Background:
Precise and up to date information on the forest area as well as on the quality, quantity and distribution of the growing stock (the trees) in forests is the primary basis for determining their production potential for management.

Data on the state of forestry resources is very vital for planning sustainable use of the resource. Forest resource inventory addresses the required information needs. Information from resource assessment is used for the following:

- Planning for sustainable forest resource use through drawing of management plans detailing prescriptions/interventions.
- National policy formulation, analysis and monitoring for the forest sector e.g. determining contribution of forestry resources to the GDP, social, environmental and forest resource management and development of policies.
- International policy development and negotiation for management of national forestry resources.

Prior to the formation of NFA (NFA took over Management in 2004); the Forest Department was the lead agency in management of forest resources. Until the 1970s Uganda had one of the most well managed forest estates on the continent. However, political turmoil for nearly over one and half decade affected the management of these resources. Activities were limited in that period, due to unavoidable constraints such as lack of adequate funds, transport facilities, tools and equipment.

During this period; Forest Department was able to conduct just a limited number of inventories through the 1970s and part of eighties. In the late eighties to date many projects which included various types of inventories to restore and enhance proper resource management were conceived.

Resource inventories/ assessments are often costly, tedious and time consuming. Some times, highly specialized technical skills are required. In all instances the objective of the resource assessment will aim at being cost effective for attaining the specific objectives of management.

National Forest Authority carries out various types of inventories aimed at inventories addressing management needs at specific levels/needs. Broadly the following types of inventories are currently being curried out.

- Exploratory Inventory (EI)
- Integrated Stock Survey and Mapping Inventory (ISSMI)
- Yield Monitoring and Growth Modeling. (Permanent Sample Plots-PSPs)
- Management Plantation Inventory
- Biodiversity Inventory
- Biomass Survey

The methodologies and out puts for the various types of Inventory have evolved over the years with advancing technologies and changing management practices/approaches.
**Exploratory Inventory (EI)**

Dating the 1950s most of the inventory activities were focused on exploratory sampling of marketable timber species in some productive natural forests. Over the time, this type of inventory has evolved to include other management needs.

**EI is normally undertaken when a reserve is first being brought under management or when management is being reintroduced after a lapse of many years.** The intention is to have an idea of possible annual allowable cut, the felling series and information on the major commercial species in the reserve.

**EI Design:**

EI is a low intensity inventory for strategic planning and normally followed by ISSMI for harvesting and other silvicultural interventions. The EI design and methodology developed by Dr. Alder and NFA staff, with a sampling intensity of 1% is currently being used for EI in NFA Forest Reserves.

The design is a stratified, partially randomized sample. Stratification is by square blocks, each normally of 1 km$^2$ (see Figure below), oriented in a NS-EW direction. Within the block, two transects are laid at random in an EW direction.

The figure below is the sampling design, showing arrangement of blocks, transects, and circular plots. Block lines are in blue, transect in red, plots in black/yellow, and forest zoning and compartment boundaries in grey.

Along the transect, plots are established at 100 m intervals, starting 50 m in from the beginning of the transect. Each plot is circular, of 500 m$^2$, having a radius of 12.6 m.
Within the plot, all trees down to 20 cm dbh are included. A subplot is established within the NE quadrant of the plot on which trees down to 10 cm are measured.

This design gives 20 plots of 0.05 ha on a block of 100 ha, or a sampling intensity of 1%. To assist geo referencing of plots transects and plots are numbered in a standard way. Transects are numbered according to their positions. The first possible position (200 m north of the block baseline) is 1; the second possible position (400 m) is 2, and so on. The plots are always numbered from one upwards from East to West, regardless of the actual direction in which plots are established.

**EI software and out puts:**
Software to process the data has evolved through a number of versions over the years to accommodate management planning procedures/ needs. The EI software comprises three packages:
- EiSys for data entry and quick stand summary reports,
- EiMAp for mapping inventory blocks, transects and plots as GIS compatible files, and for generating random inventory layouts
- Eipac for more flexible stand tables including sampling errors and defect allowances. Eipac also includes a stand growth model for allowable cut and sustained yield estimation.

Some of the outputs for stand tables with software include:
- variable diameter classes
- tabulation of quantities above a specified diameter limit (cumulative diameter classes)
- selection of variable to be tabulated (tree numbers, volumes, basal area)
- table columns based on tree quality classes
- sampling error and reliable minimum estimate calculation
- options for presentation of species and species groups

**Integrated Stock Survey and Mapping Inventory (ISSMI)**
ISSMI is an inventory done to guide silvicultural decisions and forest management and control at compartment level. In the past, the Forest Department has been carrying out diagnostic sampling (DS) and with data from Exploratory Inventory to address this level of management. This type of inventory (DS) was rather subjective in which presumed future crop trees (leading desirables) are selected to obtain an estimate of advance of growth.

Stock survey/ stock mapping in the sixties through the eighties were carried out where logging was to take place. Each tree (over 50cm dbh) was marked with a number. Some trees were selected as mother trees. However, not all trees that qualified for 50cm and above was harvested. Certain trees above commercial size were retained as seed trees to maintain the integrity of the forest ecosystem.

ISSMI was therefore developed to integrate the above operations. The system allows the operations of management inventory, stock survey/stock mapping, and diagnostic sampling to be carried out as an integrated operation and in the end reduce costs and double operations.

The forest is brought under management through an initial forest resource assessment
(Exploratory Inventory) and a management plan prepared (see above planning process). Demarcation of the main working cycles e.g. production, conservation (nature reserves and buffer zones), research, ecotourism, etc is done. Compartment boundary demarcation where they do not exist or sufficient is done. Subsequently, the cyclic operations start with stock survey, combined with management inventory. This leads to detailed silvicultural planning using the sub-compartment blocks as the basic units.

A 200m x 200m block in the stock survey becomes a semi-permanent structure for forest control. Throughout this period, the 200m x 200m block lines are kept open and used to control operations. A 5% systematic sample of trees 20-50cm diameter, 1.25% for poles 10-20cm dbh and total enumeration of all trees over 50 dbh done.

The integrated stock survey and management inventory is primarily a planning, control and monitoring tool at the compartment level as mentioned above. When a compartment has been assigned for felling within a 5-year coupe, the ISSMI survey is performed just before the start of that period, and about ¼ of the best 4-ha blocks assigned for felling. This is premised on the 25-year felling cycle.

A specified list of trees permitted to be felled is made available. Field Supervisors verify that saw millers are aware of the boundaries of poly blocks and the tree numbering system. When a block is completed, a return is made of trees actually felled. Random checks by stump surveys are done. The block level information (from management plots) is used to indicate areas for remedial treatment.
Growth modeling using Permanent Sample Plots (PSPs)

PSPs for both natural forest and plantations for growth monitoring is one of the key management tools that NFA has for growth monitoring. Because forestry is a long-term activity, models are needed to indicate the results decades hence of current actions. This is routinely undertaken in forestry using a variety of graphical and computer-based methods.

Permanent Sample Plots in Natural Forests

Estimates of allowable cut and sustainable yield, and assessment of forest response to different diameter limits, felling cycles, and silvicultural treatments depends critically on growth, mortality and recruitment rates.

PSPs provide the empirical basis for these growth estimates, and are therefore a key requirement for sustainable forest management.

However, tropical forests represent a special challenge because of the complexity of the ecosystem, the measurement difficulties involved, and the variety of management choices.

Typically, a Tropical Forest Model (TFM) should allow choices to be made, about felling cycles, species selection, and size limits. It should show the results of these choices, in terms of the future growing stock, 100 to 200 years hence in order to indicate the
Many PSPs were established in natural forests mainly in the sixties and early seventies. Activity on PSPs like most other inventory activities stalled thereafter. The plots were largely unmeasured from 1973. In 1988 the Forest department through the FMRCP project recruited a consultant (Denis Alder) to give technical guidance for the resumption of old PSP work and give an input of on new ideas and changes.

**Permanent Sample Plots in Plantations:**

In a bid to meet the rising demands for timber and also reduce on pressure on the natural forests, NFA has embarked replanting harvested areas and new areas. The Saw Log Production Grant Scheme (SPGS) financed by the EU is also aiding private farmers in establishing plantations. This program is geared at encouraging the private sector to get involved in tree planting to avert the looming shortage of timber.

However the monitoring of growth and performance of this crop is very crucial right from the onset. This requires establishment of Permanent Sample Plots (PSPs).

**Objectives of PSPs Establishment:**

Much of the knowledge on forest development is gained from focused research on the forest resources. PSPs are means of obtaining such knowledge on growth and eventually yield. The following are the major objectives for establishment plantation PSPs,

- To provide forest growth and yield information for efficient management of the forest.
- To estimate the potential productivity of the site.
- To quantify the effects of silvicultural treatment on growth and yield.
- To provide data on the effect of management of stands on physical, chemical and biological properties of the site.
- To monitor changes in site productivity over successive rotations of tree crops under management.

Information obtained from PSPs will not only be useful for monitoring growth and yield of plantations but will also demonstrate forestry potential to investors, identify potentials of various sites and species suitability; provide information on sources of improved seed. Also in stands which are scheduled to be thinned or have been thinned, to obtain information on thinning responses. In summary the objectives of introducing PSPs to private farmers are:

- Introduce scientific management to farmers through monitoring growth and yield of the crop.
- Obtain additional information on site potential

**Available Models in NFA:**

In 2003 the first ever yield models for *Eucalyptus grandis* and *Pinus caribaea* were under taken. Based on site index, yield function, stand volume equations, self-thinning function; scientifically justifiable and able to be certified models were built for the two species. It is suitable for use for the NFAs Plantations and Private Investors.
The model ideally predicts volume from age, site, stocking for unthinned stands at different spacing. In practice, it uses height as product of site and age. 10 year was used as base age for Site index (SI) for both species. Site index therefore is defined as dominant height of a stand at age 10.

Yield model for Caribbean Pine for a Moderate Site in Uganda
(Spacing of 2.7m×2.7m and 2 thinning regimes- final crop of ~500 stems)

<table>
<thead>
<tr>
<th>Site index</th>
<th>Planting N/ha</th>
<th>Survival %</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>1370</td>
<td>0.85</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Main crop before thinning</th>
<th>Thinnings</th>
<th>MAI</th>
<th>CAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Hdom(m)</td>
<td>bdh(cm)</td>
<td>G/ha(m)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1165</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
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</tr>
<tr>
<td>40</td>
<td>35</td>
<td>524</td>
<td>37</td>
</tr>
</tbody>
</table>

Note on assumptions:

1 Site index of 14 has been chosen for an average site. This is the height in metres at the age of 10 years.

2 Enspacement of 2.7m×2.7m at planting. And thereby 1370 seedling per hectare planted out.

3 A survival % of 85 in the year of planting. And thereby 1165 plants into the second year.

4 Two thinning regimes. The first non-commercial thinning at the age of 4 to 5 years, the second commercial thinning at 12 years.

5 Rotation age of 22 to 25 years. The expected, over bark volume per hectare is 450 m³ to 560 m³.

Other Inventories

(i) Plantation Inventory using Temporary Plots (TSPs):
Point sampling using relascope has been used for assessment of mainly mature crop for harvesting planning.

(ii) Biodiversity Assessments (Inventories)
NFA has a Master Plan that integrates the conservation of biodiversity and other environmental protection measures. The Authority has committed nearly 50% of its forest estate to protective management as "Nature Reserves" and "Buffer Zones". Uganda's Biodiversity is an exceptional global resource and Uganda has international responsibility to conserve biodiversity, and obligations under the Convention on Biological Diversity.

The primary source of information used in the planning the Master Plan was the Biodiversity Inventory Programme which took place between 1991 and 1995 funded by Global Environment Facility (GEF). This was designed specifically to provide data necessary for assessing the biological value of the country's principal forests, as a basis for Nature Reserve site selection.
(iii) **Biomass Inventory**

The National Biomass Study of NFA adopted a two-stage sampling technique in the assessment of the biomass resource in Uganda. In the first stage (Mapping Stage), the country’s Land use/cover (LUC) were stratified and mapped in order to quantify the area and distribution of each LUC. While in the second stage (Biomass Inventory), an inventory of the biomass resource from sample plots is done in order to quantify the standing stock of biomass in the country. For purposes of monitoring biomass dynamics on a periodic basis, the positions of these sample plots are geo-referenced by the use of Global Positioning Systems (GPS).

**a) Mapping**

Remotely sensed data from SPOT satellite imageries are used to map the location and distribution of LUC and eventually the quantification of areas of each LUC. Geographical Information System (GIS) is intensively used in the mapping process. The following are the steps applied:

- Land cover use stratification
- Preliminary interpretation of satellite imageries
- Ground truthing and
- Final Delineation

**b) Biomass Inventory**

This is the second stage in the overall assessment of the biomass resource. It involves the measurement of tree parameters for the determination of single tree weights and aggregation of standing stock of biomass per unit area. The purpose is to finally quantify the total standing stock of biomass. To achieve this, appropriate sampling techniques are applied since a complete enumeration of tree parameters for the whole country is not possible and if so, it is very costly.

**Sampling design**

Uganda was divided into three priority zones of high, medium and low based on population density according recommendations of the Review Mission in 1992. Priority zone I is approximately 64,013 km², Zone II approximately 56,375 km² and zone III is approximately 76,708 km².

After the above zoning, the country was further divided into a 5 by 10-km grid cells. At every grid intersection, clusters of 3 sample plots are measured. A sampling intensity of 3:2:1 was fixed for zone I, II and III respectively. The basis of the sampling intensity is on the fact that changes are expected to occur more in highly populated areas than for example low populated areas such as zone III.

For the 3 zones and at the sampling intensity ratio of 3:2:1, a total of 3,000 grid intersections are needed to give 1,000 grid intersections per zone. In Zone I, all 1,000 intersections are used (3,000 plots), in Zone II, 2000 plots and Zone III, 1,000 plots. Using an effective area of 180,000 sq. km (area excluding water and large swamps), the resulting grid size was 180,000 / 3,000 = 60 square km. The 5 x 10 km grid is convenient and reasonable. In practice some plots will be inaccessible physically (e.g. swamps) or socially (e.g. the owner refuses access). Therefore, it was assumed that a
total of approximately 6,000 plots were possible to be located and measured in the field.

Figure 0-1: Sample plot design

Plot Size – Depending on the heterogeneity of a population, increase in plot size generally decreases the sample variance. At the same scale of measurement, small plots will almost always be more variable than large ones (Freese, 1984). If for example, quarter hectare plots are measured and the results are to be extrapolated to hectare level, then the hectare variance is the plot variance times 16. If the variable $\chi$ has variance $s^2$ and this variable is multiplied by a constant (say $k$), the product ($k\chi$) will have a variance of $k^2s^2$ (Freese 1984). Thus, estimating biomass using big plot sizes is expected to reduce on the sample variance. Below is a list of plot sizes which were recommended by a Review Mission in 1994.
Table 0-1: Plot sizes per LUC

<table>
<thead>
<tr>
<th>Land Cover use</th>
<th>Plot Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planations and woodlots</td>
<td>20 x 20 m, all classes</td>
</tr>
<tr>
<td>Planations (Softwoods)</td>
<td>20 x 20 m, all classes (Few plots)</td>
</tr>
<tr>
<td>Tropical High Forest</td>
<td>50 x 50 m, all classes (Few plots)</td>
</tr>
<tr>
<td>Tropical High Forest (Degraded)</td>
<td>70 x 70 m (L), 30 x 30 m (M/H)</td>
</tr>
<tr>
<td>Woodlands</td>
<td>50 x 50 m (L), 50 x 50 m (M/H)</td>
</tr>
<tr>
<td>Bushlands</td>
<td>50 x 50 m (M/L), 30 x 30 m (M/H)</td>
</tr>
<tr>
<td>Grasslands</td>
<td>70 x 70 m (M/L), 30 x 30 m (M/H)</td>
</tr>
<tr>
<td>Wetlands</td>
<td>Wetlands not measured, 50 x 50 m (H)</td>
</tr>
<tr>
<td>Subsistence Framinads</td>
<td>70 x 70 m (L), 50 x 50 m (M/H/VH)</td>
</tr>
<tr>
<td>Commercial Framinads</td>
<td>70 x 70 m (L), 50 x 50 m (M/H/VH)</td>
</tr>
<tr>
<td>Built up areas</td>
<td>50 x 50 m, all classes</td>
</tr>
</tbody>
</table>

(L=low, M=medium, H=high, and VH=very high biomass).

Statistical tests on the above various plot sizes showed that CV generally decreased with increase in plot sizes but there was no significant drop after 2,500 m². In uniform vegetation like plantations, plot sizes of 400 m² (20m by 20m) were found optimal (Velle, 1997). Therefore, the 50m by 50m (2,500 m²) was then adopted as the standard plot size for field sample plots.

Plot location and establishment

The field teams use topographic maps at scale 1:50,000, the land cover maps and Global Positioning System to navigate their way to the actual location of the field plots on the ground. After locating the plot, the next step was to demarcate the 50 x 50 m plot on the ground. For consistency, the south-western corner each plot is taken as a reference point. The geographical location of this reference point is measured by a GPS in real world geographical co-ordinates. The readings in either UTM or Latitude-Longitude are recorded on the field form. From the reference point, the plot is always established eastwards and northwards. For purposes of future re-location, other descriptive information on the plot such as distance and angle to any conspicuous landmark are also observed and recorded on the field form.

After completion of the establishment of the plot, the next step is to divide the plot into 10 or 5 m wide strips (depending on plot size) running east-west direction from the reference point. Within each strip trees are measured systematically from one end of the strip to the other and each tree given a unique number to identify it (Figure 3-2).
Figure 0-2: Plot strips within the 50m by 50m plot (arrows show direction of movement within the plot and numbers refer to tree numbers)

Other information recorded are the plot number, grid reference and cover assessment of trees, bush, grass and any other LUC.

**Measurement of tree parameters**

After identifying the tree species, tree parameters such as diameter at breast height (dbh), tree height, bole height, and crown width are measured for each tree within the sample plot.
Re-measurements for Monitoring and Biomass Growth

A sub sample (about 30%) of the measured plots is usually re-measured to assess biomass net changes in biomass and vegetation composition. For the estimation of growth, a sub sample of about 10% of the measured plots are re-measured to assess biomass yield and changes in vegetation composition. Like in yield assessment, plots are re-located using Omnistar DGPS. For this assessment, all trees must be systematically matched following the standard plot measurement procedure. Caution is usually taken not to include trees that were previously left out.

Growth is a continuous process during the whole year and the time interval therefore, two sets of periodic measurements are required for the estimation of growth. The first measurements were used to calculate biomass of all ‘measurable’ trees at the beginning of the time interval. The second measurements were used to estimate the biomass at the end of the time interval. The difference in biomass from the first visit and the second visit when divided by the time interval (expressed in decimal years) then gives the annual growth rate (Figure 3-3).

**Figure 0-3: Formula for calculating biomass growth**

$$GB = \frac{(B2 - B1 + I)}{t}$$

Where

- $B1$ = Biomass standing stock 1st Visit
- $B2$ = Biomass standing stock at 2nd visit
- $I$ = In-growth since 1st Visit
- $t$ = time expressed in decimal years

It should be noted that on private land, trees are ever being cut and some die of natural physiological breakdown.

**Data capture, processing and analysis**

There are two major parts of the data processing and analysis. One relates to the spatial data and the other to the biomass inventory data from field sample plots.

**Spatial data**

Two main processes were used to capture data into the EIS namely digitising and scanning.

*Processing and analysis* - Once the spatial datasets were ready, then the various layers were overlaid and joined together for generating various statistics related to area, length and perimeter and general relationships of one feature to another. The following are some examples:

a) Analysis related to area: For example when the administrative layer was overlaid with LUC, area statistics of land cover distribution were aggregated by administrative unit such as district, county down to parish level. Similarly administrative layer overlaid with gazetted layer was done to generate area statistics of gazetted area by district down to parish level. Overlaying LUC with
gazetted area was also done to generate some statistics on the status of the gazetted areas e.g. how much was encroached or extent by types of LUC. Statistics related to distances (roads, railway lines) and perimeters (e.g. forest reserve boundaries) were also similarly analysed and aggregated on administrative units.

b) Analysis related relationships: The relationship of land use to existing or planned roads was analysed to give area statistics of likely areas threatened by for example road construction projects. Similar analysis was done around rivers to show how far river resources were to settlements or likely areas to be affected by floods.

c) Digital Elevation Models DEM, generated from the contour layers was used to visually display a three-dimensional view of land forms in a given area. From the DEM other analysis such as actual ground distance, visibility analysis, location and planning of forest roads, analysis of soil erosion risk areas etc were tried out from the DEM.

Sample plot data (Biomass standing stock)
NBS developed a Dbase program (formerly written in SAS-short for Statistical Analysis System?) for the calculation of tree biomass. The program calculates the predicted weight of the trees and plots, using both species-group functions and size-based functions. It also roughly estimates commercial weight (=volume) for timber species.

The programme has two major sections. The first section selects the area, then opens up the appropriate tree-data file and calculates wet-weight of single trees by applying the relevant coefficients of the biomass regression models (Appendix….). The single tree weights are then expanded to hectare basis by an appropriate expansion factor based on the plot size. The wet weights were also converted to air dry weight using species density values from species data file called Speclut. The second section sums up the single tree weights by plot. The resulting file can then be imported into other statistical or data base management packages for further statistical analysis such as mean, variance, standard error of the mean per each LUC and substrata.

Biomass yield assessment
Yield or growth of plants is affected by environmental or site conditions, stock of stand, and indigenous growth characteristics of tree species (Pancel, 1983). Therefore biomass data files were first sorted according to agro-ecological zone and vegetation class, before linking the two biomass files of first and second visit on plot number and tree number. In order to assess the biomass change over the time interval, the results from the first visit was subtracted from second visit. The rate of change per year or annual increment was obtained by dividing the resulting biomass by the time interval (in decimal years) between the two visits.
To assess yield among tree sizes, trees were grouped into specified diameter class intervals. Sum of yield of all trees in a diameter class, divided by the number of plots was used to calculate average biomass per diameter class. Likewise, count of all trees per diameter class divided by number of plots gave number of trees per diameter class. Note that recruits were treated as a special diameter class. Figure 3-5 gives a schematic presentation of yield assessment.

**Figure 0-4: Schematic illustration of yield assessment**

<table>
<thead>
<tr>
<th>PLOTNO</th>
<th>TREENO</th>
<th>DBH</th>
<th>BOLE</th>
<th>HEIGHT</th>
<th>CROWN</th>
<th>SPECIES</th>
<th>PWS_AIRDRY</th>
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<td>112028</td>
<td>1001</td>
<td>4</td>
<td>1.3</td>
<td>3.0</td>
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<td>1.3</td>
<td>4.0</td>
<td>1.0</td>
<td>Citrus nobilis</td>
<td>8.7</td>
</tr>
</tbody>
</table>

**Monitoring Land Use Cover Change**

The NBS tree cover database captures up to 26 different units. These units are bush, grass, grass fallow, bush fallow, coffee, matooke, cassava, sweet potatoes, maize, peas, cotton, sunflower, sorghum, tea, cocoa, water, sugarcane, residential, livestock pen, industrial business, road, miscellaneous, papyrus, reeds and floats.

To monitor land use cover assessment data files were first sorted according to agro-ecological zone and vegetation class. Cover assessment units were grouped into seven main classes viz.; 1) Bush, 2) Bush fallow, 3) grass, 4) grass fallow, 5) wet areas (including open water), 6) built up area and 7) crops. First visit and second visit files were linked to each other. Second visit class was subtracted from first visit class. Negative value for a class means decrease in cover while a positive one means an increase. Plot averages show general trend per vegetation class and agro-ecological zone.