Improving Capacity in Forest Resources Assessment in Kenya (IC-FRA)

Technical Report on the Pilot inventory

May 2016

Prepared by:
The Project *Improving Capacity in Forest Resources Assessment in Kenya (IC-FRA)* implemented 2013 –2015

Compiled by:
Peter N. Nduati, Mbae N. Muchiri, Balozi B. Kirongo, Fredrick Ojuang, John Ngugi, Willis Atie, Pekka Hyvönen, Helena Haakana, Jukka Alm, András Balázs, Heikki Parikka

Front page photograph: Natural forests in Nakuru National Park

Photos taken by: P. Hyvönen

Contents

List of Tables

List of Figures

List of Annexes

Acknowledgements

We most sincerely thank the Government of Finland and Government of Kenya for providing financial support for the IC-FRA Project that has built capacity in terms of staff, equipment and knowledge in biophysical surveys. Special thanks are extended to Directors of Luke, DRSRS, KMFRI, KEFRI, KFS and the Vice Chancellor University of Eldoret for allowing their staff to participate in the Project.

1 Introduction

In the national strategy for Reducing Emissions from Deforestation and forest Degradation (REDD+), the Government of Kenya aims to protect its remaining forest resources and enhance forest carbon stocks to improve local livelihoods and biodiversity. This requires environmentally and socially sustainable forest and land-use policies, accurate and comprehensive information on the national forest and tree resources. The Improving Capacity in Forest Resources Assessment in Kenya (IC-FRA) project, funded by the Governments of Finland (GoF) and Kenya (GoK) under the Miti Mingi Maisha Bora (MMMB) programme was started in December 2012 to support developing a Plan for National Forest Resources Assessment (NFRA) for estimation and monitoring of forest carbon stock and its changes. The project was jointly implemented by five institutions: Luke (National Resources Institute Finland), KFS (Kenya Forest Service), KEFRI (Kenya Forestry Research Institute), DRSRS (Department of Resource Surveys and Remote Sensing) and University of Eldoret (UoE).

Planning of a NFRA is a demanding task which starts with a simulation study to choose an efficient sampling design while taking into account requirements for the reliability of the main variables (volume and biomass) and constrains of resources including field measurement costs and time. To obtain prior information about forest structure on different vegetation types in Kenya for a simulation study, a pilot inventory on five test areas was carried out in 2013–2014. In addition, the pilot inventory aimed at strengthening both human and technical capacity of Kenyan partner institutions in collecting and managing information on forest and tree resources.

The pilot inventory provided an excellent opportunity to introduce selected sampling methods to test field measurements used to collect data from different carbon pools in forests, and to develop a calculation protocol to estimate all parameters required for the national and international reporting. The inventory also served as an ultimate test of the methods introduced and manuals written in different working environments in Kenya.

The NFRA under development will include variables measured from tree stands and soil carbon pools. Inclusion of soil organic carbon measurements sets a challenge for the field teams in collecting all the required data and samples within a reasonable time frame. Depending on conditions at the inventory plot, preparation of four soils pits and careful collection of litter, woody debris and the volumetric soil samples can be time consuming. There is a risk that the soil technician may be left behind to avoid delay in other cluster measurements. As a consequence, litter and soil samples can be obtained from a reduced number of plots within the cluster. Furthermore, division of the team into two sub-teams obviously adds challenges in security and logistics. A time study was included in the pilot inventory to help in setting a budgetary frame for the national level effort. The time consumption data covering all aspects of the field work in the pilot areas were used to determine the capacity of the field teams.

The specific objectives of the pilot inventory were:

i) To collect information on the variation of tree and forest structure and soil properties in different vegetation types in Kenya;
ii) To collect data on time consumption of the field work, separately for different measurements on a sample plot and moving between the sample plots;
iii) To test new measurements, for example, on dead wood and climbers, to gain experience on their feasibility and time consumption in Kenyan conditions;
iv) To test and gain experience of using field computers in data collection; and
v) To improve capacity of Kenyan partner institutions in conducting a forest inventory based on sampling, data management and calculation of inventory results.

The pilot inventory was implemented in three main phases: preparations, field work and data analyses. Preparations were completed in eight months from February to September 2013, and the actual field work on five test areas between October and December 2013. The Quality Assurance was included and a Quality Control team re-measured part of the sample plots in January 2014. In addition, a questionnaire to the field teams was administered in order to collect feedback from field teams. The calculation of results and training on the calculations were conducted in 2014. In this technical report, the main phases and lessons learnt from the pilot inventory are described and discussed.

2 Preparation phase

2.1 Meetings

The Inception Workshop for stakeholders to seek their engagement and to share experiences in natural resources assessment and expectations for the IC-FRA project and the NFRA for Kenya was undertaken in Nairobi from 18^{h}–19^{h} February 2013. During the workshop, information needs on forest and tree resources and general requirements for a nation-wide forest resources assessment were presented and discussed. The major output on the way forward was to form a Technical Working Group (TWG) to spearhead IC-FRA project activities. The pilot inventory was planned and preparations for field work were discussed in two TWG workshops and several meetings in February – June 2013. In all the meetings, the issues discussed were related to the pilot forest inventory including procurement of equipment, training field teams, selection of representative test areas, compiling field and laboratory manuals, improving capacity in national forest resources assessment for staff of four Kenya institutions, developing and testing software for data collection and analysis.

2.2 Materials and software

Materials for the pilot inventory including maps and reports were prepared from February to June 2013. It included collecting materials of the previous forest inventories (reports, maps data and other relevant documents. The maps were used to determine the ideal locations for test areas of pilot inventory. The reports of previous inventory projects were used to review the applied methodologies which assisted in writing the Field Manual for the pilot inventory.

Procurement of inventory equipment and computers (laptops) for field crews was started in March and completed in August 2013. Procurement of laboratory equipment, consumables and glassware did not proceed as planned because of administrative difficulties in money transfers. Due to this, direct purchases were done by KEFRI and Luke’s experts during their missions. However, all necessary procurements could not be procured during the pilot inventory and the following laboratory work phase. Even after completion of the pilot laboratory work some equipment (e.g. glassware and water distiller) were not purchased because of delivery problems by the selected vendors. The inventory equipment purchased included laptops, digital cameras, calipers, measuring tapes, spherical densitometers, soil sampling cores, PDAs (personal digital assistant, i.e. field computer) and clothing. Procurement of the equipment was conducted both in Finland and in Kenya.

The design for the pilot inventory and instructions for the field measurements were compiled in a Field Manual by Luke’s inventory expert together with project coordinator and TWG members. The first version was based on Field Manuals used in other similar countries e.g. Tanzania and Vietnam. The pilot inventory was designed to cover all common forest and tree variables required for area and volume estimations and to estimate forest carbon stock of different components of a forest ecosystem: growing stock, dead wood, litter and organic soil. The Field Manual was revised several times and the version applied for the pilot forest was agreed during a training session in October 2013.The Field Manual includes instructions for sampling of soil, litter and woody debris. After a training session on sampling mangroves soil sediments in September 2013, the Field Manual was supplemented with a manual for sediment sampling compiled by Luke’s soil and GHG expert, Dr. Kairo of KMFRI and soil experts of KEFRI.

The TWG agreed in a meeting in February 2013 that modern technology will be used in all project activities whenever possible. Thus, it was agreed that PDAs will be used in field data recording. Open-source software developed by FAO (Food and Agriculture Organization of the United Nations), Open Foris Collect (OFC) and Open Foris Collect Mobile (OFCM) (http://www.openforis.org/) were selected as the major software for data collection and analysis. All Open Foris tools and methods are freely available and can be modified on need. The OFCM was still in a developing stage during the year 2013 and many improvements and changes were done before the field work started.

Inventory data in the OF Collect can be saved in a SQLite or PostgreSQL database running on PC. A PostgreSQL database can also be installed on a server, which is a good solution in large scale inventories with extensive amounts of data. In this pilot inventory, work was started with a SQLite database on PC. OFC was used to design and set up the database and to design field forms. The same field forms were used in the OFC Mobile to record data in the field. From OFCM running on PDA, data was transferred to OFC running on PC. The database and the field forms were designed and tested by Luke’s inventory and remote sensing experts in Finland before the field work was started. A manual, i.e. instructions for installing OFC and using OFCM on PDA was compiled by Luke’s remote sensing expert.

Work maps for the field teams were printed by KFS before the field work. Some of KFS’s map data is digitized from the base maps, and the quality of printed maps is not as good as with original digital data. The sample plots with ID information were printed on these maps (Figure 1). The used coordinate system was WGS84/Universal Transverse Mercator (UTM) 37 S. Although, there are four UTM zones in Kenya (36 S, 36 N, 37 S, 37 N), the 37 S was selected as it is the official coordinate system of KFS digital data.

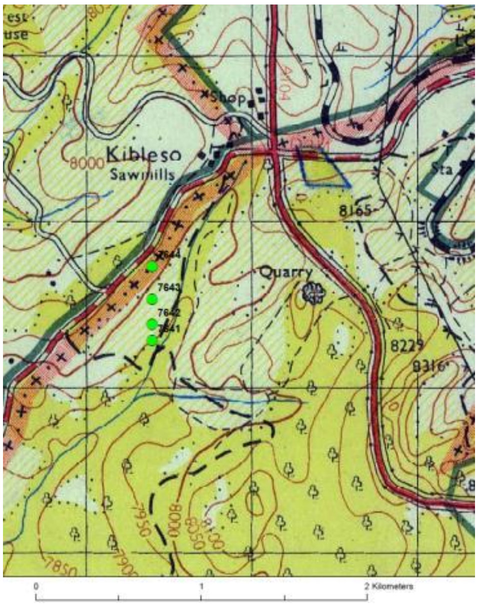

Figure 1. Example of printed field map used in the training of the field work.

2.3 Test sites

Five test sites representing different vegetation types in Kenya, namely natural forests, forest plantations, farm forests, woodlands and mangroves were selected based on office work and field visits. The tentative locations were determined during the project planning phase in 2011. The sites were first delineated by means of existing GIS data from Kenya (e.g. Based on agro-ecological zones, forest types and maps of land cover changes produced by Forest Preservation Programme (F-PP) as well as Google Earth images. In the next stage, a team of IC-FRA project members visited two areas; mangroves on the south coast and woodlands in Baringo County. The team composed of Mr. Peter Nduati (Project manager), Ms. Serah Kahuri (FIS), Ms.

Faith Mutwiri (Remote Sensing) and Mr. Dominic Musango (Management trainee). After the field visit, the test sites in mangroves and woodlands were relocated to appropriately meet the target of the pilot inventory. The area of each test site was agreed to be at least 100 km^2. However, the final area varied from 40 km^2 (the mangrove test site in Gazi) to 900 km^2 (Table 1 and Figure 2).

Table 1. Information about the test sites of the pilot inventory.

Forest ecosystem	Test site	Area, km^2	Clusters / sample plots
Farm forest	Nakuru	900	60/240
Forest plantation	Kericho	900	53/212
Mangrove	Gazi	40	41/164
Natural forest and bamboo	Aberdare	400	25/100
Woodlands	Marigat	900	52/208

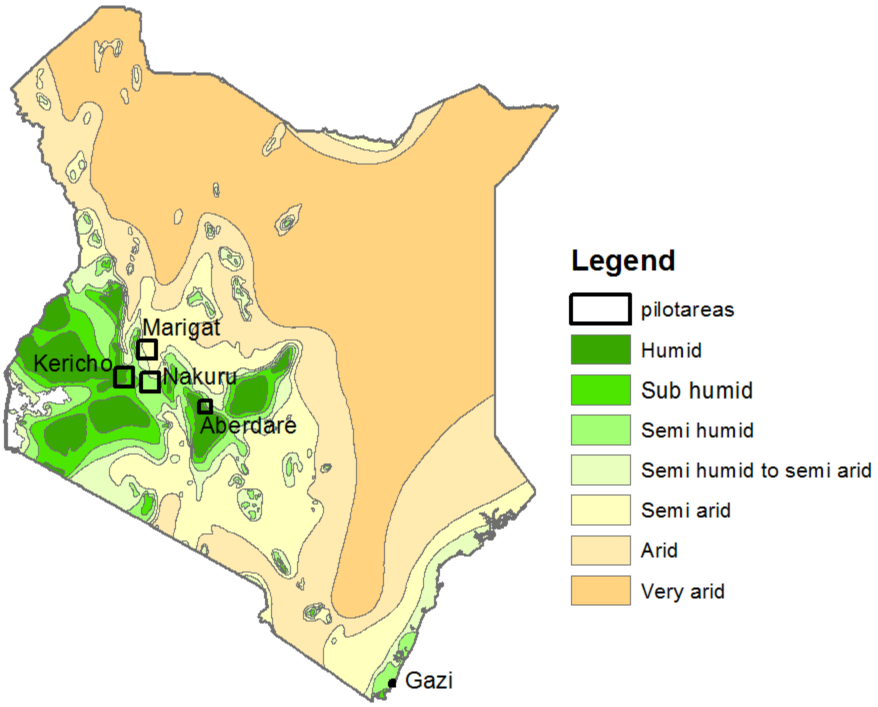

Figure 2. Agro-ecological zones and the locations of the IC-FRA pilot inventory test sites in Kenya.

2.4 Sampling design

The sampling design was a systematic cluster sampling. The position of the first cluster's sample plot number one was selected randomly and the other clusters and sample plots were systematically located. Distances between clusters were 1 km in South-North direction and 0.5 km in West-East direction in the mangrove test site (Gazi) and 4 km x 2 km in the other test sites. The sample plot distances within a cluster varied between 100 and 200 m (Figure 3). The aim of this design was to obtain comprehensive information on spatial variation of forest structure and save on the walking time between sample plots. Altogether 231 clusters comprising 924 sample plots were generated (Table 1) and 10 clusters of each test site selected for field measurement. Selection of clusters was based on Google Earth study by Luke's inventory experts.

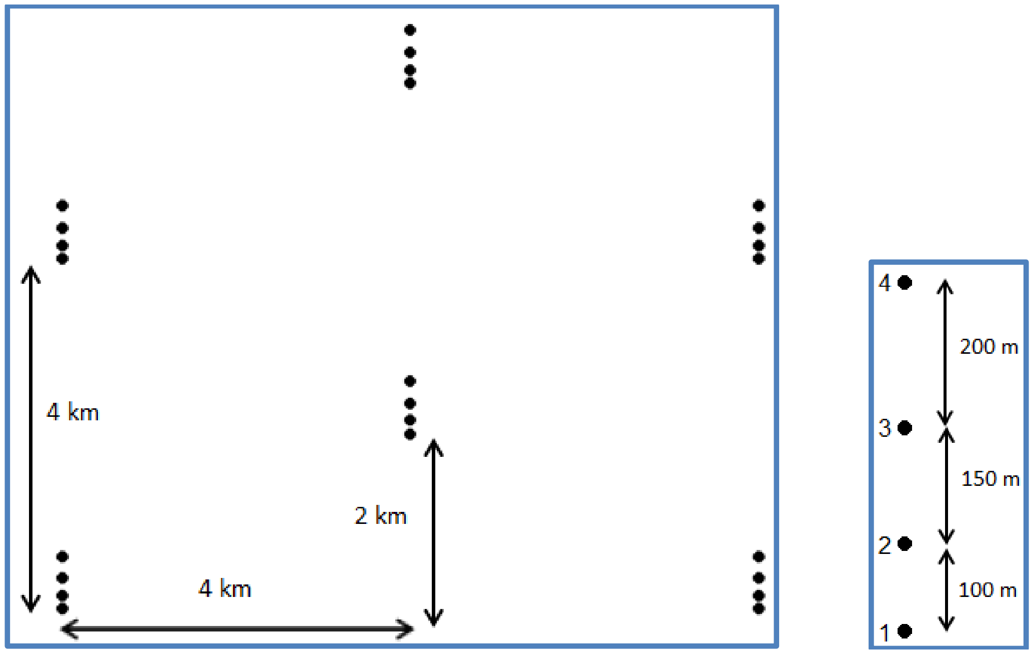

Figure 3. Sampling design on the test areas.
On the left are distances between clusters in the upland test sites and on the right distances between sample plots.

The primary sampling unit for tree measurements was a concentric sample plot (Figure 4). The sample plots were grouped into clusters to reduce inventory costs. The measurement unit was a cluster and as a rule of thumb it should to be measured in one working day by one field team. However for the purpose of planning, it was assumed that a cluster must be measured in one day in plantation forests and farm forests, and in not more than two days in natural forests, woodlands, bamboo forests and mangroves.

The use of concentric plots in forest inventory aims at increasing the accuracy of the measurements and sampling intensity of large trees, and simultaneously saving time. This is in line with the fact that subtropical and tropical natural forests are characterized by negative exponential diameter distribution such that there are more small size trees and the number of trees decreases with increasing tree size. The concentric plot design ensures that small trees are measured in small plot area and large trees (which constitute most of the biomass per unit area) are measured in large plot area. This arrangement results in measuring approximately the same number of trees for the different size classes.Also lying dead wood, stumps, shrubs, regeneration, bamboos and climbers were measured within the sample plot, and samples of soil, litter and woody debris collected for laboratory analyses. In addition, stand-level parameters were assessed on the area surrounding the plot. These included information about land use, vegetation type, human impact and biodiversity. The sample plot measurements and soil sampling procedure are described in detail in respective IC-FRA Field Manuals.

Location of the soil pits were just outside the outer perimeter of the largest sample plot radius (Figure 5). Four (minimum three) soil pits were made by default at the cardinal points (N, E, S, W). Any of the points, if inaccessible or outside the forest, could be replaced by any optional sub-cardinal point (NE, SE, SW, NW) that fell within the same stand. If the sample plot was divided into two or more stands, soil sampling was repeated for each stand and represented by at least three soil pit locations. If at least three points could not be established within a stand, soil sampling was not undertaken.

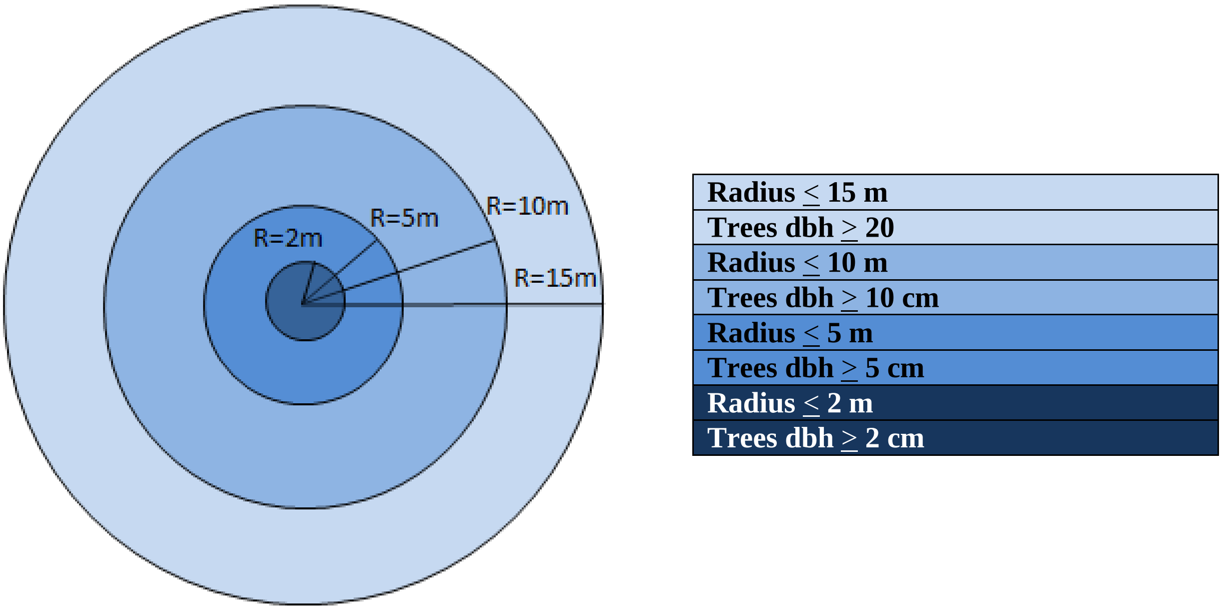

Figure 4. Concentric sample plots used in the pilot inventory.

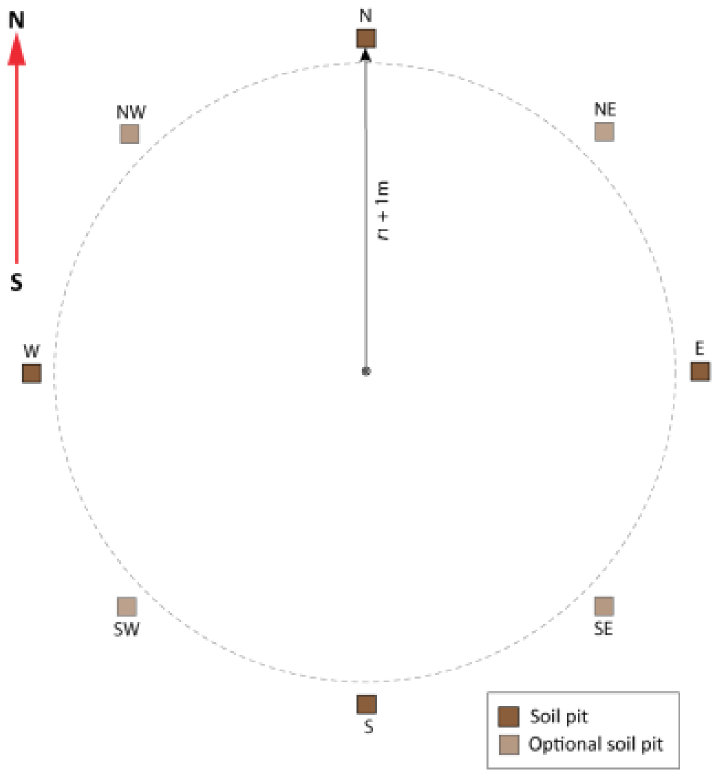

Figure 5. Locations of soil pits one m outside the outer perimeter of the largest (radius 15 m) concentric plot.

Every 4th cluster was permanent in this pilot inventory requiring additional measurements. First, directions and distances from the sample plot centre to every tree were recorded. Secondly, three fixed points were marked in the field and locations and descriptions of the points to facilitate easy relocation in re-measurements. However, the main objective of measuring permanent sample plots was to gain information on the time consumption, not to establish a network of permanent plots, because the sampling design in the national inventory under planning may differ from the one used in the pilot inventory.

3 Training forest inventory teams

3.1 Training of forest measurements

The first training on forest measurements for field teams was held in Nakuru from 2nd – 5th July 2013. There were 35 participants: 5 team leaders and their assistants, 6 soil technicians, 2 taxonomists, 10 rangers and 7 experts. Training included theories of measurements for two days and practical measurements in the field for another two days. Emphasis was laid on sample plot establishment and measurement of stand variables. This included measuring trees, seedlings, bamboos, dead wood and stumps within concentric circular plots.

The idea of using circular concentric sample plot was new to most of the participants who had previously used rectangular plots. It was therefore found necessary to undertake a rapid comparison on the efficiency of a concentric plot versus a rectangular one. This was done by assigning two field teams to simultaneously assess a concentric and a rectangular plot in a natural forest during the training session. Based on the observations it was agreed that a circular sample plot would be used in the pilot inventory.

A training course on use of PDAs, backing up and cleansing of field data for field teams was held from 1st to 2nd August, 2013 for 20 participants and was conducted by Luke's remote sensing experts. An additional training course on Open Foris software, OFC and OFCM, and developing field survey forms was held from 5th to 9th August 2013

The field work started in October, 2013 and was preceded by another training course on sample plot measurements and data recording held in Nakuru from 1st to 4th October2013. Trainers were Luke's project coordinator and remote sensing expert. During the training there was intensive revision on the Field Manual and subsequent updating of the OFC and OFCM forms. Field maps were also improved by adding new labels to the sample plots. These included the ID, the status (Permanent or Temporary) and the rank (Selected as primary or not) of the sample plot.

During the next two weeks, Luke's RS expert continued hands-on training at Gazi for the field team assigned to carry out measurements in the mangroves test site and then in Nairobi for the Quality Assurance (QA) team from KEFRI.

Figure 6. Field team members and inventory experts participating in a training course in July 2013.

3.2 Training on soil sampling and laboratory work

A training workshop on improving the draft Laboratory Manual and theory of soil sampling and analytical laboratory work was organized by Luke's soil and GHG expert at KEFRI Headquarters on 25th to 26th June 2013 (Figure 7).

Figure 7. Taking a soil sample using a volumetric corer (Photo by J. Alm).

Critical issues observed during the training session were noted and discussed between the trainers and inventory team members. Special interaction between the Team Leader and Soil Technician is required when the team reaches the plot. Because soil sampling is time consuming, soil and litter sampling was instructed to start as soon as the plot boundaries were determined. It appeared crucial that the Soil Technician immediately gets correct bearings for sectors of possible multiple stands, and can proceed to identify the soil pit locations for each stand. Equipment and practices better suitable for sampling of very large litter and woody debris quantities were innovated during the field training (Figure 8).

Figure 8. Large amounts of litter from bamboo, too much to collect using a 1 m^2 ring (Photo by J. Alm).

A special training on soil measurements and sediment sampling in mangroves was conducted from 23rd to 26th September 2013 in Mombasa at KMFRI Headquarters and South coast mangrove test sites during Luke's soil and GHG expert mission. There were eight participants from Kenyan partner institutes and in addition, 6 participants from KMFRI. After the training it became possible to write a "*Supplement to Field Manual Biophysical Pilot Survey Kenya: Sediment sampling in mangroves*" and a new section in the *Laboratory Manual*, covering procedures used in mangrove sediment sample preparation and organic carbon analyses.

During the training it became clear that the preliminary cluster constellation was too sparse to effectively catch the zoned mangrove forest characteristics as was the case in other test sites. In addition, most of the clusters fell completely outside the mangrove vegetation. Following the experience, a more dense set of clusters (1 by 0.5 kilometers between clusters) was generated for the Gazi test site.

4 Field work

4.1 Field inventory

4.1.1 Inventory team structure

The field inventory was carried out by five field teams of KFS and KEFRI staff members. Each field team was planned to consist of two Foresters, a Soil Technician, 2 Rangers when needed, 1–2 Drivers and a Taxonomist in natural forest, woodland and mangroves test sites. Each team had two Soil Technicians because Munsell colour books could not be delivered to all the teams. Soil technicians considered this solution good in terms of efficiency and quality control, since the workflow could be easily distributed between two soil experts, and subjective measurements could be controlled as per need by a second opinion. In addition, local casuals were hired as necessary. However, taxonomists were not participating in the field work in all the test sites or all the time, which was found to be insufficient. There were only two taxonomists for four upland teams and the two were rotating around the teams. It is recommended that each field team should have a taxonomist as the amount and variation of species is extensive.

4.1.2 Execution of the field work

The launch of the field work was on 1st October 2013 starting with 4 days training session. The actual field work started in Kericho County on 30 October. All field teams (5) started the measurements in the Kericho test site. The idea was to give the field teams opportunity to discuss the problems or unsolved issues face to face in the evenings (after day's work). When the Kericho test site was completed, the teams moved to Aberdares, then to Baringo and finally to Nakuru. One field team was responsible for the inventory of mangroves in Gazi. Each field team had one car and a driver for transporting the whole team. The teams found it good to work together rather than independently. In instances where the field teams were split, soil technicians continued to work at the sample plot when the rest of the team continued to the next sample plot. In these situations two cars could have been better solution.

Originally the field work was aimed to start immediately after the first training session in July to avoid the short rainy season. However, a delay of 3 months caused some troubles during the field work especially in the plantation test site in Kericho where the teams were forced to walk long distances as some roads were impossible to drive during the rainy season (Figure 9). Sometimes the distance to cluster was as long as 8 km. The control of team during the trek was a challenge due to poor visibility in rain. In some occasions a team member became so exhausted that he/she had to be left behind with a forest ranger. In those cases working communications are essential for safety, but cell phones operated only 70% of the time in the field. In the cases where the team had to divide, the communications did not always work. This is a problem when the team treks back to the car as the night approaches.

Figure 9. Muddy road after the rain **(**Photo by F. Ojuang).

Some clusters were reached in the afternoon, which reduced working time. Some plots were found to be outside the target forest type, sometimes in a river. While this is normal, the bad conditions resulted in relatively high consumption of time when identifying the location of a single plot. The teams were able to have breakfast in the morning but rarely had lunch due to field work. Carrying food over long distances was not possible, and having a lunch break was not convenient because time to finish field work had to be saved. Even water reserves were not adequate due to long carrying distances.

Moving of the field team in mangrove test site was challenging, especially in cases when a motor boat could not transport the team to a cluster (Figure 10). Other difficulties in the mangrove test site were caused by the tide. Differences between high and low tide might be near four metres and the field team had to adapt their working period to that of low tide. Thus, the potential working time in the field per day was not more than six hours and the timing changed daily following the schedule of low tide.

Figure 10. Field team going to sample plot in mangrove test site **(**Photo by F. Ojuang).

The field teams located the sample plots with the help of printed field maps and GPS. The field maps were used to approach the cluster by the vehicle and a GPS device to locate the sample plot centre on foot. The coordinates of the sample plots were downloaded beforehand as waypoints in Garmin eTrex,
Figure 11.

Figure 11. Garmin eTrex GPS used in the field for locating sample plots.

On the sample plots, information on different levels were measured and assessed. Sample plot information was collected within the sample plot area and observations for stand description were carried out on the area surrounding the sample plot. A sample plot was divided into several stands if different land use classes or vegetation types occurred within the sample plot. The stand parameters were estimated as an average of the forest or land use class surrounding the sample plot. Information for stand description was collected and recorded, for example, about land use, vegetation type, soil texture, stoniness, and forest products and services. Also shrubs, tree regeneration, bamboos, dead wood (diameter > 10 cm), stumps, woody debris (diameter < 10 cm) and litter were measured. For each tally tree inside the plot, species, diameter at the breast height, timber quality, health status and tree origin were recorded. Every 5th tree in a cluster was selected as a sample tree of which extra variables, e.g. stump diameter, stump height, total height and bole height were measured. The instructions for measurements including definitions of variables are described in detail in the biophysical Field Manual.

All the pre-selected clusters and sample plots were aimed to be visited in the field even in cases when a sample plot on the map seemed to be located off land, e.g. in a river. Some sample plots were located in a different vegetation type or even land use class than the test site was selected to represent. For example, in Aberdare's forest test site (natural forest) some sample plots were located in a tea estate while in Kericho's where the test site was a plantation forest, some clusters were in natural forest. The field teams also reported that some common farm-forest tree species including *Grevillea robusta* and *Eucalyptus spp.* were not adequately captured in Nakuru's test site (farm forest). This, however, did not matter because the main purpose of the pilot inventory was to collect information on forest structure i.e. on the variation of tree volume and biomass in Kenya and not to produce inventory results for different vegetation types. Furthermore, this is the nature of a systematic sampling where some information on all land use classes is recorded, for example estimate of areas of different land use.

Sampling of soil, litter and woody debris was carried out in one sample plot per cluster. It was predicted that soil sampling could prove more time consuming than other plot measurements, causing a delay for the rest of the team. In order to minimize the delay, it was decided the soil samples would be taken from the first sample plot to be assessed in a cluster. In case soil samples could not been taken on the first plot due to inaccessibility, soil samples were taken from the next possible plot. This was not a statistically sound method, introducing a potentially subjective choice of which plot is approached first. Soil samples were also not obtained from the plots falling outside the test sites designated vegetation type. As a result, the amount of soil data remained less than adequate for piloting the variability in soil (Table 2). However, the procedure was approved for piloting in order to guarantee a sufficient amount of sample plots with tree measurements for the design of the nation-wide inventory.

The soil data for soil samples were recorded on paper forms and later entered to the field PDA. This was because only one PDA was available for each team during the pilot inventory. Soil Technicians had the same difficulties as the rest of the inventory team, sometimes or even more. Rains were more harmful for Soil Technicians as they used paper forms for recording their measurements. Sometimes soil sampling took more time than the other sample plot measurements. This led to s soil technicians being left to finish their work while the rest of the team proceeded to the next sample plot. In difficult conditions without proper communication, possibilities between the split team, it was not a safe way to operate. A forest ranger was sometimes available for both sub-teams, but not always.

Sediment sampling in mangroves site using a different methodology was less time consuming than in the upland test sites because one soil technician was from KMFRI and had good experience with mangroves.

Table 2. Number of sample plots with soil sampled and analysed in the different test sites.

Test Site	Type of site	Soil layer, cm	Nr. of soil sample plots
Aberdares	Natural forest	0 -30	12
Kericho	Plantation forest	0 -30	13
Nakuru and Marigat	On-farm and Woodland forest	0 -30	20
Gazi Bay	Mangrove	0 -100	45
Total			90

The teams had local casuals helping in measurements and opening access lines. It was noted that local people had knowledge on how to access sample plots easily in instances where rough terrain not shown on the maps would hinder accessibility. The field teams were instructed that Regional Foresters must be informed well beforehand about the field team's arrival in the area so that they can contact and inform local community on what was being done. Apparently this was not well done because field teams encountered some hostile and suspicious local people in some areas.

Data were recorded in the field on OFCM running on PDA (BIP-6000Max) (Figure 12) and later transferred to PC and backup copies in external hard disks and Google Drive. The OFC already checked data in the field was imported to a PC. The software and PDA were functioning without disturbing problems. However, in some occasions, the OFCM became slow in data entry, but this was not a serious problem.

Figure 12. The PDA, Pidion BIP-6000Max used for data entry in the field.

The field teams spent a total of 36 working days on field measurements. All the pre-selected clusters were visited and 166 sample plots having trees were measured (Table 3).

Table 3. Measured clusters and sample plots and average measurement times on the test sites.
(Measured sample plots include only plots having measured trees).

Forest ecosystem	Test site	Measured clusters	Measured sample plots	Measurement time, plot	Measurement time, cluster
Farm forest	Nakuru	7	19	37 min	2 h 24 min
Forest plantation	Kericho	10	37	2 h	7 h 57 min
Mangrove	Gazi	13	46	1 h 39 min	6 h 37 min
Natural forest and bamboo	Aberdare	11	30	1 h 48 min	7 h 3 min
Woodlands	Marigat	10	34	58 min	3 h 40 min

4.2 Feedback on the field work

Collecting feedback on the field work was seen as one important part of the pilot inventory because the results could be used for further development of the Field Manual and the processes in the field work. A questionnaire for feedback was prepared by F. Ojuang and Luke's experts. The questionnaire was sent to field team leaders and assistants and also QA-team members. The questions dealt with definitions, measurements and practices. Opinion and suggestions were asked about the Field Manual and how teams managed the field work (Table 4. Issues concerning PDA and OFCM were also included in the questionnaire.

Table 4. Scale for the questions in the feedback.

Scale	Field (or PDA) manual	Field work
1	I understood the instructions completely, text was easily understandable, etc.	No difficulties in carrying out the field measurements
2	There were some small issues that should be revised.	Some small difficulties in carrying out the field measurements
3	There were a lots of issues that should be revised, I didn't understand the text	I had several or major difficulties in carrying out the field measurements

According to the feedback, there were some issues that need to be re-considered and revised in the Field Manual. It must also be noted that some issues that were clear in the Field Manual were somewhat difficult to implement in the field. The original questionnaire can be retrieved from Hyvönen (Luke) or Ojuang (KFS).

4.3 Quality assurance of the field measurements

The principle of Quality Assurance (QA) was to undertake control measurements of the sample plots measured by other field teams but this excluded soil sample measurements. The main purpose of QA was to ensure that instructions in the field manual were adhered to during the field work, to give feedback to the field teams during the inventory, and consequently, to improve the data quality. The plan was to re-measure one or two clusters from every field team within 1 to 2 weeks after the measurements by field teams. However, due to some logistical problems this could not be done. The feedback during the field work was given only to the mangrove team. The QA was carried out by KEFRI staff and Dr Mbae Muchiri (coordinator), John Ngugi (Team Leader), Francis Gachathi (Plant Taxonomist) and William Mucheke (Forester). In each test site, the KFS local forester, forest rangers and local guides were part of the QA team. Altogether, the QA team checked and re-measured 35 sample plots (17.5% of measured plots having trees) comprising 19 temporary and 16 permanent sample plots.

Figure 13. Two members of the Quality Assurance team re-measuring trees on a sample plot in Marigat (Photo by J. Ngugi).

The QA team used the original data and data forms on PDA to check any irregularities in the measurements. The equipment used by the QA team was similar to those used by the field teams. Before visiting a test site a thorough study of target clusters was undertaken in Google Earth and some print outs made to guide the team. The QA team coordinator randomly selected clusters assessed by the field teams in all the test sites for re-measurements. The selection was based on field teams, temporary and permanent clusters and if there was any conspicuous irregularity in the raw data. If mistakes in the original data were found in the field, the QA team corrected the data. Finally, a “Control Measurement Checklist” by re-measured clusters was filled and the re-measured data downloaded to Google Drive.

The QA team reported some common mistakes made by the field teams in the different test sites:

- Some species name were wrong
- Time studies were incomplete
- Clockwise order of the tree measurements was not followed
- Some trees were not recorded
- Some extra trees were recorded

In all, the QA team did not note any serious errors by the field teams. The field teams followed the methods described in the Field Manual quite well. To ensure good quality data in the planned NFRA, some issues in Field Manual were to be revised, for example, vegetation types and definition of shrub. The OFCM running on PDA should be modified to be more efficient and quicker in data collection.

5 Data processing

5.1 Data checking and cleansing

The collected data were checked in several phases. First was in the field by OFCM on PDA. Some basic checking and cross-checking between variables was programmed on the survey forms. Some of wrongly recorded data caused errors and some only warnings were given. The user was forced to correct errors and accept the warnings before saving the data. On the next stage, data was exported from the PDA and imported to OFC running on PC. During importing, OFC gave number of errors and warnings by clusters. The team leaders checked the data again in OFC and tried to correct the errors and resolve the warnings. In some instances a review of the whole data was done. The checked and cleansed data were then accepted in OFC for further processing. Ms. Divinah Nyasaka and Mr. Edwin Kariuki supported the team leaders in the data cleansing.

Despite the laborious work with the data cleansing, some errors were still found in the calculation phase. There were strange relationships, e.g., between tree variables (diameter–height), wrong stand numbers and stand shares. These errors were identified and the team leaders were asked to do the corrections.

5.2 Calculations

5.2.1 General

The original idea was to use Open Foris Calc, but in the beginning of 2014 this software was still in a developing state and it could not been fully utilised. Thus, the free statistical software R was used instead, and R-scripts for calculations were developed (Figure 14). It must be noted that these R-scripts can be partly utilised later in the Calc environment as Calc uses R.

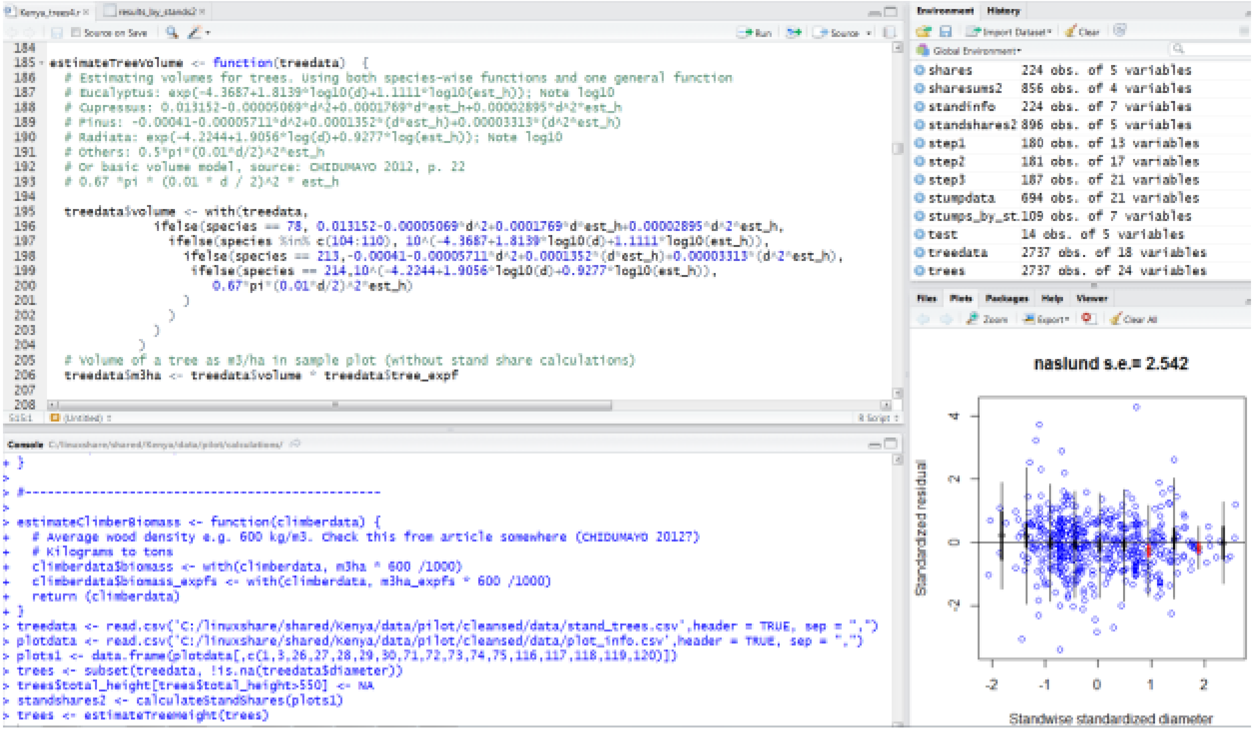

Figure 14. Snapshot of the RStudio software used in the calculations.
(R is the basic software and RStudio is a set of integrated tools designed to help run R).

The technical working group (TWG) started to collect information about available volume and biomass functions from Kenya in late 2013 and because the work was still ongoing and the summary of available models was not on hand during the calculation, Luke's inventory expert utilised selected models from scientific literature, GlobAllomeTree (http://www.globallometree.org/), and forestry experts (e.g. Martin Schweter and Lauri Vesa). The data from Collect were exported as csvfiles for further calculations in R.

5.2.2 Variables used and models applied

Tree height

Calculations started by estimating tree heights for all tally trees (measured trees) applying Lmfor R-package (http://cs.uef.fi/~lamehtat/documents/lmfor.pdf). A height model was generated with the help of sample trees having measured height and diameter at breast height. The height model can be calibrated with random effects at desired levels presuming the levels have sample trees. E.g. calibration at the cluster level means that heights of tally trees within each cluster are computed with the same model parameters and these parameters are allowed to vary between different clusters (Figure 15). In this exercise, calibration at the sample plot and cluster levels was used and dead trees were left out, i.e. dead trees were not used in the modelling phase. The fitted model was then applied in estimating the heights for the tally trees and the recorded heights were applied to the sample trees.

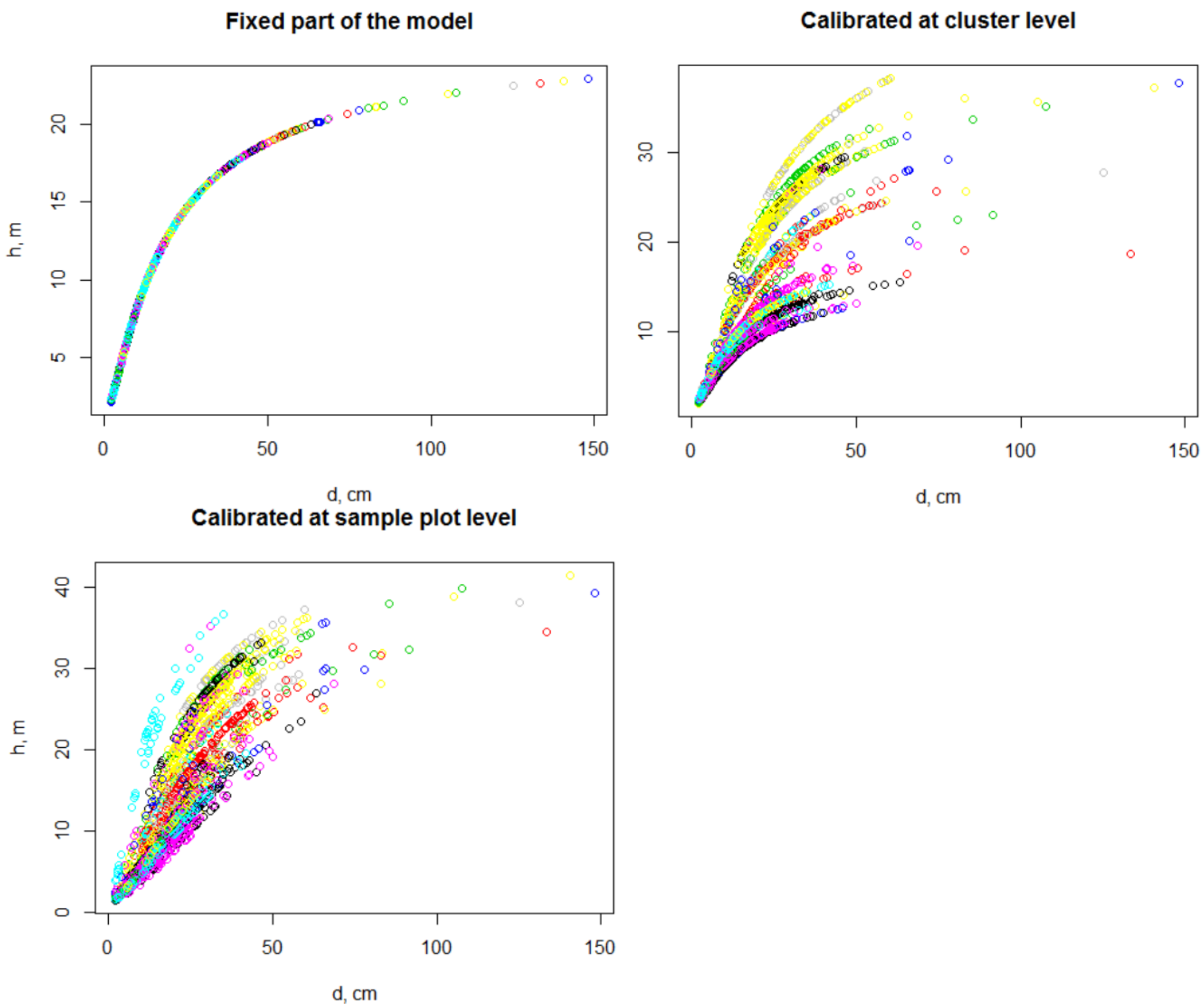

Figure 15. Graphs of the height modelling. (Each individual color indicates different clusters).

Table 5. Symbols used in the equations.

Symbol	Description
d	Diameter at the breast height, 1.3 m
d_1	Diameter at the base or at the beginning of the particle
d_2	Diameter at the end or at the top of the particle
$d_{stumptop}$	Diameter on top of the stump
$d_{stumpest}$	Estimated diameter of the stump at the breast height
$d_{stump15}$	Estimated diameter of the stump at the 15 cm height
h_{stump}	Stump height
h	Height
l	Length
db	Diameter at the base of the tree
nr	Count, number
f	Form factor
π	Pi
WD	Wood density
V	Volume
AGB	Above ground biomass
BGB	Below ground biomass
GW	Green weight
DW	Dead wood

Tree volume and biomass

In the next step, volume (m^3/tree) and biomass (kg/tree) for trees were estimated. There were only few species-specific functions available and thus, volume and biomass for most of the trees were estimated by common functions. And although there were species-specific equations for the most common tree species, the equations needed variables that were not measured in the field. The species-specific volume equations used in Kenya include the plantation species developed by Wanene (1975) and have been used in KFS:

$$V_{Eucalyptus} = e^{(-4.3687+1.8139*\log10(d)+1.1111*\log10(h))}$$

$$V_{Cupressus} = 0.013152-0.00005069*d^2+0.0001769*d*h+0.00002895*d^2*h$$

$$V_{Pinus} = -0.00041-0.00005711 * d^2+0.0001352 * (d * h)+0.00003313 * (d^2 * h)$$

$$V_{Radiata} = e^{(-4.2244+1.9056*\log10(d)+0.9277*\log10(h))}$$

And the common volume equation (Chidumayo, 2012) was also tried:

$$V_{common} = 0.67 *\pi * (0.01 * d / 2)^2 * h.$$

The biomass for trees (kg) was estimated with the following equations (Henry et al., 2013):

$$AGB_{Acacia} = 3.7704*bd+1.1682$$
$$AGB_{Rhizophora} = 0.8069 * d^{2.5154}$$

And the common biomass function:

$$AGB_{common} = e^{(0.93 * \log((d\wedge 2 * h))-2.97)}$$

The biomass equation of *Acacia* included variable "*bd*" meaning the diameter at the base of the tree. That was not measured and therefore, the diameter at breast height was used instead. Thus, biomass of Acacia is most probably underestimated.

The belowground biomass was estimated with the common conversion factor (Mokany et al. 2006):

$$BGB = AGB * 0.28$$

Volumes and biomasses of trees were transformed to values per hectare (m^3/ha and t/ha) with tree expansion factors. As trees were measured from sample plots with different radius (r) according to tree's diameter, each tree had its own expansion factor ($10000 / (\pi * r^2)$.

E.g. a tree of 15 cm in diameter had the expansion factor of 31.83 ($10000 / (\pi * 10^2)$).

Bamboo volume and biomass
In the field, bamboos growing inside the sample plot radius of 10 m were measured. The volume of bamboos was calculated with the equation (National Forest and Tree Resources Assessment 2005–2007):

$$\mathrm{V}_{\mathrm{bamboo}} = d^2 - (d * 0.7)^2 / 4 * \pi * h * 0.8$$

The Biomass of bamboos was calculated with the equations developed by Muchiri and Muga (2013). These functions give biomass of merchantable bamboo. The fresh weight was calculated with the following equations:

$$\mathrm{GW}_{\mathrm{bamboo}} = -1.11 + 0.36 * d^2 \qquad \text{bamboo diameter} > 3 \text{ cm}$$
$$\mathrm{GW}_{\mathrm{bamboo}} = -1.11 + 0.36 * 3.1^2 \qquad \text{bamboo diameter} \leq 3 \text{ cm}$$

In the formula, a constant"3.1" was used for small bamboos instead of diameter as the volume function gave negative values for bamboo less than 3 cm diameter.

And then the dry weight (biomass) of bamboo was calculated with the formula:

$$\mathrm{AGB}_{\mathrm{bamboo}} = 1.04 + 0.06 * d * GW_{bamboo}$$

The volume and biomass of bamboo were transformed to values per hectare in the same way as for trees.

Dead wood volume and biomass
In the field, dead wood particles up to the top diameter of 10 cm inside the sample plot radius of 15 m were measured. The diameters at the base and at the end, and length of the particle were measured and the decay class assessed. The volume of dead wood was calculated with the following equation:

$$V_{dw} = \pi * ((d1/2)^2 + \pi * (d2/2)^2)/2 * l * nr,$$

Where nr is the number of similar particles.

The biomass of dead wood was calculated with the two following equations:

$$B_{dw} = WD * V_{dw} \qquad \text{solid dead wood}$$
$$B_{dw} = 0.5 * WD * V_{dw} \qquad \text{rotten dead wood}$$

WD was set to 0.6. The volume and biomass of dead wood were transformed to values per hectare in a similar way as the trees.

Stump volume and biomass

In order to be able to calculate below ground biomass of the stump, above ground biomass of the cut tree must be known first. This means that diameter at breast height and height must be estimated for the stump. Sample tree data were used to estimate the diameter before felling and the height was estimated with the fixed function parameter from the tree height estimating process. The formula to estimate tree diameter before felling was:

$$d_{stumpest} = -3.59024 + d_{stumptop}/10 * 0.85299 + h_{stump} * 0.07856$$

The formula to estimate tree height before felling was:

$$h_{felledtree} = 1.3 + \mathrm{d}_{\mathrm{stumpest}}^2 / (2.6999234 + 0.1442704 * \mathrm{d}_{\mathrm{stumpest}})^2$$

The formula to estimate the felled tree's volume was:

$$\mathrm{V}_{\mathrm{felledtree}} = 0.67 * \mathrm{pi} * (0.01 * d_{stumpest}/2)^2 * h_{felledtree}$$

And the above ground biomass of the felled tree

$$\mathrm{AGB}_{\mathrm{felledtree}} = \exp(0.93*\log((d_{stumpest}^2 * h_{felledtree}))-2.97)$$

The below ground biomass of the stump was finally calculated with the formula:

$$\mathrm{BGB}_{\mathrm{stump}} = \mathrm{AGB}_{\mathrm{felledtree}} * 0.28$$

To calculate the stump correct volume, stump's diameter at 15 cm height was estimated with the following formula:

$$d_{stump15} = d_{stumpest} + (d_{stumpest} - d_{stumptop}/10) / (130 - h_{stump}) * (15-130)$$

In the field, stumps with the top diameter equal or larger than 10 cm inside the sample plot radius of 15 m were measured. The volume of stump was calculated with the equation:

$$V_{stump} = \pi * ((d/2)^2 + (d_{stump15/2})^2) / 2 * h * nr,$$

Where, *nr* is the number of similar stumps. (See Altrell et al.).

The above ground biomass of stumps was calculated with the following equation:

$$AGB_{stump} = V_{stump} * WD$$

WD was set to 0.6. The volume and biomass of stumps were transferred to values per hectare in a similar way as trees.

Climber volume and biomass

Climbers with diameter equal or larger than 2 cm were measured in the field. For volume calculation the cylinder equation was used:

$$V_{climber} = \pi * (d/2)^2 * h$$

The above ground biomass was calculated as follows:

$$AGB_{climber} = V_{climber} * WD$$

WD was set to 0.6.

At the next stage, the tree level results (or stump, bamboo etc.) were summarized (aggregated) for the stand level to get total values of volumes and biomasses at the stand level to be used in further calculations (see chapter 5.3). In addition, the results were summarized (aggregated) at the plot level. The plot level results were used in developing biomass maps. The biomass maps for Nakuru and Gazi test sites were estimated with the *k* Nearest Neighbour (*k*NN) method using Landsat satellite images and plot level results as reference data (Figures 16 and 17).

5.3 Forest estimators

5.3.1 General

The stand level data (results by stands) were exported to R statistical software and processed to get estimates for areas mean and total values of the biomass and volume for different vegetation types. The estimates were calculated separately for all the test sites. In addition, data from Kericho, Marigat and Nakuru were merged together and estimates for the combined area were calculated. The three test sites were located near each other and had the same sampling design. In that case, it was meaningful to calculate estimates for the combined area. The main results of the calculations are presented in Annex 1. The point estimators are valid as the method used in the pilot inventory was one phase systematic sampling. A sample plot may have several stands in case the plot was located at the border of several land use classes or vegetation types. However, in such cases the sample plot centre unambiguously falls in only one land use class or vegetation type. The equations presented in 6.3.2 are based on point estimators.

5.3.2 Area estimates

Proportion of forest area (or proportion of other category of interest) from the land area was estimated using the following formula:

$$\bar{p}^{(F)} = \frac{\sum^{n} p_i^{(F)}}{\sum^{n} m_i},$$

where

$$p_i^{(F)} \quad = \sum_j^k t_{ij} m_{ij} \ ,$$

where

t_{ij} = 1 if the plot center of plot *j* in cluster *i* is in forest (or in the category of interest); 0, otherwise
m_i= number of plot centers (in land if A is land area) in cluster *i*
k = number of plots in cluster (in IC-FRA *k* = 4)
n = number of clusters.

Forest area (or the area of the category of interest) was estimated with the following formula:

$$A^{(F)} = A \cdot \bar{p}^{(F)}$$

Variance of the forest proportion estimate was obtained with the following formula:

$$v(\bar{p}^{(F)}) = \frac{1}{(\sum^{n} m_i)^2} \cdot \frac{n}{n-1} \cdot \sum_{i=1}^{n} (p_i^{(F)} - \bar{p}^{(F)} m_i)^2$$

And variance of the estimated forest area (or any category of interest) was estimated as:

$$v\left(A^{(F)}\right) = A^2 \cdot v(\bar{p}^{(F)})$$

5.3.3 Mean value estimates

The mean value estimates, e.g. mean volume and mean biomass in total land area were estimated in a similar manner as the forest proportion. However, the mean value in forest (or in a sub-category) is more interesting or relevant than the mean value over the whole population. This can be estimated with the same formula as forest proportion, but in this case only the sample plot parts in forest (or in the category of interest) are considered when calculating the sum in the nominator (sum of x_i) and plot centres that are in forest (or in the category of interest) are considered when calculating the denominator. The mean values were estimated with the following formula:

$$\bar{x}^{(F)} = \frac{\bar{x}}{\bar{t}}$$

$$\bar{t} = \frac{\sum^{n} t_i}{\sum^{n} m_i}$$

$$\bar{x} = \frac{\sum^{n} x_i}{\sum^{n} m_i}$$

where

$t_i = \sum_j^4 t_{ij}$, number of plot centers in forest (or category of interest) in cluster i.

$x_i = \sum_j^4 x_{ij}$, sum of variable (biomass, tons/ha) in plots (or parts of plot) that are forest (or category of interest) in cluster i (x_{ij} is set to 0 if the plot (or a part) is not in forest (or in the category of interest)).

It must be noted that when the mean value of a variable (e.g. volume or biomass) of forest was estimated, the values of single trees were multiplied by their diameter-specific expansion factor as described in the chapter 5.2.2. When a sample plot was only partly in forest, no correction for the sample plot size was done when calculating the x_i values. The divided plots are handled correctly by the fact that trees are measured also in the case when the plot center is outside forest and only part of the plot is in forest. In this case the values of variable of trees are summed for the nominator but nothing (or zero) is summed for the denominator.

The variance of mean value of variable of forests was estimated with the following formula:

$$v(\bar{x}^{(F)}) = \frac{1}{(\sum^{n} t_i)^2} \frac{n}{n-1} \sum^{n} \left(x_i - \bar{x}^{(F)} \cdot t_i\right)^2$$

In other words, when calculating the variance of mean value of variable in forests, only those clusters that have at least one sample point in forest for calculating the denominator part (sum of t_i) are considered. Correspondingly, only those clusters that have at least one part of plot in forest have effect on the sum of $(x_i - \bar{x}^{(F)} \cdot t_i)$ because both x_i and t_i are 0 if there is no plot part in forest in cluster i.

5.3.4 Total value estimates

The total value estimate of the variable of interest (like volume or biomass) in forests (or in a category of interest) is estimated as a product of the mean value and area estimate.

$$X^{(F)} = A^{(F)} \cdot \bar{x}^{(F)}$$

The variance of total variable of interest in forest is estimated as:

$$v\left(X^{(F)}\right) = A^{(F)2} v\left(\bar{x}^{(F)}\right) + \bar{x}^{(F)2} v\left(A^{(F)}\right)$$

The above formula in its presented form estimates the variance of total variable in interest in absolute units (e.g. biomass in metric tons). The formula can be presented also in the form that the relative standard error of total estimate of the variable in interest is the square root of sum of squared relative standard error of mean estimate of the variable in interest and squared relative standard error of forest area estimate:

$$se\%(X^{(F)}) = \sqrt{se\%^2(\bar{x}^{(F)}) + se\%^2(A^{(F)})}$$

where

$$se\%(\bar{x}^{(F)}) = \frac{100\sqrt{v(\bar{x}^{(F)})}}{\bar{x}^{(F)}}$$ (Relative standard error of forest area estimate)

and

$$se\%(A^{(F)}) = \frac{100\sqrt{v(A^{(F)})}}{A^{(F)}}.$$

5.4 Logistics and analyses of litter, woody debris, and soil samples

5.4.1 Transport and preparation of soil samples

Soil and sediment samples from the test sites were planned to be transported to KEFRI soil laboratory at Muguga by bus. In practice, samples were mostly transported by the field team members. Transport requirements were covered in the Laboratory Manual (IC-FRA Pilot Inventory, 2013). However, timely transport of soil samples to laboratory appeared very difficult. The samples waited for transport in warm and moist conditions from 10 to 15 days. It is possible that some organic matter had decomposed and escaped the samples e.g. as CO_2.

5.4.2 Analyses of soil carbon and physical parameters

A total of 45 soil samples were processed for the upland test sites and 45 for the mangrove test site, respectively. Details of the laboratory procedures for both upland mineral soil and mangrove sediment sample preparation and analyses are described in detail in the Laboratory Manual (IC-FRA Pilot Inventory 2013). In addition, excel-based laboratory calculation applications were created for upland soil and mangrove sediment samples separately.

Litter and woody debris samples were oven dried to constant mass and their organic carbon content determined assuming a carbon content of 50%. That is slightly higher than applied by e.g. the IPCC (47%), but is based on the fact that a fraction of the litter has already decomposed thus gaining a higher carbon density.

Soil organic carbon was determined for the upland samples using wet combustion (Walkley-Black) methods, and for the mangrove samples with higher expected organic content using loss of ignition (LOI) methods. Stock of organic carbon in 0-30 cm topsoil and 0-100 cm mangrove sediment was calculated by multiplying the organic content with bulk density of the fine earth (<2mm) fraction. For the litter and woody debris samples, the organic carbon content was determined from dry matter. Laboratory calculations and consistent data management were supported by providing an excel application separate for analysis results of the upland samples and the mangrove samples.

Coarse soil particles (>2 mm) such as gravel form a part of the volumetric sample and thus contributes to the total bulk density of soil. In the calculation of soil organic carbon stocks the coarse fraction was eliminated by measuring the dry mass of the coarse fraction and calculating the bulk density of the fine fraction (BD_{FF}) as follows:

$$BD_{FF} = \frac{(mass_{total} - mass_{coarse})}{\left(V - \frac{mass_{coarse}}{2.65}\right)},$$

Where
$mass_{total}$ is the total dry mass of the composite sample,
$mass_{coarse}$ is the dry mass of the coarse fraction,
V is the total volume of the composite sample, cm^3, and 2.65 is the assumed density of the stones in the coarse fraction.

Soil organic carbon (SOC) density was calculated using the BD_{FF} (g cm^{-3}) and the fraction of organic carbon (OC%) in each individually analyzed 10 cm deep soil layer:

$$SOC, g\ cm^{-3} \ = BD_{FF}\frac{OC\%_i}{100}.$$

The soil organic carbon in the 0-30 cm topsoil layer was obtained as a sum of SOC in the 0.1 m^3 volumes of the individual 10 cm deep soil layers per square meter. The result was then converted to units of kg SOC m^{-2} and t SOC ha^{-1} for reporting purposes. The mangrove sediment organic carbon stocks were calculated in a principally similar means, despite the different sediment sample and the subsamples representing a total of 100 cm deep sediment layer. Furthermore, the estimates of stoniness (*S%*) made in the field from the mineral soil pit wall, were utilized in correcting the organic carbon stock results during the post processing of the laboratory results. The correction of ($1 – S\%/100$) ·SOC is necessary, since the soil volume occupied by stones does not contain organic matter. Without the correction the carbon stock would be overestimated in stony soils.

5.4.3 Experiences from the laboratory work

The laboratory work was delayed because of difficulties in getting the planned procurements done. However, when the samples were transported to the laboratory, they were immediately air dried in order to stop the degeneration of fresh samples. In some cases all information needed in the laboratory was not found in the field forms. In those cases the laboratory calculations especially for litter and woody debris became incomplete or were rejected. In addition, some fresh mass values, marked in the field forms, were contradictory to the results obtained from oven dried samples in the laboratory. Such problems can occur when the fresh mass weighing fails in the field. Another reason may be that only a small proportion of the litter or debris was sent to the laboratory in cases when the total amounts collected in the field were very large. The calculation procedure of litter and debris uses the total field measured fresh mass and the respective fresh mass of the sample to be sent to the laboratory for dry mass determination. In case the field measurements for some reason are incorrect, the back-calculation fails to produce a sensible result.

All the upland samples were analyzed by late May 2014. Most of the mangrove samples were also analyzed by that time, but because of lack of crucibles used in incineration of the samples in high temperature furnace, the capacity of that analysis run low. More crucibles were procured during the Luke's Soil and GHG Expert's mission to Kenya, and the rest of the mangrove samples analyzed. All the results were calculated by 23rd May 2014.

The Excel applications performed well, but small additions (extra columns for more calculations or inclusion of laboratory measured fresh mass of the samples) were planned in order to improve the quality checks and usability of the applications in the future inventory work. The upland application also had an error. A column representing important parameter "Soil stoniness" was missing from the application. A correction was done so that the cluster code and the parameter values from the field forms were input in a separate excel sheet, and the data were merged with other data prior to statistical analysis of the results.

All the calculations were browsed through in detail together with the laboratory personnel, and some errors were noted from the input data, including conflicts in time representation (use of A.M. / P.M. in non-consistent manner) and some erratic data values, which were corrected or removed if untraceable.

6 Results

6.1 Forest estimates

The results were clearly different for the test sites according to the area level results. The proportion of forest area was biggest in Marigat (95%) and lowest in Nakuru (37.1%) (

Table 6 and Annex 1. Main results of the test sites). Correspondingly, the relative standard error of forest area was lowest in Marigat (5.3%) and biggest in Nakuru (35.8%). The Mean volumes between test sites varied a lot. The mean volume for Kericho (454 m^3/ha) was about 60 times compared to that of Nakuru (7.6 m^3/ha).

Volume and biomass estimates varied between the test sites. The lowest mean biomass was in Nakuru (14.4 tons/ha) and the highest in Gazi (1,259 tons/ha). It must be noted that there were few extra large trees in Gazi tree data that exaggerated the biomass estimates upwards.

In Nakuru test site, there were only 13 sample plots in forest and 22 sample plots on other land use classes. In addition, volumes (m^3/ha) and biomasses (m^3/ha) on sample plots by clusters varied considerably. This caused big standard errors on volumes and biomass estimates in every test site.

Table 6. Main results by test sites.

Variable	Test site				
	Aberdare	Gazi	Kericho	Marigat	Nakuru
Clusters	13	13	10	10	9
Sample plots	47	52	40	40	35
Proposed Sample plots	45	49	40	40	35
Sample plots in forest lands	40	41	37	38	13
Forest area proportion	0.889	0.837	0.925	0.950	0.371
Forest area, standard error (%)	10.0	8.3	5.8	5.3	35.8
Mean volume, m^3/ha	200.0	118.2	454.1	14.5	7.64
Mean volume, standard error (%)	34.9	37.3	20.2	12.6	53.8
Mean biomass, ton/ha	123.8	1,258.9	263.2	20.1	14.4
Mean biomass, standard error (%)	20.1	75.2	18.0	25.6	64.6

6.2 Biomass maps

The biomass maps developed using plot level results were used in the development of biomass maps. The biomass maps are presented in Figures 16 and 17.

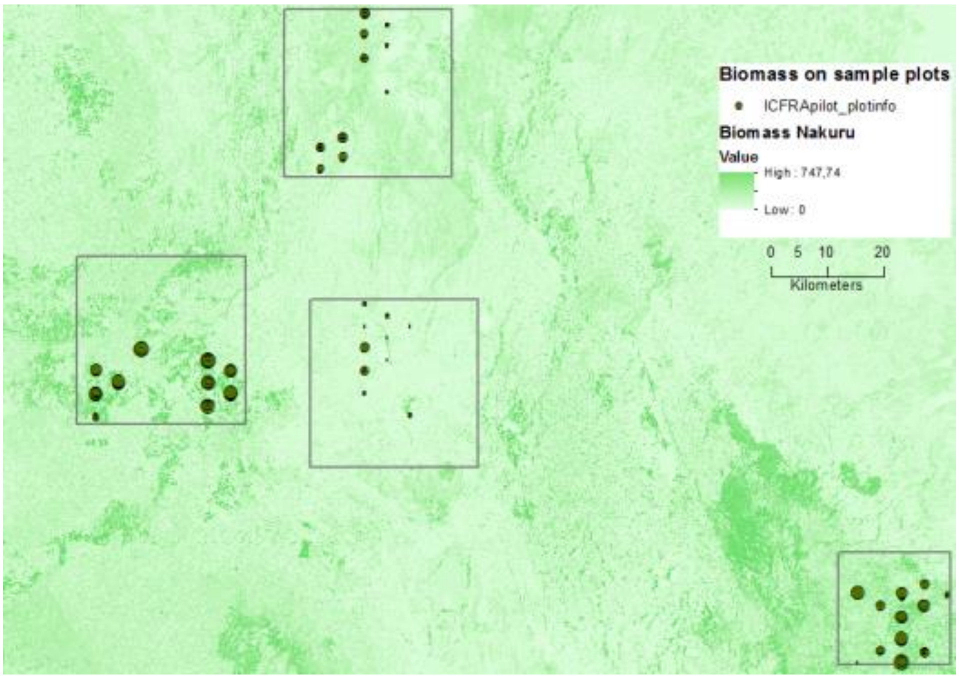

Figure 16. Estimated biomass map and measured sample plots in Nakuru area.
(The size of the plot symbol indicates the amount of tree biomass on the measured sample plot).

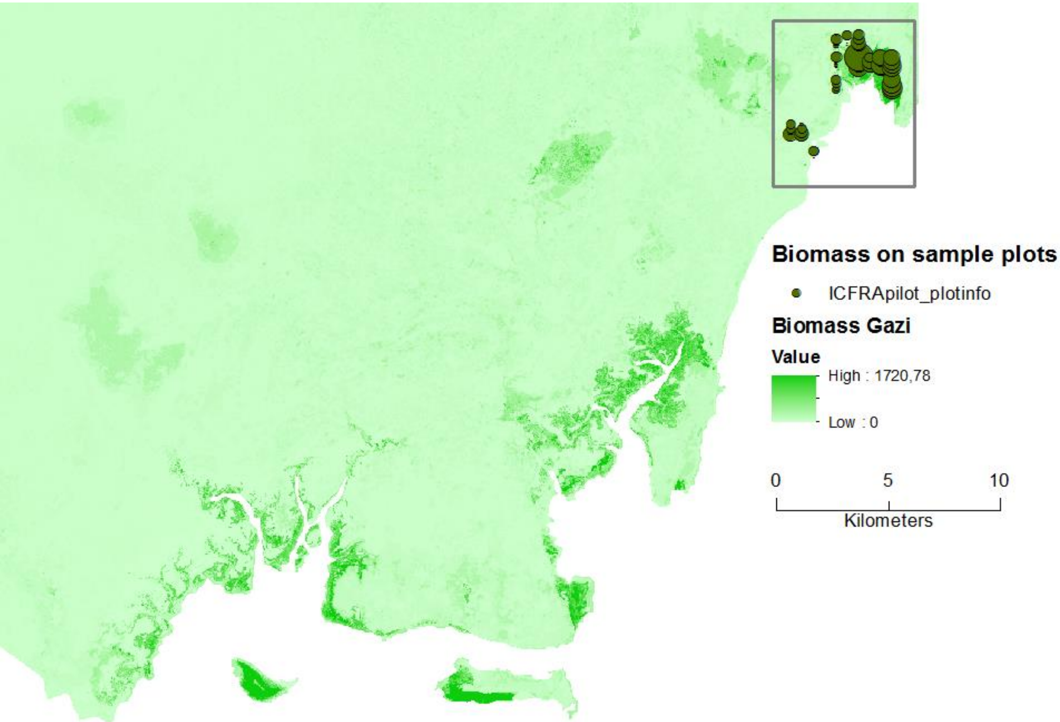

Figure 17. Biomass map and measured sample plots in Gazi area.
(The size of the plot symbol indicates the amount of tree biomass on the measured sample plot).

6.3 Soil, woody debris and litter calculations

The soil carbon data, obtained in the pilot inventory, showed values that are reasonably comparable to those published elsewhere. The average distributions of organic carbon in the vertical soil profiles of the upland mineral soil pilot areas are shown in Figure 18. The highest organic content was e found in the top 10 cm layers. A tentative comparison of the regions reveals that Aberdare and Kericho possess the soils of highest organic carbon content, while the woodlands and farm forests of the Nakuru region have least organic content in soils. It is worthy to note that the average carbon content in the 30-60 cm layer, where no volumetric samples were taken, is almost as high as that in the 20-30 cm layer. The data indicates that the soil organic carbon stock is significant more in soils deeper than the quantitatively collected 0-30 cm results show. In particular in natural forests and mature plantations it might be wise to extend the collection of volumetric samples deeper in those areas that are planned to be included in REDD+ projects.

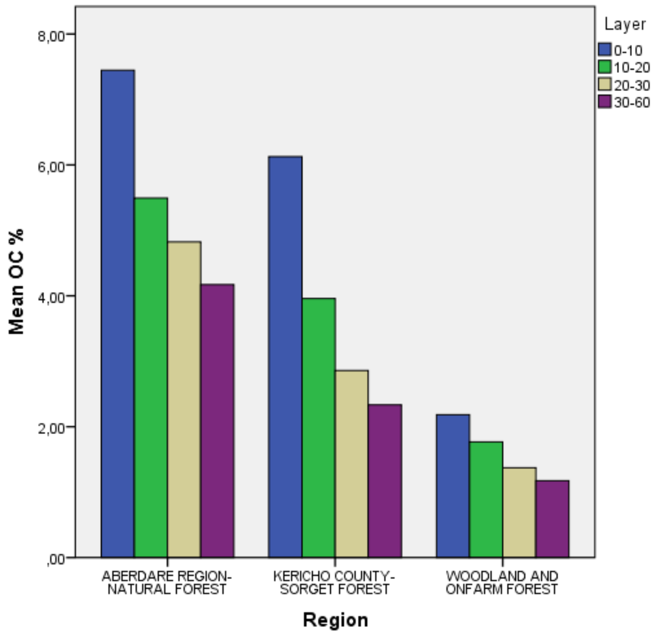

Figure 18. Mean organic carbon content in different soil layers in the vertical profiles of the upland mineral soil pilot regions.

Stoniness (Figure 19) was greatest in the Nakuru region woodlands and farm forests. Here, stoniness and crop management systems were identified as a reason for the low SOC stocks (Figure 20). Surprisingly, the average SOC stocks in the Kericho region appear higher than those in Aberdare, even when the results of soil organic content (%) are higher in Aberdare. The reason seems to be in the different bulk densities that are much higher (about 0.6 g cm^{-3} in Kericho compared to the 0.4 g cm^{-3} found in more organic rich soils in Aberdare).

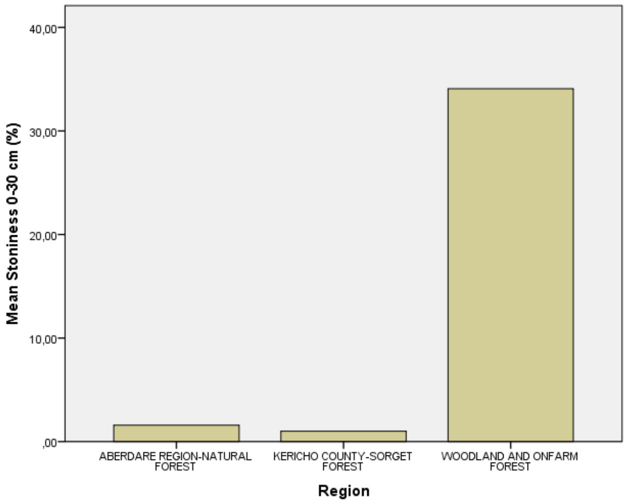

Figure 19. Mean stoniness (%) in the 0-30 cm soil profiles as estimated for the upland mineral soil pilot regions.

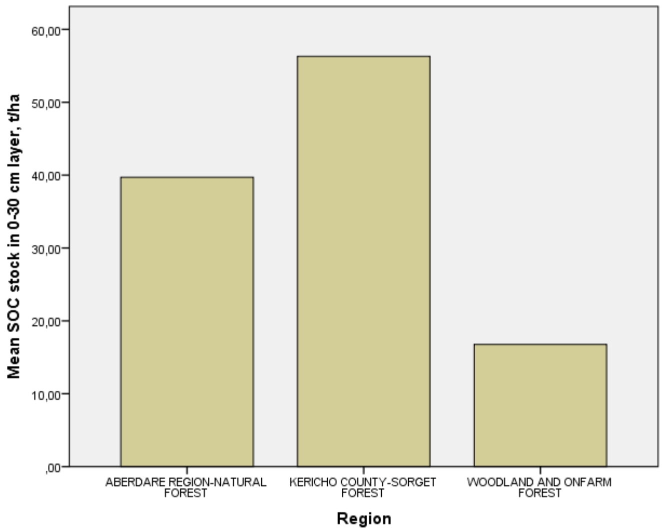

Figure 20. Mean SOC stocks in the 0-30 cm layers in the upland mineral soil pilot regions.

The litter and woody debris carbon stocks comprise up to ca. 2 t ha-1 in Aberdare and Kericho, but is almost negligible in the woodlands and farm forests of Nakuru (Figure 21). Overall, the share of organic carbon in the litter and debris is around 1 % of the total organic carbon stock in the upland pilot regions (Figure 22). When all biomass fractions and SOC are compared (Figure 22), the role of SOC is most prominent, actually the largest organic carbon pool, in Aberdare natural forest and the woodlands and farm forests of Nakuru.

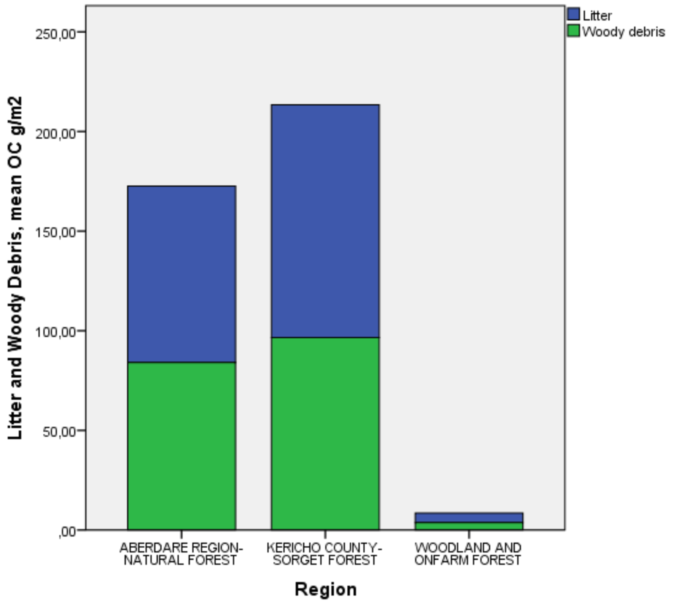

Figure 21. Mean Litter and Woody debris organic carbon stocks (g m^{-2}) in the upland mineral soil pilot regions. The value of 200 g m^{-2} corresponds to 2 tonnes of carbon per ha.

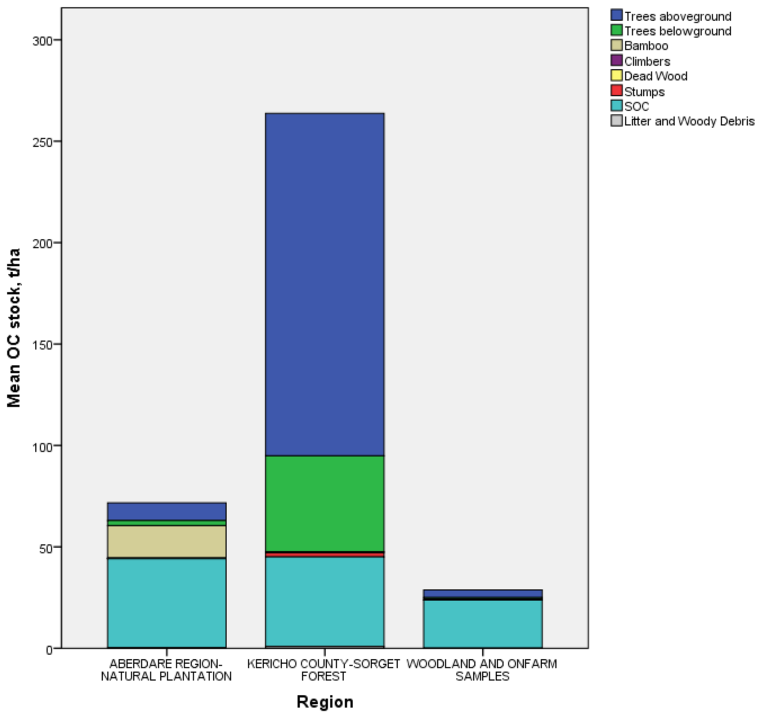

Figure 22. Comparison of mean organic carbon stocks in the different biomass fractions and soil in the upland mineral soil pilot regions.

Organic carbon pools in the 100 cm deep mangrove sediments are astonishingly high. The average carbon stock calculated for each cluster sampled varies from about 200 to over 800 t ha^{-1}. The sediment carbon alone is a triplicate of the biggest total carbon stocks detected in the upland pilot regions (Kericho). The tentative Gazi Bay estimate combining the organic carbon in trees and sediment reaches on average a total of 700 t ha^{-1}.

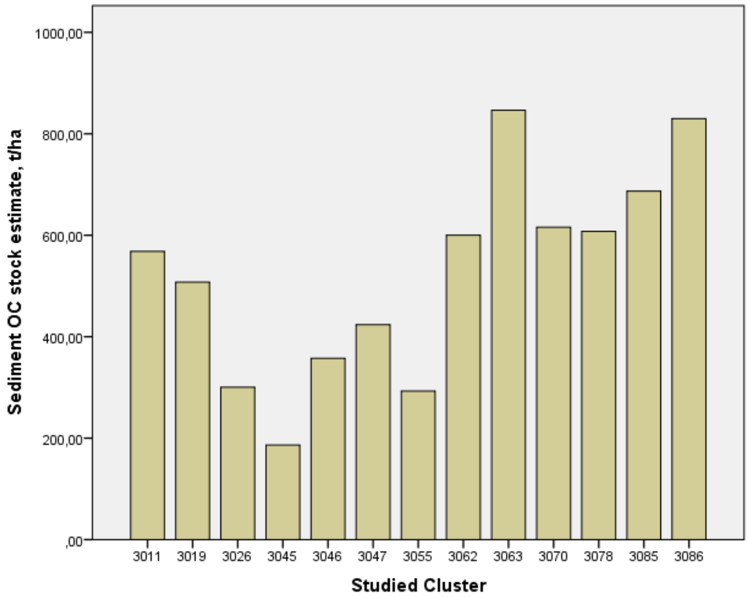

Figure 23. Mean sediment OC stocks in the clusters measured in Gazi Bay.

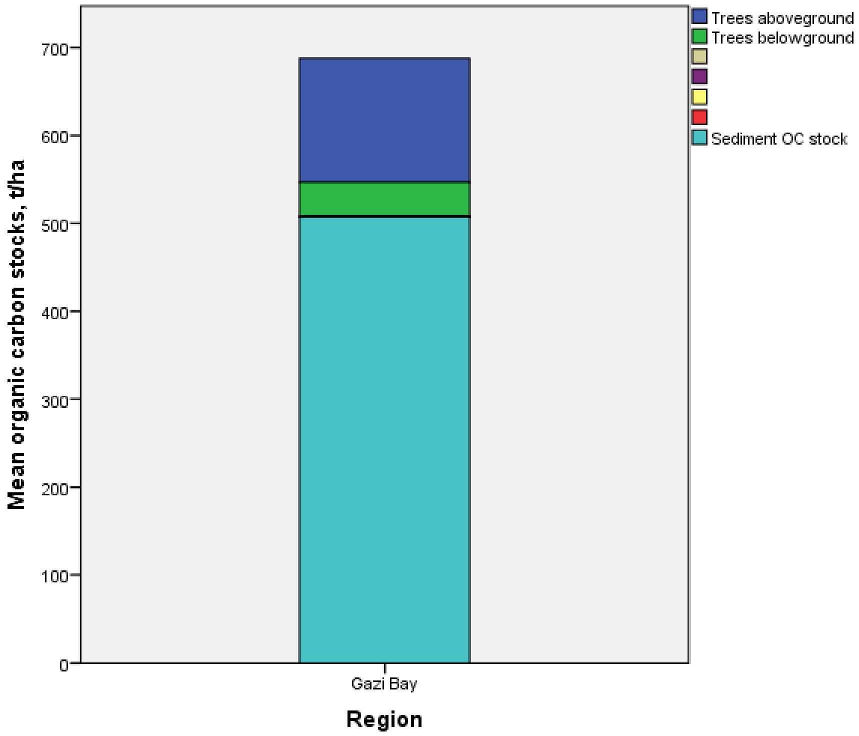

Figure 24. Mean organic carbon stocks of mangrove trees aboveground and belowground biomass and sediment in Gazi Bay region.

6.4 Availability of Kenyan soil laboratories for soil analyses in NFRA

Depending on the design of the sampling grid for the National FRA the number of soil samples may become very large. In the pilot inventory a total of only 90 plots were sampled for soil or mangrove sediment organic carbon. Each sample consisted of separate samples from four soil or sediment layer, and the total number of samples analysed in the KEFRI Soil Science Laboratory was 300. Such an amount of samples does not compromise the analysis capacity of the laboratory. However, during the National FRA the laboratory involved needs to save enough capacity for other everyday workload. Thus it is necessary to assign samples to several soil laboratories in Kenya.

In order to map the present availability of laboratories and their personnel, and their instrumentation status Mr. Willis Atie (KEFRI) visited several laboratories which are involved in soil analyses. He listed and described the potential laboratories and investigated their willingness to participate the National FRA. This work directly supported the planning of soil analyses and QA/QC of the analysis results in the NFRA. The original plan of the IC-FRA project was to distribute a query among Kenyan soil laboratories, but it is evident that the work done by Mr. Atie has got a better coverage and communication especially with the less active laboratories.

Mr. Atie’s main findings were:

- Several laboratories, including those of KEFRI, KARI and UoE, could contribute to the National FRA by means of providing altogether about 20 Soil Technicians to the inventory teams. A complete list of suitable laboratories can be found in the report (Annex 2)
- Preparation and analysis of soil samples could be distributed to laboratories situated in different parts of Kenya, thus decreasing the duration and cost of transportation of samples, and improving the sample quality for those samples that do not have to wait for transport in field conditions
- University of Eldoret is willing to train Laboratory Technicians to apply the specific field sampling methods and equipment of FRA
- KMFRI Mombasa is willing to participate in field work and analysis of mangrove sediments

Using the report of laboratory tour by Mr. Atie, the participation of regional soil laboratories can be planned for the NFRA.

6.5 Time study

Time study data in different phases was recorded during the field work. Data was needed for the simulation study of different sampling designs for the nation-wide FRA, and to analyse more carefully the time consumption and to figure out if there are some “bottlenecks” in the measurements that need to be solved. The results of time consumption in different measurements are shown in Table 7 and 8. Time consumption at the plot level includes sample plots without trees, so the measurement times differ compared to the times inTable 3. The results of the time study by vegetation types were utilized in the sampling design simulations.

Time for moving was also recorded during the field work. The time consumption at the cluster level by test sites was calculated (Table 9). The results confirmed that it took several days to complete measurements in one cluster if conditions were difficult (Aberdare and Gazi) or the number of trees was high (Kericho). Note; some errors were still found on the time data, for example, the total time in the field was shorter than the time spent in plot measurements at the cluster level. These erroneous clusters were left out from the calculations, Tables 7 and 8. The average working day was longest in Aberdare and in Nakuru test sites, Table 10.

Table 7. Count of trees and sample trees (in average) and time consumption by the test sites and measurement stages.

	Count		Time by stage (in minutes)							
Test site	Tree	Sample tree	Plot	Tree	Bamboo	Regeneration	Stump	Dead wood	Climber	Soil
Aberdare	12.9	3.3	108	27	30	10	8	13	8	75
Gazi	21.9	4.8	99	53		8	16	20	34	44
Kericho	27.1	5.7	137	59	27	11	18	13	6	122
Marigat	7.1	2.2	58	20		10	5	4	2	82
Nakuru	5.1	1.5	37	9		10	5	1	2	66

Table 8. Count of trees and sample trees (in average) and time consumption by vegetation types and measurement stages.

	Count		Time by stage (in minutes)							
Vegetation type	Tree	Sample tree	Plot	Tree	Bamboo	Regeneration	Stump	Dead wood	Climber	Soil
Bamboo	1.6	1	95	5	39	9	2	14	3	100
Crop - and Grassland	6.3	1.9	50	13		11	6	5	2	66
Mangrove	25.6	5.4	112	62		8	17	22		43
Natural forest	14.7	3.3	124	36	28	12	14	15	11	69
Plantation	29.5	5.9	141	62	1	10	18	12	10	93
Settlement	5.4	1.5	59	26		5	9	11		75
Woodland	6.7	2.1	57	18		9	6	4	2	75
Other			34			9	18	7	17	

Table 9. Time consumption at the cluster level by the test sites. Times are in hours and values are mean values.

	Time from camp back to camp	Time from car park back to car park	Working time on cluster	Moving time on cluster	Number of days visited
Aberdare	26.27	12.60	6.18	6.42	2.8
Gazi	17.60	10.00	6.61	3.39	2.5
Kericho	30.27	16.88	9.16	7.72	3.2
Marigat	10.70	7.35	3.76	3.59	1.7
Nakuru	11.38	5.00	2.46	2.54	1.3

Table 10. Mean values (hours) of working days and time in the field by the test sites.

	Working day	Time in the field
Aberdare	9.02	4.23
Gazi	7.15	4.06
Kericho	8.65	4.82
Marigat	7.22	4.41
Nakuru	9.31	3.75

6.6 Quality Assurance

Data collected by the QA team were downloaded from the Google Drive and imported to OFC for analysis using R. There were no Significant or systematic errors in the quality assurance data (QA data). On the stand level, the variables collected by visual interpretation were basically in line with the QA-team's opinion. Vegetation type was classified differently in 6 stands (Table 11). In addition, "Cropland" (303) on one stand was classified as "Plantation forest" (134, PELIS) in the QA data.

Table 11. Differences in vegetation type.

	QA team	
Field team	**Woodland, open (crown cover (15–39%)**	**Woodland, open (crown cover < 15%)**
Natural forest (crown cover (10–39%)	2	
Woodland, closed (crown cover (40–64%)		1
Woodland, open (crown cover (15–39%)		2

No systematic errors were found on tree measurements either. There were 165 trees that differed in diameter at 1.3 m height (dbh), as shown inTable 12. In average, tree diameters were under measured in Gazi and over measured in Kericho, Marigat and Nakuru (Table 133). On Kericho and Marigat, the heights of sample trees were measured to be about one meter too high. The bigger issues were unmeasured or extra trees. There were 39 trees that were not measured but according to the QA-team these trees were inside the sample plot. In addition, 15 trees were booked as extra by field teams, Table 14. Missed trees count 7.8% of measured trees and extra trees 3.0%, respectively. Especially the count of missed trees is too big and certainly had some effect in stand level calculations.

There were only few small differences with measurements of dead wood and stump data. E.g. the measured diameter of 7 stumps was too big and the height of 5 stumps too small. But, these differences were small in measurement units.

Table 12. Differences in diameters by classes.
E.g. there were 14 trees that field teams had measured to be 10–25 millimetres smaller than the QA-team.

Tree count by diameter difference classes (mm)								
-100– -50	-50– -25	-25– -10	-10– -5	-5–5	5–10	10–25	25–50	50–100
4	5	14	29	58	18	25	4	8

Table 13. Differences in tree measurements by test sites.
Measured: all measured trees; different: count of trees that differ between field team and the QA-team; mm and m: the average difference on diameter and height.

	All trees, diameter			Sample trees, height		
	measured, n	different, n	mm	measured, n	different, n	m
Aberdare	32			3		
Gazi	100	66	-0.6	18	14	0.04
Kericho	254	42	7.3	50	16	1.15
Marigat	75	46	2.5	13	8	0.96
Nakuru	40	11	8.5	7	4	0.2
In total	501	165		91	42	

Table 14. Trees that were missed or measured as extra by the test areas.

	Trees not measured	Trees measured as extra
Aberdare	-	-
Gazi	11	7
Kericho	18	1
Marigat	7	6
Nakuru	3	1
In total	39	15

7 Recommendations for NFRA

According to the experiences and results from the Pilot Inventory, some recommendations were made for the coming NFRA, both planning and conducting phases.

First, the design of the sampling should be efficient. It was noted that much of the time was spent moving within and among clusters on rough terrain and long distances. It is recommended that more effort should be put on clusters and sample plots in forest rather than sample plots on other forest types. One suitable method for this is a two phase sampling. However, other forest types must be included in the sampling design.

The maximum sample plot radius was 15 meters meaning an area of 707 m^2. According to field teams it was seen to be suitable, also in mangrove forests. However, it might be better to have bigger sample plot, say 20 m radius (1,256 m^2), on areas having few scattered forests, like on arid areas, and also on areas with scattered trees, like grasslands. By this way it is more likely to capture these scattered trees.

Secondly, the safety of the teams should be carefully planned. Roads might be in a bad condition during rainy season, as was in Kericho. So it is advised to plan the field work in a way that field teams should not work during the rainy season. The field teams had one big car to transport the whole team. The car was not adequate and it is better to have two cars per team. This will give the opportunity to split the team if needed, e.g. soil sampling might need more time in sample plot than other measurements; or vice versa. Thus, others can proceed to the next sample plot as the rest continue the work on the current sample plot. In this kind of situations communication between groups must be organized in a reliable way. Mobile phones will not work in all places, so teams should have 2–4 walkie-talkies for communication between team members and drivers. Accommodation is also related to the safety of the officers working in the field and options should be explored on whether camping or hotel accommodation is better.

Thirdly, proper equipment for measurements and suitable clothing is needed. The used PDA (Pidion BIP-6000Max) for data recordings worked quite well. However, it might be better to use more powerful PDA or rugged tablet with Collect and leave the OFCM; in case this program is selected for NFRA. The ALS field surveys used the smartphone and rugged tablet which was found preferable.

While the mangrove test protective clothing performed well in part (hats, coats), it was not possible to dry shoes completely prior to the next day’s field work. Therefore the shoes soon started to stink and became unpleasant to use. Two pairs of shoes would be needed to enable proper cleaning and drying. In addition to current equipment, umbrellas for protecting the papers from wetting would be useful, and durable water-proof bags for the papers, cell phones and other equipment would be needed.

Laboratory work for the analysis of soil and sediment samples is only possible when the obligatory equipment, glassware, and reagents are available. It is highly recommended on the basis of experience during the pilot inventory that funds are allocated as soon as possible for the laboratory procurements and that the procurements are done immediately for all laboratories. Any delays in procurements would severely affect the success of the laboratory work. The samples could also be destroyed by a long period of waiting before laboratory analysis.

Fourthly, there should be a nominated team (supervisory team) to supervise and coordinate the NFRA. Members of this team should come from the main institutes and organizations dealing with forest issues. Under this team there should be another team (management team) that is responsible of the implementation and daily management of the NFRA. This team supervises the work of the field teams. It was noted during the pilot inventory that people living in the test sites weren’t always informed about the coming activity. The responsibility of introducing the NFRA to local people could be put to this management team.

Fifthly, a quality assurance (QA) team must be able to start controlling the work of the field teams immediately as the field work starts. Feedback to controlled field team should be given immediately after the

QA-team has re-measured the field team's sample plots. To guarantee the quality of the data, about five (5) percentages of the measured sample plots should be re-measured by the QA team.

Soil sampling can be best performed by Technicians already familiar with soil physical and chemical characterization. Analysis of soil samples further calls for availability of adequate capacity in laboratory personnel and facilities. Because the field procedures for litter and soil sampling are designed to minimize the workload over the sampling and analysis chain, success in obtaining good quality at the reporting phase greatly depends on the quality of the field work. Poor quality measurements in the field can lead to disqualified samples after the calculations of results following the laboratory analyses. Great care in litter and soil sampling and the associated fresh mass weighing and recording should be taken in the field data. Careful sampling is even more important, because no field data collection QA was planned to control the soil sampling. In the laboratory, the excel application prepared for calculations, flags those data that would give nonsense results. It is advised that the possible problems in the sampling and analysis chain for those erratic results are immediately inspected and the conclusions communicated. A particular "error log" could be kept in the laboratory so that the field and laboratory procedures can be improved if necessary.

It is recommended that QA/QC is extended to the soil laboratory work. The relevant means are inter-laboratory comparisons, inter-laboratory auditions, and use of an authorized reference laboratory to analyse a representative set of the same samples analysed by all participant laboratories in Kenya.

REFERENCES

1. Altrell, D., Branthomme, A. & Tavani, R. Assessing Growing Stock and Stock changes through Multi-Purpose National Forest Monitoring and Assessment. FAO report.12 p.
2. Chidumayo, E.N. 2012.Assessment of Existing Models for Biomass and Volume Calculations for Zambia. Report prepared for FAO-Zambia integrated land use assessment (ILUA) phase II project. 58 p.
3. FAO. 2006. *Guidelines for Soil Description, 4th Edition*. Food and Agriculture Organization of the United Nations, Publishing Management Service, Information Division. Rome, Italy. 97 p.
4. FAO. 2008. *Technical Review of FAO's Approach and Methods for National Forest Monitoring and Assessment (NFMA).*By Erkki Tomppo and Krister Andersson. National Forest Monitoring and Assessment Working Paper NFMA 38. Rome
5. Field Manual, Biophysical Pilot Survey, Kenya. 2016. Improving Capacity in Forest Resources Assessment in Kenya (IC-FRA) project. KFS, KEFRI, DRSRS, UE and Luke. Compiled by Hyvönen, P., Haakana, H., Alm, J., Balázs, A., Parikka, H., Muchiri, M., Kinyanjui, M., Balozi, K., Ojuang, F. & Nduati, P.68 p. Unpublished project document.
6. Henry, M., Bombelli, A., Trotta, T., Alessandrini, A., Birigazzi, L., Sola, G., Vieilledent, G., Santenoise, P., Longuetaud, F., Valentini, R., Picard, N. & Saint-André, L. 2013. GlobAllomeTree: international platform for tree allometric equations to support volume, biomass and carbon assessment. Technical report – doi: 10.3832/ifor0901-006. iForest – Biogeosciences and Forestry. 5 p.
7. Hyvönen, P. & Ojuang, F. 2014.Questionnaire on the field work in IC-FRA Pilot Inventory, 2013. Questionnaire_results.docx, 13 p. Unpublished project document.
8. IC-FRA Pilot Inventory 2013, Manual for Preparation and Organic Carbon Analyses from Forest Soil and Mangrove Sediment Samples. Draft Manual 1.0. Improving Capacity in Forest Resources Assessment in Kenya (IC-FRA) project. KFS, KEFRI, DRSRS, UE and Luke. Compiled by Jukka Alm (LUKE), James Gitundu Kairo (KMFRI), 15 p. Unpublished project document.
9. IPCC 2008.*2006 IPCC Guidelines for National Greenhouse Gas Inventories – A primer.* Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Miwa K., Srivastava N. and Tanabe K. (eds).Publisher: IGES, Japan.
10. Mehtätalo, L. 2013. Package LMFOR Manual. http://cs.uef.fi/~lamehtat/documents/lmfor.pdf
11. METLA 2006.*VMI10 Maastotyöohje*. Field Manual for NFI-10 in Finland. Finnish Forest Research Institute. Helsinki, Finland. (in Finnish).
12. Michalak, R. 2008. *Comparison of the scope, terms, definitions and classifications applied for the FAO Global Forest Resources Assessment 2010 and the MCPFE/UNECE/FAO Report on State of Europe's Forests 2007.* Part I - Definitions and classifications structured according to FRA reporting tables. UNECE/FAO Timber Section, Geneva. 38 p.
13. Ministry of Natural Resources & Tourism. 2010. *National Forestry Resources Monitoring and Assessment of Tanzania – Field Manual Biophysical survey.*Dar es Salaam, Tanzania. 96 p.
14. Mori, Sah, B.P., Hämäläinen, J., Latva-Käyrä, P., Musila, W., Kinyanjui, M., Muchiri, M. and Wamichwe, K. 2012. Forest Inventory Lecture Note and Manual. The Forest Preservation Program for the Republic of Kenya. PASCO Corporation. 86 p.
15. Muchiri, M.N. &Muga, M.O. 2013.A Preliminary Yield Model for Natural *Yashina alpina* Bamboo in Kenya. Journal of Natural Sciences Research.Vol 3, No. 10: 77–84.
16. Muchiri, M.N. & Ngugi, J. 2014.QA_report_draft-1.docx.KEFRI, 5 p.
17. National Forest and Tree Resources Assessment 2005–2007. Chapter 9.2.Bangladesh. 57 p.http://www.fao.org/forestry/15464-08f7605c2c73c077460d884f8ec11856c.pdf
18. Report on National Forest Resource Mapping and Capacity Development for the republic of Kenya, Volume 2. 2013. Forest Preservation Programme. PASCO Corporation. Rep No.: KEF09/11494/01. 160 p.
19. Supplement to Field Manual Biophysical Pilot Survey Kenya, Sediment sampling in mangroves. 2013. Improving Capacity in Forest Resources Assessment in Kenya (IC-FRA) project. KFS, KEFRI, DRSRS, UE and Luke. Compiled by Jukka Alm (LUKE), James Gitundu Kairo (KMFRI). 16 unpublished Document.
20. Wanene, A.G. (1975). A provisional yield table for *Pinus patula* grown in Kenya. FD technical note 143

Annex 1. Main results of the test sites

Note, forests include vegetation classes 101–212 (forestland and woodland). For calculation purposes, land area was estimated to be 90% of the test site area; it was not taken from map data or other data sources.

Variable	Test site					
	Kericho, Marigat&Nakuru	Aberdare	Gazi	Kericho	Marigat	Nakuru
Land area, km^2	2,430	360	36	810	810	810
Clusters	29	13	13	10	10	9
Land clusters	29	12	13	10	10	9
Forest clusters	25	11	13	10	10	5
Sample plots	115	47	52	40	40	35
Proposed Sample plots	115	45	49	40	40	35
Sample plots in forest	88	40	41	37	38	13
Forest area proportion	0.765	0.889	0.837	0.925	0.950	0.371
Forest area, km^2	1,859	320	30	749	770	301
Forest area, standard error (%)	8.7	10.0	8.3	5.8	5.3	35.8
Total volume, 1,000 m^3	36,879	6,401	356	34,022	1,119	230
Total volume, standard error (%)	30.7	36.3	38.2	21.0	13.6	64.6
Mean volume, m^3/ha	198.3	200.0	118.2	454.1	14.5	7.64
Mean volume, standard error (%)	29.4	34.9	37.3	20.2	12.6	53.8
Total biomass, 1,000 ton	22,594	3,963	3,792	19,722	1,550	434
Total biomass, standard error (%)	27.2	22.4	75.6	18.9	26.1	73.8
Mean biomass, ton/ha	121.5	123.8	1,258.9	263.2	20.1	14.4
Mean biomass, standard error (%)	25.7	20.1	75.2	18.0	25.6	64.6

Annex 2. National inventory of soil laboratories for soil carbon analysis for the National Forest Resources Assessment (NFRA)

Proposed soil laboratories to considered for engagement during the national forest inventory exercise

1. .KALRO- Mtwapa- Coastal region, Mombasa
2. Kenya Marine & Fisheries Research Institute- Magroves, Mombasa
3. National Agricultural research laboratories- Central Highlands, Nairobi
4. Kenya Forestry Research Institute, Muguga- Central Highlands
5. University of Eldoret, Soil Science Department lab, North Rift Valley Region
6. KALRO- Kitale- North Rift Region
7. KALRO- Kakamega- Western region
8. KEFRI- Maseno- Western
9. KALRO- Kisii- Southern Nyanza and South Rift Region
10. KALRO- Tea Research Institute, Kericho
11. KALRO- Food Crop Research Institute, Njoro, Nakuru
12. KALRO- Crop Research Institute, Muguga
13. Jomo Kenyatta University of Agriculture and Technology, Horticulture Department, Juja
14. Kenyatta University, Environment Department, Nairobi
15. World Agroforestry Centre (ICRAF), Nairobi
16. Crop Nutrition Laboratory Services

Annex 3. Results of the questionnaire by field forms

NR: Not relevant; codes 1–3 see Table 4. Scale for the questions in the feedback

Sample plot	NR	1	2	3		NR	1	2	3	Comments / suggestions
Concept/determination of stand		6	1				5	2		Perfection comes with practice which I achieved.
Recording of coordinates		6	1				5	2		Field manual not clear on determining plot stand, decision to rate stand difficult
Different radius sample plots		7					6	1		
Order of tree measurement in sample plot		6	1				7			
Slope measurement		5	2				5	2		Problem to decide if slope is in the plot and direction
Use of slope correction		6	1				7			
Concept of FRA land use/cover class		4	3				4	3		There’s slight conflict in interpretation. Difficult to decide FRA in the field
Determination of Vegetation type		7					5	2		
Measurement of canopy coverage		4	1				4	1		
Shrubs & regeneration	NR	1	2	3		NR	1	2	3	Comments / suggestions
Definition of shrub		6	1				5	2		Different definition of what is a shrub in the field
Estimating shrub coverage		6	1				6	1		Improve on field manual and field on estimate of shrub coverage
Locating of regeneration plots		7					6	1		
Counting of saplings/seedlings		7					6	1		In the field decision of what is a sapling or seedling not clear
Tree	NR	1	2	3		NR	1	2	3	Comments / suggestions
Definition of tree		7					7			
Definition of species		7					6	1		
Definition of bole height		6	1				6	1		Lower Branches on the bole of the tree confused what is bole height
Definition of breast height		7					7			
Definition of tally tree		7					6	1		
Definition of sample tree		7					6	1		

Measurement of total height		7					6	1		Difficult in indigenous forest that has heavy undergrowth
Measurement of tree distances		7					6	1		
Tree quality		5	2				4	3		By observing a tree in the plot may give incorrect quality status
Dead wood & stumps	NR	1	2	3		NR	1	2	3	Comments / suggestions
Sample plot radius		7					6	1		
Measurements of diameters		7					6	1		
Determination of specie		4	3				2	5		Very old dead wood and stamps was difficult to identify species
Bamboo	NR	1	2	3		NR	1	2	3	Comments / suggestions
Sample plot radius	1	4	2			1	4	2		Highly dense bamboo vegetation is difficult to form plot radius not very clear in manual
Measurements of diameters	1	6				1	6			
Measurements of height	1	4	1				5	2		
Climbers	NR	1	2	3		NR	1	2	3	Comments / suggestions
Sample plot radius		6	1				5	2		
Measurements of diameters		7					6	1		
Measurements of height/length		5	2				2	5		Estimation of height/ length quite challenging climbers coil can't be seen clearly.
Determination of specie		6	1				3	4		Was a challenge in the absence of a qualified Botanist.
Litter, debris & soil	NR	1	2	3		NR	1	2	3	Comments / suggestions
Locating the soil pits with the help of the team leader	3	4					4			
Collection and weighing of litter and woody debris per each stand	5	2					2			
Procedure of mangrove sediment sampling	5	1					1			

Extracting the lab samples from litter and woody debris	5	2				1	1			
Making the soil pit and collecting the volumetric composite soil samples (0-10, 10-20, 20-30) per each stand	5	2				1	1			
Taking the deep, non-volumetric soil samples (30-60 cm)	5	1					1			
Mangrove sediment penetration depth study	5	1					1			
Sending the litter, debris and soil samples	4	1	1				1		1	
Labour force available for the sampling	3	2	1				1			
PDA, usability & OFCM	NR	1	2	3		NR	1	2	3	Comments / suggestions
Starting program (OFC Mobile)		5	2				5	2		
Exporting data from PDA		4	3				4	2	1	
Importing data to PDA		4	3				3	4		
Recording measurements on survey form		6	1				6		1	
Making backups of recorded data		4	1	2			4	1	2	
Navigating on survey form		6	1				6	1		
Correcting of recorded data		6	1				6	1		