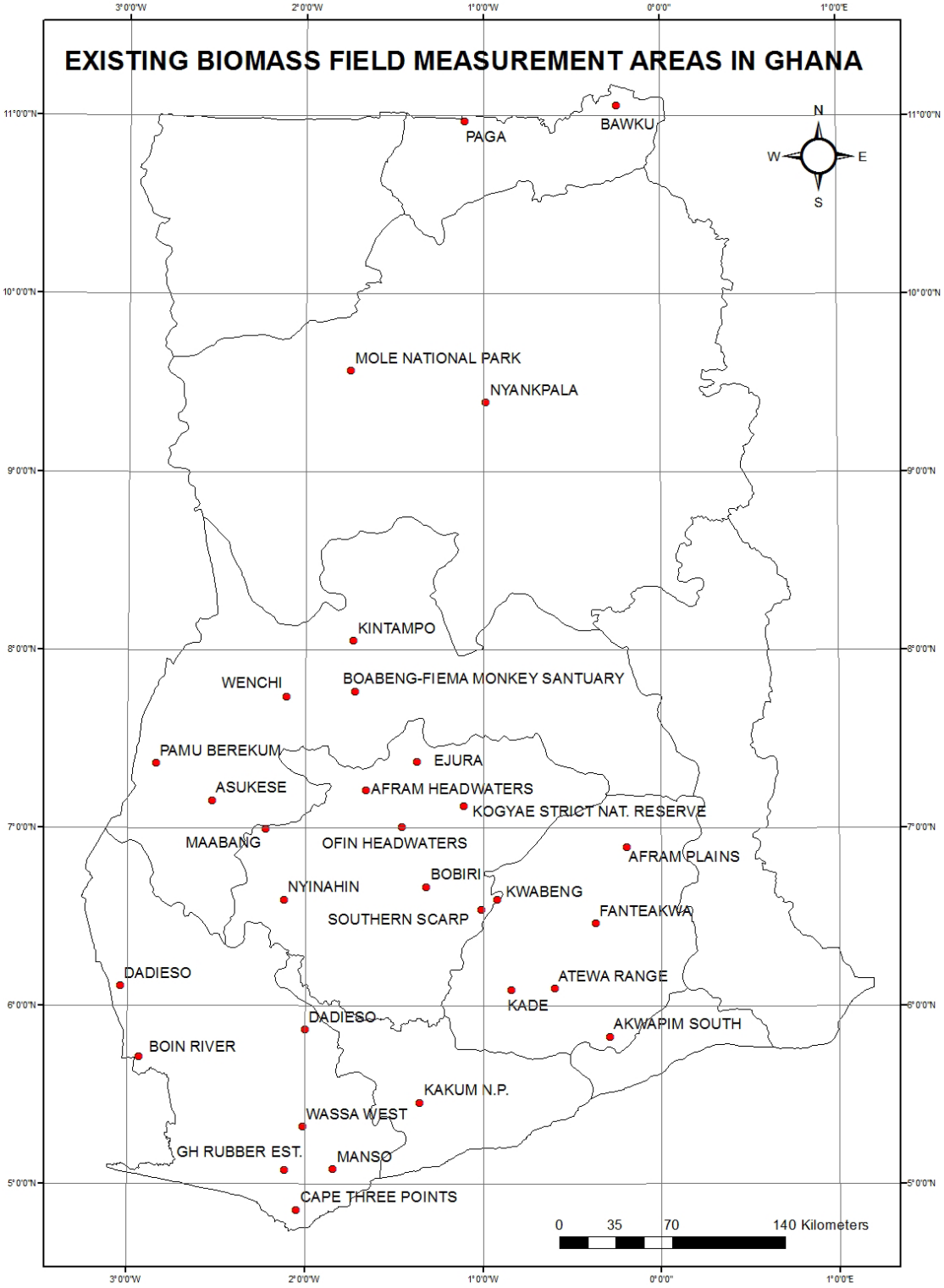
6. Conclusion

The scoping workshop proved to be highly successful, with most data on carbon stocks being identified, including gaps and areas which need to be improved. Participants freely and actively took part in discussions, which is very encouraging for the compilation of data for the carbon map project.

However, a key priority of the carbon map project is to obtain as much of the existing data as possible so that the map analysis structures can be developed and further data collection can commence on the gaps that remain in the available carbon stock data.

It is expected that follow-up meetings on discussions held during the workshop will receive similar level of cooperation. This will facilitate the completion of the map by the end of 2010.

7. Map Showing Existing Carbon Data Points in Ghana



8. Summary Table

Land Cover Type	Location	Name	Organisation	Biomass
Forest	Forest Reserves (FRs)	Kofi Affum Baffoe	RMSC	Y
Forest	Bobiri FR	Stephen Mensah	RMSC	Y
Forest	Bobiri FR	Stephen Adu-Bredu and Gloria Djagbletey	FORIG	Y
Forest	Kakum	Stephen Adu-Bredu	FORIG	Y
Forest	Ejura	Stephen Adu-Bredu	FORIG	Y
Forest	Bawku	Stephen Adu-Bredu	FORIG	Y
Forest	Awura FR	Stephen Adu-Bredu	FORIG	Y
Forest	Upper Tamne FR	Stephen Adu-Bredu	FORIG	Y
Forest	Boi Tano FR	Stephen Adu-Bredu	FORIG	Y
Forest	Pamu Berekum FR	Dominic Blay	FORIG	Y
Forest	Southern Scarp FR	Dominic Blay	FORIG	Y
Forest	Afram Headwaters FR	Francis Dwomoh	FORIG	Y
Forest	Asenanyo FR	Simon Lewis et al	University of Leeds/RMSC	Y
Forest	Asukese FR	Simon Lewis et al	University of Leeds/RMSC	Y
Forest	Cape Three Points	Simon Lewis et al	University of Leeds/RMSC	Y
Forest	Dadieso	Simon Lewis et al	University of Leeds/RMSC	Y
Forest	Kade	Simon Lewis et al	University of Leeds/RMSC	Y
Forest	Mole National Park	Simon Lewis, Gloria Djagbletey et al	University of Leeds/FORIG	Y
Forest	Kogyae Nature Reserve	Simon Lewis, Gloria Djagbletey et al	University of Leeds/FORIG	Y

Appendix 1 – Workshop Contact List

Name	Organisation	Email
Kwabena Asubonteng	APERL	kwabena.asubonteng@gmail.com
Bhat Roopak	Cadbury	roopak.bhat@cadbury.com
Ulrich Bang	CARE	Ulrich.bang@gmail.com
Foster Mensah	CERSGIS	fmensah@ug.edu.gh
Vincent Awotwe-Pratt	Conservation Alliance	vawotwe-pratt@conservealliance.org
Opoku Pabi	Consultant	opabi@yahoo.com
Daniel Tutu Benefor	EPA	dbenefor2000@yahoo.com
Dr. Stephen Adu-Bredu	FORIG	sabredu@gmail.com
Gloria Djagbletey	FORIG	abenakyaa@yahoo.com, gdjaney@csir-forig.org.gh
Dr. Dominic Blay	FORIG	drdominicblay@yahoo.com
Rebecca Ashley Asare	Forest Trends, Incubator	rasare@forest-trends.org
Atsu Fumey	Ghana Wildlife Division	selorm12@hotmail.com
Evelyn Asante	KNUST	eveyeb84@yahoo.com
Prof. Samuel Oppong	KNUST	Sko86@hotmail.com, kobbyoppong@yahoo.com
James Agyei-Ohemeng	NCRC	jaohemeng@yahoo.com
Daniel Bewong	NCRC	dengtelbw@yahoo.com
Atsu Titiati	Rainforest Alliance	atsu@africaonline.com.gh
Kofi Affum Baffoe	RMSC	kofi1964ba@hotmail.com, kofi@rmsc.fcghana.com
Stephen Mensah	RMSC	tastylord@yahoo.com
Valerie Nasah	RMSC	valfn2003@yahoo.co.uk
Jesse B. Naab	SARI, Wa, Upper West Reg Ghana	jnaab@ufl.edu
Dr. Edward Yeboah	Soil Research Institute	eyeboah5@hotmail.com
Enoch Boateng	Soil Research Institute	enochboateng06@yahoo.com
Prince Gyekye	Soil Research Institute	princeg772002@yahoo.com
Jim Gockowski	STCP	j.gockowski@cgiar.org
Prof. Mark Abekoe	University of Ghana	k_abekoe@ug.edu.gh
Dr. Morgan Attua	University of Ghana	
Vincent Vordjober	University of Ghana	
E.M. Altua	University of Ghana	emaltua@ug.edu.gh
Prof. Yadvinder Malhi	University of Oxford	yadvinder.malhi@ouce.ox.ac.uk
David Aitken	University of Oxford	david.aitken@ouce.ox.ac.uk
Norma Salinas	University of Oxford	
Jason Ko	US Forest Service	jko@fs.fed.us
Seth Gogoe	West Africa Fair Fruits	sgogoe@gmail.com

Appendix 2

Methods for Sampling Belowground Organic Pools

Soil sampling procedures

Two types of soil samples can be distinguished:

- Disturbed soil samples for chemical analysis (where the results will be expressed per unit dry weight of soil).
- Undisturbed soil samples for physical analysis, especially the 'bulk density' (specific gravity) of the soil which is essential to convert the soil dry weights into soil volume.

Procedure for taking disturbed soil samples for chemical analysis

Field procedure

Locate sampling frames within the transect or quadrat.

1. Continue after removing the 0-5 cm (usually organic) layer, and take samples of the 5-10, 10-20 and 20-30 cm soil depth. Approximately 1 kg of fresh soil is sufficient.
2. Soil samples from the same depth taken in the replicate sampling grids within a single transect can be combined directly in the field, or subsequently mixed in the sample processing site.

Sample processing

3. Mix the composite sample thoroughly, and divide into 3 bags: 1 kg of fresh soil for SOM fractionation, 0.5 kg for chemical analysis and another 0.5 kg of soil for archiving; the remainder can be discarded.
4. Air dry the soil of all three subsamples by placing them in a shallow tray in a well ventilated dust and wind free area. Break up any clay clods, and crush the soil lumps so that gravel, roots and large organic residues can be removed.
5. Sieve the soil samples intended for chemical analysis through a 2 mm sieve, and grind them in a mortar in order to pass through a 60 mesh screen.
6. Sieve the soil samples intended for SOM fractionation (without grindingWrite clear labels for each sample using a waterproof marker pen of each sample, and wrap into a second plastic bag to prevent it from physical damage during transportation. Send it to laboratory for chemical analysis.

NB: This process will be done at the Soil Research Institute, Kumasi.

Equipemnet: Core sampler or ring, 5cm x 5cm.

Procedure for taking (undisturbed) soil sample for soil bulk density measurement

Equipment:

1. Ring samples (stainless steel) with a sharp edge and of known volume and 100-200 cm3, for example 5 cm diameter and height.
2. External ring to push ring samples gently into the soil

3. Soil knife to remove the ring and any excess soil adhering to it
4. Plastic bags, rubber bands and marker pen

Procedure:

1. Sample close to the sample sites for destructive samples, but avoid any place with possible soil compaction due to other sampling activities.
2. Remove the coarse litter layer and insert the first ring gently directly from the soil surface, to sample the 0-5 cm depth layer; if the sample could not be inserted smoothly (e.g. due to woody roots or stones), try again nearby.
3. Excavate the soil from around the ring and cut the soil beneath the ring bottom.
4. Remove excess soil from above the ring using a knife: first remove excess soil on top of the sample, then place a cover on top of the ring and turn it upside down to remove soil adhering to the ring and cut a smooth surface at the bottom of the ring.
5. Either transport the cleaned ring to the laboratory, or remove all soil from the ring to a plastic bag which is closed immediately.
6. On a nearby site, remove the top 5 cm of soil and insert a ring for sampling the 5-10 cm depth layer in a similar way. Repeat for the 10-20 and 20-30 cm depth layer, taking samples around 15 and 25 cm depth.

Sample processing:

Weigh the samples fresh W1, (dry at 105°C for 2 days), and weigh again (W2)
Bulk density = W2/V (g/ cm^3)