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RECOMMENDATIONS CONCERNING INVENTORY OF TIMBER, FUELWOOD, AND NONTIMBER PRODUCTS AND CHARCOAL SPECIES REGENERATION

for Areas of Wula Nafaa Intervention in Eastern and Southern Senegal

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Jim Alegria

Biometrician BLM/FS
Vegetation Inventory

Cecilia Polansky

Participatory Inventory Consultant
Senegal

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RECOMMENDATIONS CONCERNING INVENTORY OF TIMBER, FUELWOOD, AND NONTIMBER PRODUCTS AND CHARCOAL SPECIES REGENERATION in Eastern and Southern Senegal

SUMMARY

CONTEXT OF THE MISSION: Wula Nafaa (WN) is a natural resource management program funded by USAID/Senegal and implemented by International Resources Group, with technical assistance provided by US Forest Service and others. One of WN's goals is to put large forest areas under community-based **management**. Another is to market **forest products**, including charcoal and non-timber products, in a sustainable way.

In December 2006, the US Forest Service assisted WN to complete a step-by-step procedural guide to development of community-based forest management plans (PAFs) based on WN experiences in Tambacounda and Kolda Regions. The guide acknowledges Senegal's legal requirement that the PAF "establishes the **maximum standing wood that can be cut** each year, as a function of the regeneration of the forest stands" (Code Forestier Titre I, Ch 2, R.17). This requirement is met by producing a table of volumes and a work parcel map resulting from inventory fieldwork. Thus "carrying out an inventory" is one of the steps in the guide, but it is insufficiently detailed.

One recommendation from the US Forest Service 2006 mission was to add more detail to the inventory step. The detail will describe how the inventory is carried out by consultants who use the SYSTEME D'INFORMATION ECOLOGIQUE ET FORESTIERE (SIEF, developed under the Programme de Gestion Durable et Participative des Energies Traditionnelles et de Substitution or PROGEDE) to produce tables for, and to map, the legally-required annual allowable cut. It will also provide information on using the same SIEF to extract information on non-charcoal forest products. Since the SIEF is used to make maps based on an 8-year rotation for charcoal parcels in Tambacounda, another recommendation from the 2006 mission was to explore the regeneration and productivity aspects of cut trees by following charcoal-producing operations in the field.

Based on the recommendations related to the procedural guide and to the WN objective of sustainably marketing forest products, the tasks of this technical assistance mission were to answer certain questions.

- QUESTIONS ON THE SIEF: What is the procedure used to incorporate standing volume and allowable cut data from the existing plot and software system into the PAF? Does the SIEF output satisfy the need for statistical rigor as well as it does for volume estimates required in the management plan? Given that the SIEF was strictly based on charcoal volume estimates, can it be applied to trees providing certain non-timber products targeted by WN marketing groups? Given its heavy computer orientation, can it be made more participatory? Is a different system needed?
- QUESTIONS ON ROTATION AGE: How many years does it take a coppiced tree to grow back to the same size and density as the original stem? Is the protocol established for cutting charcoal parcels reasonable, and is it being respected? How can the answers to these questions be verified?

The mission answered these questions as follows.

INVENTORY AND MAPPING SOFTWARE: Rather than setting up a completely new inventory system for future managed forests in WN zones, the SIEF software and its consultants should be supported by WN because SIEF is user-friendly and already accepted by the Senegalese Forest Service. We believe the quality of the SIEF output can benefit by following these recommendations:

- A review of the original SIEF-1 and the recently released SIEF-2 revealed solvable problems with the statistics in the SIEF-2 program. It is recommended that the Wula Nafaa project use only SIEF I program until such time that the SIEF II program has been corrected.
- Regression equations for volume estimates were developed from trees cut on sites that match Tamba and Kolda forests in the 400-700mm rainfall zone. If WN extends to ecologically different areas (either higher rainfall or different soils), then it should

- (for charcoal:) collect additional felled tree data to validate the existing charcoal models, or review modeling options using old and newly-recorded cutting data;
- (for sawtimber:) record data from actual cutting operations in appropriate areas and diameter classes to update/validate existing regression equations for *Bombax, Cordyla, Erythrophleum g, Lannea a, Prosopis a, Pterocarpus e*rinaceus. For new species important to management that are not yet modeled in SIEF (especially *Afzelia, Antiaris, Ceiba, Chlorophora, Khaya, Sapium, Swartzia,* teak), existing valid volume equations may be found, or else sawyers may estimate volumes from standing trees on a forest-by-forest basis, to avoid cutting simply for the sake of research.

- SIEF volume equations were constructed to estimate the above-ground woody biomass including both stems and small branches) and not just the merchantable portion of stems for charcoal production and sawtimber. While it is valuable to have above-ground biomass equations, using them will overestimate the quantity of charcoal expressed in quintaux in the management plan. Enough data appear to be available for the trees used to construct the biomass equations, so they can be adjusted to predict only the merchantable portion of the stem. A preliminary estimation of the proportion of volume that is overestimated is about one-third for fuelwood and one-fifth for sawtimber.
- The SIEF program reports outputs in terms of basal area, number of stems, and cubic volume per hectare. While they should be retained, these units of measure are not very meaningful to villagers. The program should have the option of displaying the results in terms of sacks of charcoal or quintaux, the units of measure familiar to the villagers.
- There have been many regeneration plots recorded in the field, but no use is made of them for the PAF. Since the Senegalese Forest Service's requirement includes the clause "...maximum standing wood that can be cut each year, as a function of the regeneration", it is recommended that tables summarizing the data on regeneration be added into the report-producing modules of the SIEF and into the PAF itself.
- Regarding interface between SIEF and ArcView to produce maps for the PAF: it would be helpful to add some modules in the Access foundation of SIEF to produce certain summary tables and reports automatically, rather than relying so much on cut-and-paste between Access and Excel and back again.
- Regarding the method of using a 1-ha square grid to construct management block and parcel boundaries by summing their broadly averaged volumes per hectare: this procedure is rigid, independent of natural boundaries, 100% based on charcoal volumes, and still leaves room for human error. It would benefit from a more participatory, rather than strictly charcoal-based, drawing of block and parcel boundaries.

INVENTORY PLOT WORK: The nested plot design that is in use appears to be efficient, with the right balance of subplot size and diameter ranges (except that the middle range, 10- 19cm, should be changed to 10-25cm to match charcoal production rules). The only subplot size that may need to be reviewed is the regeneration plots.

To simplify and render the plotwork more participatory, the following could be considered:

- Define tasks of field team members to include forest users' (villagers') feedback on tree uses, products, and condition as well as actual measurement; but keep the team small;
- Simplify/shorten measurement techniques for dead wood by defining and estimating numbers of "charettes" contained in the dead tree;
- Reduce the number of variables recorded (how likely is it that Erosion, Distance to road, Distance to Water, Degree of Vegetation Cover, and Soil Texture will be used, for example?);
- It may not be necessary to count all stems below a threshold diameter or height on the regen plots; the regeneration data collection could be reviewed.

SPECIFIED NON-TIMBER PRODUCT ESTIMATIONS:

- MBEPP GUM (*Sterculia setigera)*: The SIEF-based plot and sample design is adequate for estimating the number of gum trees in specified areas, and no special study is warranted. However, if known "gum parks" exist, they should be recorded with GPS and put on maps in the PAF or in the Land Use Map for the rural community. Additionally, the productivity per tree figure used at WN (2.5 kg of gum/tree) should be verified by choosing and following a few trees at random and following them through the season.
- BAOBAB (*Adansonia digitata)* AND MADD (*Saba senegalensis)*: Special plot and sample designs are recommended for baobab trees and for the madd vine. The design would depend on whether these species (baobab), or their habitat (madd vine) can be identified on aerial photos. It will be preferable if both species could be surveyed at the same time. Procedures are presented starting on page 21.

CHARCOAL REGENERATION AND PRODUCTION: The point of reference for this part of the mission was the charcoal-producing protocol currently required by the Senegalese Forest Service. It consists of cutting half the charcoal species stems (mostly *C. glutinosum*) between 10 and 25cm in diameter within a parcel; pre-stacking them to measure *stères* (stacked cubic meters) before building a *meule* (pile of wood to be burned into charcoal); and then returning to the parcel after 8 years to cut remaining mature stems. The origin of the protocol, which is repeated everywhere in the region, is a 1988 study attached to a management plan for Koupentoum. The mission made the following observations:

- From an economic perspective, there is a lack of information to make a well-informed decision on the length of the cutting cycle for Combretums. More information should be sought from these:
    - Visits to cut sites of known ages;
    - Remeasurement of the 247 permanent plots that PROGEDE installed in 2004; and
    - Counting tree rings on stumps. If this is found to be an accurate means of aging stems, the project could cut stems of unknown age and reconstruct diameter growth curves according to methods well described in the literature.
- The existing cutting protocol which leaves half the stems will result in an increasing volume of wood left in the forests and a decrease in the amount legally available for firewood over time. Thus different diameter-based protocols should be applied for all stems 10cm and above.
- The stakeholders would benefit from knowing and homogenizing the relationships between volume of charcoal produced in the field (in quintaux or 100kg units), volume of wood estimated in the PAF (by SIEF software), and associated coefficients that convert stères to cubic meters, meules to sacks, and sacks to truckloads. It is recommended that the volume of all meules on a parcel be estimated directly and then cumulatively summed, rather than rely upon the proper stacking and record keeping of stères that is the existing practice.
- There is a preponderant assumption that the Casamance kiln yields more charcoal per kg of green wood. Since this method is less accepted than traditional meules, WN should invest some time and personnel (possibly student interns) in designing and carrying out a simple comparison study.
- The French agronomic research organization CIRAD is interested in natural root and branch suckering to regenerate sahelian species. It is recommended that WN collaborate with CIRAD as a way to involve more scientists and to ensure more regeneration.

RELATIONSHIP WITH PROGEDE: Should the WN program continue past 2007, it should support the efforts of PROGEDE to develop a national inventory by providing assistance in implementing recommendations of this report.

RECOMMENDATIONS CONCERNING INVENTORY OF TIMBER, FUELWOOD, AND NONTIMBER PRODUCTS AND CHARCOAL SPECIES REGENERATION

for Areas of Wula Nafaa Intervention in Eastern and Southern Senegal

CONTEXT OF THIS TECHNICAL ASSISTANCE MISSION

Wula Nafaa (WN) is a natural resource management program funded by USAID and implemented by International Resources Group. One of WN's main goals is to put large forest areas under community-based management in partnership with the Senegalese Forest Service. Another is to market forest products in a sustainable way.

As these tasks have certain technical requirements, WN has signed protocols with various technical collaborators, of which USDA Forest Service is one.

In December 2006, the US Forest Service assisted WN to complete a step-by-step procedural guide on developing community-based forest management plans (PAFs). The guide is based on WN experiences in Tambacounda and Kolda Regions. It acknowledges Senegal's legal requirement that the PAF "establishes the maximum standing wood that can be cut each year, as a function of the regeneration of the forest stands" (Code Forestier Titre I, Ch 2, R.17). This requirement is met by producing a table of volumes resulting from inventory fieldwork. Thus "carrying out an inventory" is one of the 13 steps in the guide. Below is the pertinent excerpt from the newly developed "Procedural Handbook for Natural Resource Management Plans for Rural Communities and Community Forest Management".

(From the WN Procedural Handbook:)

STEP 6. Gather and compile existing data for drafting the management plan

(Objective: Describe the current condition of the forest; identify potential activities for the workplan; calculate sustainable yield and potential production of woody and nonwoody products.)

- Acquire satellite images and/or aerial photos if possible
- Analyze the available information so as to make a decision on whether complementary inventory information is needed. For example:
    - Boundaries and vicinity map of the forest
    - Statistical information on species, density, volume, diameter distribution, and so on, already available from PROGEDE's System of Information on Ecology and Forests in places.
    - Map of biophysical data
- Report back to the community the findings of the analysis

Decision Point:

Given the available information, is any more needed for the PAF?

If yes, go to step # 8; if not, go to step # 7.

Step 7. INVENTORY OF THE FOREST RESOURCES

- (This step is to be expanded describing PROGEDE's SIEF system as it is used by WN)

Step 8. WRITE THE MANAGEMENT PLAN (PAF) ....

The main objective of this mission was to flesh out Step 7 in the Procedural Handbook to reduce ambiguity and clarify how foresters, consultants, and decentralized administrative bodies can fulfill legal requirements in a timely way as they begin a more localized control and harvest of forests. The objective was accomplished through several activities: verification of how the SIEF was developed and how it is currently used; describing how the inventory system is extrapolated for new areas with few or no plots; describing how its results are incorporated into PAFs; conversion factors between calculated and true volumes; how one may use the inventory system for non-charcoal forest product quantification; and the appropriateness of the 8-year rotation prescribed for Tambacounda forest cuts.

FOREST INVENTORY PROCEDURES AND MAPS USED IN THE FOREST MANAGEMENT PLANS (PAFs)

DESCRIPTION OF THE SYSTEM IN USE

Overview of the "Système d'Information Ecologique, Forestière, et Pastorale" (SIEF)

Since Wula Nafaa (WN) started assisting with writing forest management plans (or PAFs) in 2005, it has depended on the Système d'Information Ecologique, Forestière, et Pastorale (SIEF) inventory software that was developed by *the Programme de Gestion Durable et Participative des Energies Traditionnelles et de Substitution (PROGEDE).* The software has a pastoral component and a forestry component. The forestry component is the one used to produce allowable cut tables for PAFs written with WN's assistance. Therefore our investigations began with gaining a deeper understanding of how the system works, whether it is being used appropriately, and how it can be applied to forests and forest products targeted for new PAFs.

SIEF is based on 1999 orthophotography-based Yangambi classifications whose main forest strata are: woodland, shrub, tree, and wooded savannas, fallows, and riverine forest. The inventory is carried out using an established field method (described below) and data are entered into the SIEF. The software analysis of inventory data incorporates regression equations developed around 2003 for above-ground biomass volumes. Because the software outputs tables of volumes in specified areas, it can -- when put together with a cutting protocol -- fulfill the legal requirements in the Forestry Code cited above. The software also summarizes field data into tables used to make thematic maps of the forest in ArcView mapping/GIS software.

There are two consultants in Tambacounda who understand the use of the SIEF sufficiently to perform all the steps (detailed in Appendix B) that lead up to drawing management maps. The maps divide a forest's area, based on per-hectare estimated wood volume, into a predetermined number of blocks with 8 parcels each (based on a commonly-accepted rotation age of 8 years). The availability of the consultants and their ability to use the GIS together with the SIEF software has sped up the management plan writing process for WN and given more credibility to the PAFs themselves.

Using the SIEF software requires a level of understanding and expertise that goes beyond the field technician level and is taught in two-week mini courses to university-educated foresters in the Senegalese Forest Service. Combining the SIEF output with the GIS use takes even longer, especially if the agents are uninitiated in GIS. Fortunately, each region has been allocated the needed computer and software for the GIS aspect of interfacing with the SIEF, which is just part of its greater mapping and inventory needs.

An undeniable characteristic of the SIEF software is that it is geared for charcoal-based management plans, as opposed to all-species, timber, or non-timber products. There has been an attempt to make it into a more inclusive, national inventory software by matriculating the original program (termed SIEF-1) into another complementary version (SIEF-2) that uses a broader Landsat-based vegetation-classification process and has more plots throughout the country.

In the following paragraphs we will describe how the field and office components of the SIEF works, and verify its effectiveness as used in the writing of PAFs by Wula Nafaa in its community-based forest management program.

Description of the SIEF inventory protocol

In order to verify the effectiveness of SIEF, it is necessary to

- review the sample and plot designs,
- evaluate the volume equations, and even
- review PROGEDE's ability to perform supporting services to projects such as Wula Nafaa to ensure consistent and correct use of the SIEF system.

Below is a synopsis of PROGEDE's work from a number of sources including a visit to their office and a discussion with Dr. Cheikh Dieng, the PROGEDE coordinator, followed by a review of Wula Nafaa project's use of the SIEF program.

Special attention is given to the procedure used for stratification of forest types before fieldwork began, because the method of stratification affects the accuracy and precision of the reported average volumes per hectare. Since SIEF averages are being applied over thousands of hectares at a time, it is important to understand how these inventories were executed in order to assess the implications of extrapolating this data for the Wula Nafaa project.

Aerial photography was taken in 1999 at a scale of 1:30,000 over 1,165,000 ha in the Tambacounda – Kolda regions of eastern and southern Senegal. In 2001, another 130,000 ha over the forests of Diambour, Guimara, Nétéboulou and Thiéwal was procured. Both sets of photos were ortho-rectified. From these aerial photos, a vegetation polygon map based on the Yangambi classification system (woodland, shrub, tree, and wood savannas, fallows, and gallery forests) was developed across all lands.

Figure 1 shows Tambacounda and Kolda Regions, where the Wula Nafaa project operates, and the extent of the aerial photography used by PROGEDE.

Figure 1: Wula Nafaa project area and the extent of 1999/2001 aerial photography

Inventory work was concentrated in forests of interest to the Senegalese Forest Service and to PROGEDE (an energy project assisting in seeking sustainable fuel sources for urban centers). Some of these forests are already legally protected as classified forests; others are designated "community forests" with rough boundaries, ostensibly under the control of local decentralized government structures. Four of these forested areas were chosen for a **pre-inventory** in 2001 comprised of 247 plots used to estimate the variance of the basal area of forest populations distributed across the forested Yangambi classes of shrub savanna, tree savanna, wooded savanna, woodland, and fallow. The three savanna types had approximately equal numbers of plots; the jachère received the most and woodlands received the fewest plots.

After the variance was estimated in each Yangambi class, the number of additional plots required per class was calculated (1,050) based on the goal of estimating basal area within ± 10 percent of the average square meters per hectare at a 90% confidence level (Cheikh Dieng, 2006 and personal communication).

Within the WN work regions of Tambacounda (Tamba) and Kolda, a 1,000 meter by 1,000 meter grid of potential sample centerpoints was constructed, creating approximately 5 to 6 times the number needed for the required confidence interval. A subset of the intersections was selected without replacement by Yangambi classes across the photo-covered part of the Tamba-Kolda regions, exceeding the estimated total number of plots needed, over 1,200. Some of these additional plots were more concentrated than others, within Yangambi classes, in several forests of interest. These differences in plot concentration within the same Yangambi class must be taken into account to produce unbiased estimates across forests. Thus at this point in 2003, we believe that over 1,600 plots were measured in the field. There are differing accounts of how many pre-inventory plots were carried out; it varies between 246 and 273. See Figure 2. (Note: there were some 800 plots measured for pasture characteristics only; although these

plots are contained in parts of the SIEF, the analysis here is restricted to plots used in forest wood volume calculations.)

A map of the Tamba region's areas where the plot intensity was considerably higher than surrounding areas is shown in Figure 3: the greatest density is within Nétéboulou and Missirah forests.

In 2004, PROGEDE measured an additional (approximately) 1,300 forest and pasture plots in all regions of Senegal as part of a national survey. With the exception of the Bakor classified forest, these additional plots were outside of the extent covered by the aerial photography indicated in Figure 2.

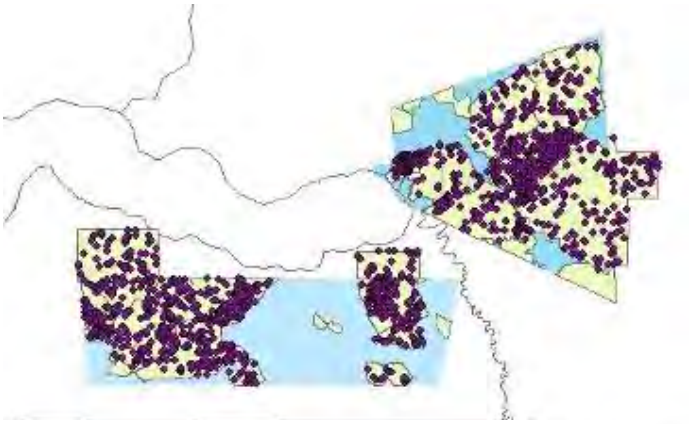


Figure 2: Locations of field plots (purple dots), forests with described boundaries (yellow polygons), and aerial photo coverage (blue)

Every plot in the SIEF is associated with two classification systems: one based on the Yangambi system, and one based on satellite imagery which is more generalized. The satellite classes are *weak, somewhat rich, rich, and very rich.*

It is not clear if the 2004 national inventory plots were pre-stratified with differing probabilities of selection, or post-stratified into satellite classes, as the Tamba-Kolda inventory surely was since it started out in Yangambi classes. These additional national inventory plots are only available in the SIEF-2 database.

Figure 3: Differences in sampling intensity between Missirah and Neteboulou, compared with Diambour, Bala-Ouest, and others

The original Tamba-Kolda sample design (SIEF-1) kept Tambacounda and Kolda regions separate and stratified each by five Yangambi classes. The analysis for each region was completed on a stratum by stratum basis. This approach reduced the analysis to a series of random samples for each stratum within each of the two regions.

With the SIEF-2 program, the user can display data from only the Tamba-Kolda inventory (over 1,200 plots), from all the "bassins d'approvisionnement" (1700+ plots), or from all the inventories that are contained in the database including plots outside WN project areas (over 2,900 plots). Sub-population analysis is conducted by choosing Departments, Arrondissements, classified forests, or community forests. SIEF-2 can display information on a given forest and stratum, using all the plots in the chosen boundary/stratum combination to calculate mean values as in a simple random sample.

There are provisions in SIEF-2 for producing results for non-wood products, but these options currently do not work since the basic information is not available in the data base.

In Figure 4, one can see the different inventories that make up the total of over 2,900 plots in the SIEF-2 database.

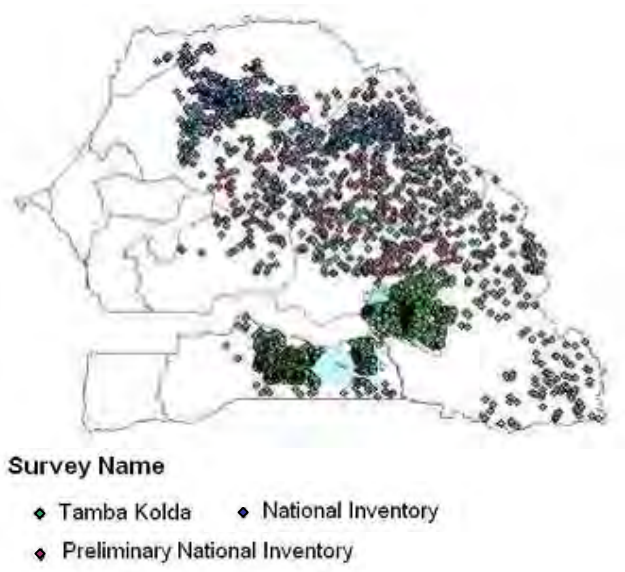
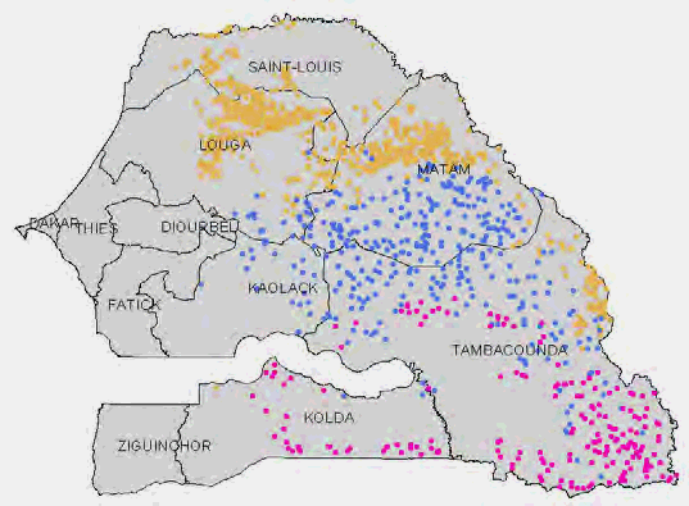


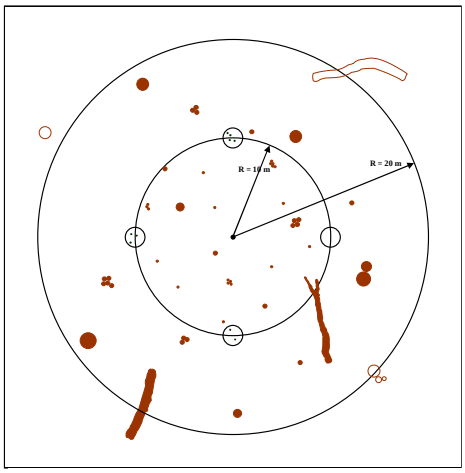
Figure 4: Forest Surveys in SIEF-1 and -2, showing the different origins of plots

FEATURES OF THE NATIONAL INVENTORY



- Pre-inventory to determine variability in each Yangambi stratum
- Calculation of the number of samples points needed to obtain a precision of « 85% » in each stratum
- Distribution of the samples using a 1km square grid of points
- In all, 1,788 inventory plots were spread throughout the fuelwood-producing watersheds of Senegal

(From the slideshow presentation of the SIEF 2003)



Nested design for the National Inventory plots in the SIEF

- A fixed-radius plot of 10m radius for trees and stumps 3 to 9.9cm diameter
- A fixed-radius plot of 20m radius for trees, stumps 10cm diameter and up, and dead wood of minimum length and diam
- A cluster of 4 regeneration subplots 1m in radius, 10m from the plot center

Plot execution in the field

The initial plot used in the Tamba-Kolda inventory was a nested design with 4 subplot sizes for live trees: a 10-meter radius subplot for trees greater than or equal to 3 cm and less than 10 cm in diameter; a 15-meter subplot for trees greater than or equal to 10 and less than 20 cm in diameter; and a 20-meter subplot for all trees greater than or equal to 20 cm in diameter. The plot design was eventually changed to the simpler 3-subplot size design used in the national inventory (see box above). Still in use are the four 1-meter radius subplots for trees less than 3 cm in diameter located in the four cardinal directions straddling the inner 10-meter subplot (see Figure 5). All trees 3 cm or less in diameter at 1.3 meters above the ground are recorded by group tally by species.

Standing dead trees at least 3 cm in diameter are recorded on the entire 20 meter subplot. Down woody stems are also recorded if the mid-point of the length that is at least 3 cm in diameter is within the subplot. There are also stump and length criteria for dead wood to be entered on the inventory sheet.

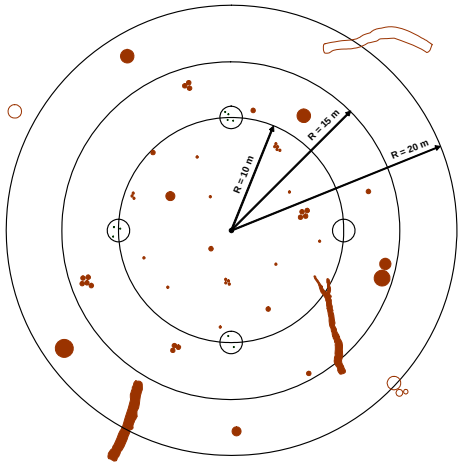


Figure 5: Original nested plot design in the Tamba-Kolda inventory for the

Development of the volume regression equations

A subsample of 102 of the pre-inventory plots was chosen for destructive sampling for the development of volume equations. The first tree in each diameter class per targeted species was selected to cut. The volume of stems to a 10 cm top diameter limit was determined by cutting the tree into sections and using Smalian's formula and summing the sections. For branches or stems less than 10 cm, they were cut into 1-meter lengths and tied into fagots. One fagot was chosen at random to immerse in water to determine the displaced volume, from which the specific gravity was calculated and applied to the rest of the weighed fagots. The Smalian's and the weight-based volumes were added together to produce the total volume of above ground biomass for each tree.

One- and two- parameter models (dbh and total height) were fitted to the data to produce several predictive functions of volume, and that with the best fit was retained for the SIEF. A total of 439 stems covering 14 species were measured using these procedures (Diop, 2002). Since only one or 2 stems of *Combretum nigricans* were cut, it was combined with *Combretum glutinosum*. In the end, 13 valid volume equations were produced. They are incorporated into the SIEF so that when inventory field data are entered OR when specific plots are chosen, the volume estimates per hectare are automatically calculated along with the basal area and stems per hectare.

Establishment of permanent growth plots and research parcels

PROGEDE established 57 permanent plots throughout Senegal in different ecogeographical zones. Some of these plots (around 20) are in areas of intervention of interest to PROGEDE and Wula Nafa. The permanent plots are arranged in clusters of 4 subplots separated by 1km (see Figure 6). The standing living and dead wood and stumps were first measured in 2004. The more dense the vegetation, the more concentrated the clusters were.

The subplot centers were marked with cement markers and metal rods so they could be relocated with a metal detector and GPS.

The permanent plot protocol was set up in 2002 with the cooperation of the Centre National de Recherches Forestières (CNRF) and the Centre de Suivi Ecologique (CSE). Plots that were measured were incorporated into the SIEF.

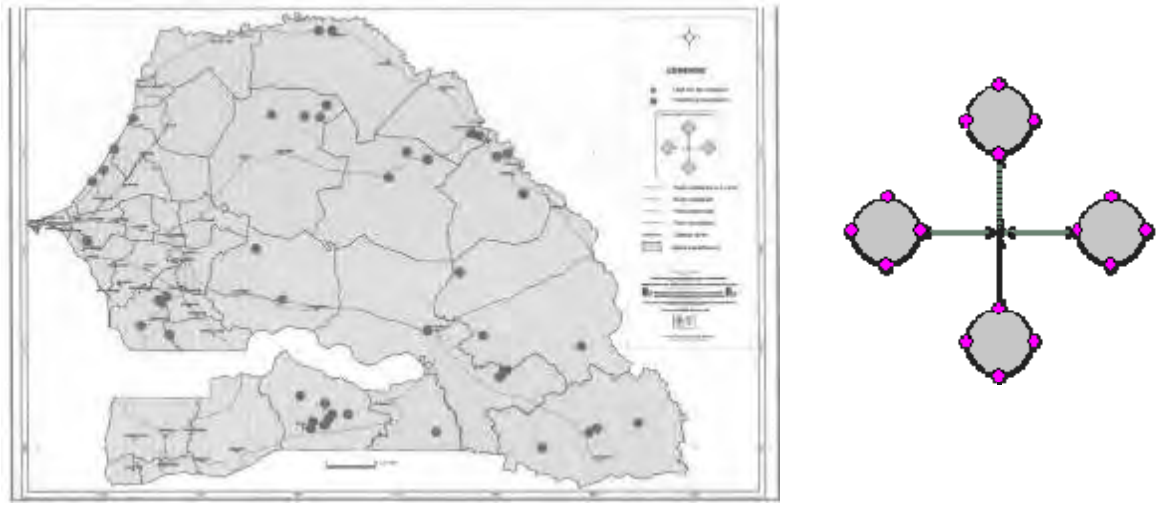


Figure 6: PROGEDE Permanent/Growth Plots: map and layout of 4 subplots separated by 1 km

There are also four fenced research-oriented parcels 20m x 40m set up within the charcoal producing areas in the vicinity of Tambacounda. A France-based researcher was to oversee the cutting of all stems within the parcels and all stems in a paired plot with no fence, and compare the rate of regeneration between the two cut areas. Although Wula Nafaa is not directly involved in these plots yet, it could take advantage of the setup (see recommendations).

The method of incorporating SIEF data into PAFs

The SIEF program is well accepted within Wula Nafaa and the Senegalese Forest Service. It has become essential to completing forest management plans (PAFs) since, by law, the management plans must include information on the volume of wood that can be cut each year on a sustainable basis. The volume to be cut is determined by a combination of measuring field plots, analyzing the data in the SIEF, and interfacing SIEF output with ArcView GIS.

The steps used to get SIEF output into the PAF can be summarized as follows (from the manual used by Canadian International Development Agency's PAEFK project in Kolda):

- Yangambi strata within a selected forest area are synthesized into a "Série de Production" map; using overlaid or borrowed plot data, total forest values are calculated from averages per hectare.
- On the forest map, a fine grid composed of one hectare squares is created and intersected with the vegetation map containing the five Yangambi classes. (According to the manual, this step is the most complex and the heaviest.)
- Each hectare square is assigned a volume that is the sum of (the average volume for each Yangambi stratum as calculated from all plots selected) X (the area of the square in each stratum) (This step requires multiple interactions with the GIS).
- A management block of volume (total forest WOOD VOLUME) divided by (number of blocks foreseen) is defined. The block is created on the computer screen by adding or subtracting hectare squares with their associated individual volumes, until all the blocks have an equal number of cubic meters.
- Each block is further divided into 8 parcels; one parcel a year is assigned to villages in charge of the block for harvest of wood for charcoal production. The parcel boundaries are formed in the

same way as the blocks: clicking on hectare squares until they add up to one-eighth the volume contained in the block.

The following box further expands the subtasks involved.

STEPS FOR THE INCORPORATION OF SIEF DATA INTO THE PAF

1. CREATE THE NECESSARY DIRECTORIES AND SUBDIRECTORIES
2. CREATE A NEW PROJECT IN ARCVIEW
3. GET DATA FROM EXISTING THEMES: Forest boundaries, Roads, Hydrology, Villages, Inventory plot locations, Occup Sol, Mares; Clip all to one forest boundary and make a map
4. MAKE THE 3 SERIES OUT OF THE BASE MAPS: Agriculture (from OccupSol); Protection (Mares + Hydrol with buffers); Production (ForetClaire + Savanes Arbustive/Arborée/Boisée + jachères)
5. ANALYZE, SUMMARIZE AREA AND LENGTH DATA FROM SERIES MAPS
6. DISPLAY VARIOUS INVENTORY PLOT CHARACTERISTICS THAT DESCRIBE THE TERRAIN
7. MAKE A 1-HECTARE GRID FOR THE BLOCK AND PARCEL CALCULATIONS
8. DRAW OUT DATA ON YOUR FOREST FROM THE SIEF AND SAVE OR WRITE DOWN THE DATA TO ADD TO ACCESS: Stems/Basal area/volume per hectare living and dead; no. of plots; Total for forest and for utilization type especially Bois d'énergie
9. SYNTHESIZE AND INCORPORATE DATA BY STRATUM INTO FOREST POLYGON TABLES (for later estimation of stems, basal area, and volume in the forest, the blocks, and the parcels)
10. EXTRACT AND GROUP DATA FROM FOREST POLYGON TABLES FOR THE FOREST, FOR EACH STRATUM
11. DO CROSS-ANALYSES IN ACCESS TO GET STEMS/BASAL AREA/VOLUME BY DIAMETER CLASS AND BY STRATUM -- PER HECTARE, PER UTILIZATION
12. CREATE BLOCKS WITHIN FOREST BOUNDARY BY CLICKING 1-HA SQUARES AND APPLYING THE AVERAGE "SERIE PRODUCTION" VOLUME TO EACH (based on one criterion: total of forest volume of bois d'énergie divided by the number of blocks)
13. CONSTRUCT PARCELS SIMILARLY BASED ON BOIS D'ENERGIE VOLUME IN EACH BLOCK DIVIDED BY NUMBER OF PARCELS (=8 in Tamba; =12 in Kolda); MAP THE SEQUENCE OF EXPLOITATION WITH COLORFUL POLYGONS (Criterion: no parcel is connected to another being worked in the same year)

An important recommended change to this process is to draw block and parcel boundaries together with community members rather than computerizing the entire process (see below). Then the average volumes per hectare can be simply applied to the number of hectares in each stratum as with the more complex grid-creation method.

Appendix B contains a more detailed description from the PAEFK manual of how the tables from SIEF output are prepared and placed in the management plan. Alternative block-and parcel-drawing procedure is given in more detail there.

RECOMMENDED MODIFICATIONS TO THE INVENTORY AND MAPPING SYSTEM FOR THE PAFs

Making proper use of the SIEF software

All the volume estimations for PAFS written with the Wula Nafaa project have been accomplished using the original SIEF-1 program with its approximately 1,280 plots. As written and designed, it produces unbiased results for any one delimited forest that it was designed to sample. It will also produce unbiased results for combinations of forests that were sampled with the same sampling intensity. It will produce *biased* results when combining forests with two different sampling intensities. This is due to the program's inability to add another level of stratification based on sampling intensity.

The effect of having a biased result is the improper assignment of the contribution of a given sample plot to the calculated average, and there is no way to know if the bias is in the direction of overestimation or underestimation. Thus it may take some years to detect that over- or under-harvesting is taking place. But overall, SIEF-1 works well for its intended use with the above caveat.

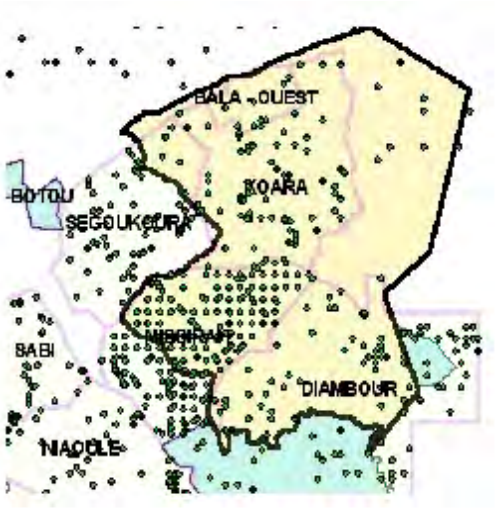


Figure 7: Kothiary Rural Community (thick line) contains both densely-sampled Missirah ZPC and lightly-sampled classified and community forests

An example of likely bias in reported results due to differing sample intensity is shown in Figure 7. The differences in sampling intensity within Kothiary Rural Community (CR) are due to the inclusion of part of the legally-recognized Missirah Zone de Production Contrôlée, the Forêt Classée of Bala-Ouest, and an area with no label in the northeast corner of the rural community, all having gone through different plot selection. Some of the plots are part of the national inventory and are not present in the original SIEF database (SIEF-1). Other plots are part of the Tamba-Kolda inventory, and others may have been added as part of an intensification policy in forests of interest.

Only if all of the 5 key Yangambi forest strata in a rural community are wholly included in its boundary, each with its own uniform sampling intensity, will the results be unbiased. The results for rural communities with a mixture of sampling intensity will be biased towards the conditions found in areas that are heavily sampled. The magnitude of the current bias cannot be ascertained.

The same principle will apply to any forest area's reported volume per hectare: plots within each given stratum should have their own sampling intensity and their own error (variance and confidence interval) calculations; and the combined stratum polygons that make up the forest would each contribute an appropriate weight to the average and the error.

In sum, the SIEF-2 program ignores how plots are distributed on the map and can produce biased results of unknown magnitude if the user requests average volumes per hectare in areas containing different sampling intensities. The good news is that this problem can be rectified with changes to the program and does not require new field information. There need to be provisions for differences in sampling intensity by using references to hectares represented by each plot. Some of this information is already available within the database; other information can easily be derived using the GIS interface.

Applying these needed changes to the program would be part of a larger issue involving the role of PROGEDE and that project's relationship with other projects that are involved with writing PAFs for/with the Senegalese Forest Service. Corrections to SIEF-2 should be a high priority for PROGEDE since the program is providing critical information for land management plans.

Using the SIEF in new forests or in plantations

NEW FORESTS: It is possible to enter additional plot data into the SIEF-1 database, but before this is attempted, there are two aspects that should be observed.

> 1) The database is a series of tables that are accessed by visual basic macros embedded within the database. It is recommended that PROGEDE staff assist, at least initially, someone from the Wula Nafaa project or that PROGEDE assigns someone from their staff to work on Wula Nafaa projects when needed, so that the addition of new plot data and its analysis can be done correctly.
>
> 2) Entering additional plots may change the sample design of the target area. **The sample design with the additional plots should be fully understood and the ability of the program to accommodate any design changes should be reviewed prior to collecting additional field data.** Such a review needs to be carried out by persons with sufficient statistical background to avoid building on faulty bases.

Based on the above information, it is recommended that the Wula Nafaa project continue to use the original SIEF-1 program with the help of someone in PRODEGE that completely understands the database, until members of the Senegalese Forest Service are sufficiently trained in its use. SIEF-2 may be useful in the future for writing PAFs once its mission and the sampling intensity issues are resolved.

PLANTATIONS: There are some plantations containing *Khaya, Gmelina,* teak (*Tectonis grandifolia*), and other species, especially in the regions of western Kolda and Ziguinchor. Since these plantations are typically more dense and uniform than the Yangambi class-based forests discussed until now, a different system of inventory may be more efficient when sampling these forests, for example, if they are large enough to become a community forest. The first requirement would be to map these plantations from photography (if the maps don't already exist), then make decisions on the appropriate sample design. This needs to be accomplished together with Centre de Suivi Ecologique and the regional Senegalese Forest Service offices, as well as with any other forestry projects intervening in the regions.

Potential changes to plot design

In the context of using the SIEF in natural forests in the rainfall zones already covered, the nested plot design appears to be an efficient design with the right balance of subplot size and diameter range. The only subplot size that may need to be reviewed is the regeneration plots. If natural regeneration from seed is a concern for the Wula Nafaa project, a review of the data should be made to determine if a larger subplot sizes are warranted for management purposes.

If forest types inventoried in new areas differ much from what is managed now, *i.e.*, if they become more sawtimber-oriented or if they are plantations, a smaller, more intense plot design or a prism/relascope sample may be more appropriate. In order to recommend a plot configuration, it will be necessary to see the hectare size and the variability of the composition of the forests in question, with the assistance of aerial or satellite imagery interpreters from CSE.

Include traditional volume units in the PAF

The SIEF programs report outputs in terms of basal area, number of stems per hectare, and cubic volume per hectare. While these attributes should be retained, these units of measure are not very meaningful to villagers. The program should have the option of displaying the results in terms of sacks of charcoal or quintaux, the units of measure familiar to the villagers, using the appropriate conversion factors (see chapter on factors under charcoal below). The current practice is to convert by hand for use in the PAF, which is another opportunity for the introduction of human error.

SIEF-1 and -2 both display sample errors for basal area, number of stems, and cubic volume for the total population of trees on the plots selected, but the output should include sample errors in all of the strata's output tables separately. A common method is to produce the standard deviations within parentheses as a second output line immediately below the estimate of the mean or total population. This would give the user some sense of the variability inherent in the data and the confidence with which one can harvest the estimated product.

Include SIEF nontimber product species outputs in the PAF

The program should expand output tables to include non-wood products. The SIEF-2 already includes some non-wood product options which are inoperable due to the lack of data. These should be expanded, in cooperation with their clients such as Wula Nafaa, and have the outputs in terms of units that are used in the marketplace. Examples of the SIEF output for selected nontimber product trees are in Appendix A.

Include SIEF regeneration outputs in the PAF

The legal requirement for volume information is linked to the status of regeneration in the forest. Therefore, in order to better orient activities in the workplan, the PAF should contain SIEF-generated reports of the amount of regeneration found on plots during the inventories. There are data from hundreds of regeneration subplots available, so it should be possible to provide a thorough analysis to include in the management plans (PAFs). An automated process for generating useful regeneration tables for different Yangambi classes would be simple to build into the SIEF.

Assess and adjust volume equations

Adequacy of current models: The selection of pre-inventory plots on which trees were cut for volume equation development was clustered in several areas. While it would have been preferred to not cluster these plots, the clustered areas are distributed fairly well across the intended area and probably adequate when using the two parameter models in the SIEF. There are some three parameter models that attempt to adjust for difference in the form of a tree with the same diameter and height, but such refinement, if possible in hardwoods, is not warranted.

Systematic overestimate of volumes: The current volume equations were constructed to estimate the total biomass above ground and not just the merchantable portion of the stem for charcoal production. While it is valuable to have above-ground biomass equations, using these equations for charcoal production will overestimate the quantity of wood available to harvest. The above-ground biomass equations were derived from two components, the woody portion of the stem that is used for charcoal and the remaining small branches. Fortunately both pieces of information appear to be available for all of the trees used to construct the biomass equations. A preliminary estimation of the unusable proportion of volume in the overestimate is about one-third for fuel wood and one-fifth for saw timber. Calculations showing the overestimate are in Appendix C.

Extension into new areas or species: If the Wula Nafaa project extends to ecologically different areas, particularly to the west of Kolda, then additional tree data should be collected to validate or revise the existing models. Also, if other species in these areas are important to management, then volume equations should be assigned to these other species by using one of the alternatives listed below. The entire list of species treated in the SIEF is in Appendix E.

- EXISTING BOIS D'OEUVRE EQUATIONS: Data should be updated/validated for the SIEF regression equations for *Bombax, Cordyla, Erythrophleum g, Lannea acida, Prosopis africana, Pterocarpus erinaceus*
- MISSING BOIS D'OEUVRE EQUATIONS: Data should be collected for new species important to management that are not yet modeled in SIEF, especially *Afzelia, Antiaris, Ceiba, Chlorophora, Khaya, Sapium, Swartzia,* and teak.

For each species of interest to WN, the following alternatives are available to construct volume equations:

1. USE DATA FROM THE AREA OF INTEREST:
   - If there is already an existing volume equation for this species but the data come from outside of the area of interest, visit active logging operations within the area of interest. Work with sawyers to record the basic dimensions of the tree and record its yield to validate the equation. The visited logging operations should be well distributed across the area of interest and not clumped in one portion of the intended area of use.

- If there are no logging operations in the area of interest, fell trees and record measurements for volume calculations within the area of interest.
- If there are logging operations in only a portion of the area of interest, collect information from those where it is available and complement with either felling or non-destructive sampling of standing trees.

2. OBTAIN A NON-DESTRUCTIVE SAMPLE: Non-destructive sampling can be accomplished by measuring a subset of the trees on PROGEDE or WN plots. Use a Barr & Stroud dendrometer or similarly accurate instrument that can take upper stem measurements of standing trees (non-destructive sampling).
3. BORROW FROM ANOTHER SPECIES: If there is an existing volume equation from another species with a similar growth form, validate it by following the procedure in Step 1 above.

Development of a future Wula Nafaa – PROGEDE Relationship

PARTICIPATION IN THE NATIONAL INVENTORY: From a broad perspective, Wula Nafaa should support the maintenance of PROGEDE as leader of the national inventory program. PROGEDE has most of the elements to perform this service and is willing to play this role. However, with this role come additional responsibilities that PROGEDE should embrace and that Wula Nafaa, through the Senegalese Forest Service, should promote. PROGEDE should have a charter clearly stating its role in the national inventory program. The charter should include the service-oriented nature of the unit.

The objective of PROGEDE to estimate the cubic volume of the major charcoal species was achieved by a simple but very effective sample design for the Tamba-Kolda area. Now the objective of the unit is changing to a supporting role for the all of the Forest Service and projects such as Wula Nafaa. This changing role requires a different strategy that grapples with the question as to whether previously installed plots are a one time phenomenon or part of a monitoring system where some of these plots will be re-measured.

There were different objectives for each of the three types of inventory plots within the SIEF-2 database: pre-national inventory plots to calculate variability; Tamba-Kolda inventory plots to estimate fuelwood in selected forests; and national inventory plots to estimate ecological characteristics and wood volumes at the same time. Projects such as Wula Nafaa simply need a volume estimate to satisfy legal requirements for their community-based management plans. It is tempting to use the SIEF "off-the shelf" to obtain the volume estimate; complex software and supporting research were used to develop it so its credibility is high. However, its current limitations should be understood by those who want to sustainably manage forests. This is an opportune time to carefully set up the SIEF for future use at the forest level as well as the national level. For this reason, it is worthwhile for WN and other forest management projects to support the continual improvement of PROGEDE's SIEF system.

SIEF AT THE NATIONAL VERSUS THE FOREST LEVEL: An example of WN assistance to PROGEDE that will be valuable to Senegal is supporting the remeasurement of permanent growth plots established in Senegal's eco-geographical zones. If, at a minimum, WN supports the remeasurement of Tamba-Kolda permanent growth plots, even though they also fall within a national monitoring framework, then the need for more growth data to support rotation ages at the forest level would be fulfilled, while contributing to the improvement of the SIEF.

An example of the confusion between national- and forest-level data needs is the stratification of the existing 2,900 plots by the Yangambi system (as in SIEF-1) versus their classification by the more generalized satellite system (as in SIEF-2). The satellite classification system was added at a later date to track ecological trends by taking advantage of the repeatability of satellite coverage. There is no doubt that this satellite stratification, which is based on density and size of trees, is an efficient design for estimates of current volume. But potential problems arise when an efficient design such as this, made for current wood volume, transitions into a national ecological monitoring program, where the objective is to track trends over time. By requesting targeted area-based information, projects such as WN can support those aspects of PROGEDE that lead to improvements in the forest-level components of the SIEF.

CONSIDERATIONS FOR FUTURE INVENTORY: In the coming years, it would be natural to avail a fresh set of photography or satellite imagery. If these were to be stratified into the same classes as

before, these strata will be different from the past due to changes in land uses, growth, photo interpreters, or technological advances. Should the re-measurement be on the original stratification or should the plots be re-stratified? A rule in sampling is that the original sample design must always be taken into account. Estimates using a new stratification scheme and ignoring the original sample design will be biased (Schreuder and Alegria 1995). It is possible to re-stratify, and properly take into account the original sample design, but this is another level of complexity that should be made with full understanding of the maintenance involved.

Finally, PROGEDE developed relationships with many external parties including the Direction des Travaux Géographiques et Cartographiques (DTGC), CSE, CNRF, and ISE, as well as Universities of Freiburg, Munich, and Gembloux. Relationships with all these organizations, as well as with CIRAD the French agronomic research institute and the US Forest Service, should be supported by WN.

ADDITIONAL RECOMMENDATIONS FOR MAKING THE INVENTORY PROCESS MORE PARTICIPATORY

Among the SIEF's original intentions was to estimate fuelwood volumes available for urban centers. Knowing the quantity of wood available in the charcoal-producing areas of Senegal is required for the Senegalese Forest Service to carry out the "Schema Directeur".

The Schema Directeur seeks to provide a stable and uninterrupted supply of energy-wood while using the profits from this market to alleviate poverty. Figure 8 is a map of potential fuelwood from inventoried parts of the country that figure into the Schema Directeur.

In this report, we are talking about adapting this estimation system to the community-based management focus of Wula Nafaa.

In order to achieve a more community-based or participatory orientation of the SIEF, we make the following recommendations.

Plotwork with communities

- For dead wood: with villagers' help, measure the volumes of wood in a sample of charettes. Then, rather than measure all the dead wood on the plot, have village members indicate how many charettes or bundles of wood are in dead standing or fallen trees on the plot. Modify the SIEF slightly to produce output dead wood volumes in terms of charettes.
- Define tasks of field team members to include forest users' (villagers') feedback on tree uses, products, and condition as well as actual measurement; but keep the team small. It is possible to program SIEF to include a few generic fields that would accommodate these special uses. Of course, clear protocols must be developed prior to collecting the data.
- Reduce the number of variables recorded (how likely is it that Erosion, Distance to road, or Distance to Water will be used, for example?). For variables that may be retained, such as degree of vegetation cover and soil texture, their usefulness should be explained to participating communities and they should be allowed to collect the data as much as it is possible; then the resulting maps should be included in the PAF.

Figure 8. Potential fuelwood yields from parts of Senegal inventoried under the SIEF and used in the Schema Directeur

- It may not be necessary to count all stems below a threshold diameter or height on the regen plots; the regeneration data collection could be

reviewed. One proposal is that the regeneration plots will only group tally, by species, stems up to 3 cm in diameter at dbh. Changing this protocol should depend partly on what the rules are for achieving forest certification by the FSC standard, should WN or Senegal ever strive for this in the future.

- Include sawyers on the team who can estimate volume in a tree to avoid destructive sampling. Use an accurate dendrometer to verify such work, at least in the beginning.
- Include village workers in research as important team members; explain what is being measured and report back results.

Software output in local units

- Incorporate additional output tables that display units understood and used by charcoal workers, sawyers, and management committees
- Have local species names as options in output tables
- Add automatic report-producing modules to existing software as needed
- Incorporate quantitative regeneration data from the many plots measured into the PAF
- Incorporate quantitative non-timber product information in the PAF
- Explain the charcoal volume, regeneration, and non-timber product output to village members involved in the forest, including what the error estimate implies, during the PAF restitution

Forest division into blocks and parcels

- Draw block and parcel boundaries directly on a paper map or photo of the forest while sitting at a table with representatives from around the forest, rather than clicking on squares that are independent of forest features (see STEPS FOR THE INCORPORATION OF SIEF DATA and Appendix B).
- Include land uses just outside the boundaries on the map so the sense of place is more inclusive.
- Resolve the issue of what to do with lands classed as “agricultural” by the Yangambi system that are inside forest boundaries; explain to villagers that “jachères” (fallows) are considered part of the “productive forest” included in the charcoal production areas.

Senegalese Forest Service participation

- “Participatory” includes the Senegalese Forest Service. Support for their training in the use of the SIEF should be continued and monitored by WN. The SIEF in its corrected format should be kept as user-friendly and as foolproof as possible with the Forest Service in mind as some of the “users”.

CHARCOAL - RELATED QUESTIONS

VALIDATION OF THE LENGTH OF CUTTING CYCLE /REGENERATION TIME FOR CHARCOAL SPECIES

The cutting protocol currently in use

The cutting protocol in practice allows for cutting stems that are between 10-25 cm in diameter. Stems less than 10 or greater than 25 are left standing. Also, for the sake of cutting conservatively and because of a lack of research on regeneration time and quality, producers have instructions to cut only one-half of the stems within this diameter range, and some species of trees are not to be cut regardless of their diameter. So if there are single-stemmed trees, the cutters are to cut one and leave the other. In multiple-stemmed trees with more than one stem between 10-25cm in diameter, the cutter will cut one and leave the other if the tree has two stems; cut two and leave one if the tree has three stems; etc.. The parcel is then left to regenerate for the next 8 years without cutting.

If the protocol is followed, the percent of the basal area or volume removed depends on the diameter distribution of the stand. Clearly, in stands with relatively few stems in the 10-25 cm range, the cutting acts as a light thinning. As the distribution shifts towards the larger stems, the proportion of wood removed will increase, but only to a point; then it will decrease as a significant amount of wood is left in large stems greater than 25 cm.

This protocol does not lend itself to the term 'rotation age'. The key question is the rate of growth of the charcoal species and what are the criteria in determining when cutting should begin. Since the cutting prescription is light, the criteria should be based on economics. How long does it take for the amount of harvestable stems to reach a point where it is economically feasible to thin again? At the moment the criterion is size (10-25 cm) and the interval is every 8 years. The eight years is based on only one study in 1988 by Arbonnier and Faye in the classified forest of Koumpentoum, which simply stated that the maximum regrowth occurred within 8 years after cutting a stand in this rainfall zone.

We found one study on the density or energy value of wood that grows back from stumps: the proportion of bark to commercial wood increases in younger stems, so the shorter rotation would produce less dense wood with less energy value, although it is **volume** rather than weight which determines forest taxes.

We don't know how the charcoal diameter range used in the forestry rules was defined. Surely there is a minimum diameter below which woodcutters would find it not cost-effective to cut.

A proposal to adjust the cutting protocol

It is not clear if this protocol would be or even should be applied **in stands with significant amounts of wood in the 25 plus cm range.** After eight years, the same protocol will be applied again, so that not only will there be even more wood tied up in large stems, but some of the stems left after the first round of cutting may have grown past the 25 cm mark and will be left until they die from other causes. Thus in a stand of many larger-diameter stems, this protocol will change the composition of the forest by favoring protected trees and increasing the amount of wood left standing even in the species allowed to be cut. Every piece of land has a maximum biological capacity in terms of biomass; thus as the stems that are off-limits to cutting increases, the amount available to cut will decrease.

To prevent an eventual shortage of legally-available stems in forests with a diameter distribution favoring stems 25cm and greater, Wula Nafaa could propose changing the cutting rules to allow cutting stems over 25cm. First the diameter distribution should be evaluated by eye in the field, or by graphing the SIEF data. Divide the entire range of diameters into very few, maybe only two sub-ranges to apply rules specific to each one. For example, for every stem cut greater than 25 cm leave one. Continue to apply the current rule for trees between 10-25 cm in diameter. There could be a different prescription applied for each diameter range.

Regeneration time and cutting protocols found in the literature

These are some estimates of the productivity of the sahelian zone found in the literature (Appendix D):

Productivity per area

"If protected for 5 yrs after clearcutting, productivity = 0.6 to 3 m3/ha/yr" (1)

Devineau (1997) used repeated meas. to estimate increment at 0.7 m3/ha/yr (mature savanna) and 0.3 m3/ha/yr (12-yr fallow) (1)

Cameroun regrowth @ 800mm rainfall = 0.5 m3/ha/yr, 3 yrs after clearcut. (1)

Botswana regrowth @ <1000mm rainfall on sandy soil = 0.9 m3/ha/yr (1)

Burkina regrowth @ 1000mm rainfall = 0.7 m3/ha/yr in mature savanna

Guinea regrowth @ 1300mm rainfall = 1.3 m3/ha/yr in savane arbust; 2.3 m3 in savane boisée (1)

"Exploitable" =15 stères/ha green + 3st/ha dead *(Combretum micranthum, C. nigricans, Guiera senegalensis)- Maradi and Dosso(2)*

11.3 m3/ha/year all species mixed (Kaolack) (3)
= 2640 kg/ha/yr
= 290 kg charcoal/ha/yr
= 3 quintaux/ha/yr

6 years of cultivation leads to 50% density loss and 14 years leads up to 80% loss. (6)

Total production of 1 million quintaux in Senegal in1994, and of 1,500,000 in 1988 and 1993. (7)

Productivity along Dakar-Bamako rail corridor in **m3**/ha/yr = .051 + 1.082(rainfall in meters)^2 (8, pg. 11)

500mm yields 0.3 m3/ha/yr; 800mm yields 0.7m3/ha/yr (8)

Protected: increase by 25%; Degraded: decrease by 25% (8)

Regeneration info; rotation age

"Short" (<20-yrs) coppice cut rotation recommended in Abbot and Lowore, 1999; Bellefontaine/Gaston/Petrucci 1997; Jensen 1995; Catinot 1994. Short rotation means a different proportion of bark and branchwood than older trees. This affects density although volume is the variable that is taxed and that is predicted in equations. Thus dry mass=more appropriate for evaluation of growth and fuelwood value. (Burkina Faso 620-785 mm rainfall) (1)

"If Burkina Faso Forest Service applied the same cutting criteria for firewood trees as was used in 1982, a rotation period of more than 30 years would be required for regrowth to the same volume.

(Based on 29 to 70 m3/ha that were removed during clearcutting in 1982) -- i.e. woody Dry Mass in mature stand would be less than reported in other studies in same rainfall conditions.

Coefficients of variation compared between current study 2004 and the CV for harvested wood in 1982 are comparable (11 to 29% range for both).

"Longer rotation periods may produce a larger proportion of commercial fuelwood and this option should therefore be investigated." (Burkina Faso 620-785 mm rainfall) (pg 84) (1)

Annual cut allows 69% to 80% of the annual growth (2)

Protocol = >6cm diam "taillis fureté" or selective removal of sprouts *(Combretum micranthum, C. nigricans, Guiera senegalensis)- Maradi and Dosso(2)*

For low-cost regeneration, cut into the roots at moment of high nutrient reserves for Combretums and many other sahelian species (= drageonnage) (4)

Combretum/ Anogeissus forests as "pseudo-climax" remain in spite of decreasing rainfall and degradation because of ability of stumps to regenerate since 1950s (pg. 25) (5)

The quota system directs woodcutters to specific Regions by limiting quotas from each. (7)

Note: A cutting permit has an expiration date, but once it is granted, an extension can be obtained so that cutting can continue past the original date.

TABLE SOURCES

(1) Nygard, R., L. Sawadogo, and B. Elfving. 2004. Wood-fuel yields in short-rotation coppice growth in the north Sudan savanna in Burkina Faso. *Forest Ecology and Management* 189 77-85. Elsevier B.V.

(2) (c. 2003?) n.a. Résumé du Plan d'Aménagement forestier du massif de Baban Rafi Sud (Département de Madarounfa) 3 pages -- internet site

(3) Visites de terrain a. Kaolack 2005 b. Missirah 2006 c. *Tamba- Koulor -Nétéboulou 2007*

(4) Bellefontaine, R, E. Nicolini, S. Petit. 1999. Réduction de l'érosion par l'exploitation de l'aptitude à drageonner de certains ligneux des zones tropicales sèches. Bulletin Réseau Erosion (IRD-Montpellier et CTA-Wageningen), no. 19, p. 342-352

(5) Ba, M., A. Toure, and A. Reenberg. Mapping land use dynamics in Senegal. Case studies from Kaffrine Departments. Working paper 45.2004 for Sahel-Sudan Environmental Research Initiative, Institute of Geography, Copenhagen. 33 pages

(6) Faye, E., D. Masse, and M. Diatta. 2002. Dynamique de la régénération ligneuse durant la phase de culture dans un système de culture semi-permanente du Sud du Sénégal. In Savanes africaines: des espaces en mutation, des acteurs face à de nouveaux défis. Actes du colloque, mai 2002. Marouna, Cameroun. 30 pages.

(7) FAO Documents 1 and 5 on Consommation en Charbon de Bois au Senegal: Dept des Forêts Rapport d'étude sur les Données du Bois-Energie au Sénégal", and "Etude sur les Ressources Forestières et les plantations Forestières au Sénégal".

(8) Clément, J. 1982. Estimation des volumes et de la productivité des formations mixtes forestières et graminéennes tropicales. B.F.T., No. 198, in CTFT Mémento Forestier page 507.

The above references point to typical growth of 0.4 to 0.7 m3 per hectare per year in sahelian rainfall zones. Clément's (1982) study includes data from Senegal but used a conservative conversion of stères to m3 of 0.4. Re-applying the currently-used 0.65m3/stère, the data showed that the 600-700mm zone produced 0.4 to 0.6 stères per hectare in unprotected cut areas separated by 20 years. Using the value of 0.5m3/ha/yr, if a parcel is clearcut and yields 10 m3 per hectare (or 15 stères or 25 quintaux/ha), then it would take 20 years to grow back to the same volume.

If the parcel is only partially cut and yields 5 m3 per hectare (or 12 quintaux/ha), then it would take 10 years to regrow the removed volume**. This illustrates why we should want to know how much wood or charcoal is coming off each hectare, and why we should compare that with what is written in the PAF.**

RECOMMENDATIONS FOR DETERMINING GROWTH RATES

There may a lack of definite information to make an informed decision on the cutting cycle, but there are opportunities to gather information on growth from cuts of known ages.

Permanent plot remeasurement

PROGEDE established a series of permanent plots that in 2004. (See Figure 6.) They are scheduled to be re-measured in 2007. The number of plots in any ecogeographical zone is not large, and should be augmented, but the data should be available this year if PROGEDE follows through were their plan.

Re-visiting previously cut areas

There are areas in Tamba and Kolda where cutting occurred in known years. These should be re-visited for two reasons: quick information and the potential for tree-ring data.

In areas where the year of cutting is known, re-measuring plots can be a quick way to gather information on the re-growth of the charcoal producing species. Ideally, the cut areas would be areas of known age spanning up to 10 years. During this trip, we were only able to visit an area that was cut two years ago, but we were told that areas up to 10 years are known to exist. While these cutting areas are 'opportunistic', meaning that they probably are not distributed according to a well thought out plan, they would give the Wula Nafaa project some indication as to whether to continue or alter their current cutting strategy.

Counting tree rings

Re-cutting and then examining stumps in a previously-cut area could verify that counting tree rings is accurate for aging trees for charcoal species in the Tamba-Kolda regions. The Mémento Forestier (Centre Technique Forestier Tropical, France 1990 p. 92) states that growth rings are visible on some species of trees in the tropics. Alegria (1988) found that Combretums in Niger could be aged using tree rings by comparing the number of growth rings with the ages of known stems. Samples cut in Tamba are indicative (Figure 9).

Figure 9. Cut stems of Combretums from a Tamba charcoal producing area show potential for aging by rings

If counting tree rings is found to be an accurate means of aging stems, then the project could cut stems of unknown age and reconstruct diameter growth curves. A standard method is to cut disks along the main stem at a set height interval above the ground, and count the annual rings. Using the diameter of the rings at the base disk, and the number of annual rings along the stem, the past diameter and height of the stem can be reconstructed. A sample of these stems by diameter class and species at each of a number of plots randomly scattered across the ecogeographical area of interest. The plotted diameter and height data would be the basis for estimating the number of years until stems achieve a desired diameter.

Analysis of growth data

Once plots are re-visited and data from re-measured sites are available, the following can be applied.

A simplistic model of growth is:

$$\Delta G = S + I - M - R$$

where ΔG is the change in growth over a unit of time

S is survivor growth. This is growth on a stem that was present and measured at the beginning of the time period and also measured at the end of the time period

I is ingrowth. These stems were too small at the beginning of the time period to be measured but grew across the threshold during the time period and measured.

M is mortality. These stems were live in at the beginning of the time period and measured but died some time before the end of the time period

R is removals or 'cut'. These stems were present, live and measured in the beginning of the time period but were cut before the end of the time period.

There are other minor components not listed such as stems that were live but too small to be measured in the beginning of the time period, grew across the threshold but died before the end of the time period and a similar component for removals.

- Using data from re-measured cut plots of known age will give you ΔG: the first time period would be age zero and the end of the time period would be the age of the stand, but you will not be able to tease out the other components.
- Using data from tree rings only will give you survivor growth and ingrowth.
- Permanent plots will give you all of the components in the formula, but it will take years to fill in all the variables.

Other unanswered questions

There are additional complications and concerns when determining the growth rates of these species even if the annual rings can be discerned. Some of these are:

- Do single stem trees grow at the same rate at coppice stems?
- Do the coppice stems grow at the same rate if all of the stems in the tree are cut as compared to coppice stems within a tree that has uncut stems?

There is also the possibility that the stems that were cut versus the stems that were left may not represent the same population, *i.e.* the stems left (or cut) were somehow different. Only a long-term study using permanent plots would be able to confirm or allay fears of these types of confounding effects.

These questions could be addressed in a carefully constructed study as soon as time and money are available. As before, it may be possible to locating existing cut sites of known ages to look into these issues, but the down side is that it may be difficult to find combinations of single stem trees, trees with all coppice stems, and trees with only some stems cut in the same general vicinity.

VALIDATION OF THE USE OF DIFFERENT VARIABLES BY THE SENEGALESE FOREST SERVICE IN CALCULATIONS FOR CHARCOAL TAX AND QUOTA PURPOSES

Sacks of charcoal in a meule, in a truck, or on a hectare

In a management plan or PAF, there is an estimate of the cubic meters of wood available within a parcel. Wula Nafaa consultants and field facilitators work with the villagers to determine whether the villagers can cut the estimated amount, or whether they should contract part of the cutting to a third party.

The amount of wood that is actually made into charcoal in a season is based on a number of quintaux (100-kg units) allocated to a department by the central Senegalese Forest Service (as in the Schema Directeur depicted in Figure 8). To ensure the total allotted quintaux are produced, the Forest Service delegates the appropriate number of professional migrant charcoal producers ("Sourgas") to the area. All the actors in the charcoal market chain use factors that convert cubic meters of wood to stères, to sacks of charcoal, or to quintaux; 300 is the number of charcoal sacks per truck.

The "Sourga" is assumed to produce **150 quintaux per year.** Outside the community-based PAF areas, the Senegalese Forest Service plans its annual quota production around this factor and stations Sourgas in producing areas according to the volume available, according to our colleagues.

The table below gives an idea of the variability inherent in the constants being used. Double asterisk ** indicates definite discrepancies in conversion factors being used.

CHARCOAL-RELATED CONVERSION FACTORS

Dry wood conversion to m3	**Weight of a stère**	**Stères in a cubic meter**	**Coefficient of empilage (m3/stère)**
▪ 670kg/m3 (1) ▪ 680kg/m3 (1) species weighted basic density ▪ Trunk + branch + stemlets =each 1/3 total Dry Mass (1) ▪ Trunk + its bark = 32-44% of Dry mass (1) ▪ Basic density of Anogeissus, Combretum glutinosum, and C. nigricans = 720-800kg/m3 (1) ▪ 1 tonne dry wood = 4 m3 (2a) ▪ 1 tonne dry wood = 20 sacks (2a)	▪ 1 stère = 215 to 600 kg (twisted branches versus straight wood from thinning) (3) ▪ 1 stère = 130 kg green wood (2a) ▪ 2 stères = 260 kg green (2a) ▪ 8 stères = 1tonne dry wood (2a) ▪ Tonnes/stère = 0.27 (4) ▪ *1 stère = 80 to 130 kg of charcoal (2c)* ▪ Sack of charcoal = "45kg" (4)	▪ 1 m3 = 2 stères (2a) ▪ 1 m3 = 260 kg green (2a) *In 900mm rainfall natural forest:* ▪ stère/m3 = 3.5 (bois 3-6cm) (4) ▪ stère/m3 = 2.2 (bois 7-12cm) (4) ▪ stère/m3 = 1.7 (bois 13cm+) (4) ▪ 1 stère = 0.5m3; 2 stères/m3 (Wula Nafaa)	▪ (if all wood is round, straight, and of same diameter: = pi/4 = 0.785) ▪ 0.45 to 0.8 (5) ▪ .29 to .59 for wood ranging 3cm to 13cm diameter (4) ***** 0.65 m3 = 2.5 sacks (2c)*** **Weight of a cubic meter** Density of wood T/m3 = 0.8 (4) Density of kerosene = 0.79 (4)
Volume in a "camion": *1 camion = 150 quintaux (2c)* *1 camion = 40-50 stères (2c)* *1 camion = 1 meule (2c)* *1 camion = 300 sacks loaded in front of Service Forestier (2c)* *1 camion = 150-170 quintaux* *= 300-350 sacks* *= 1 "meule"* *= 9 "tas" (2c)*	**Volume in a "meule"** ▪ 20m diameter kiln p = 400 sacks (Casamance) (2b) ▪ *13m diameter kiln = 200 sacks (2c)* ▪ *6m radius kiln= 100 quintaux (2c)* ▪ 1 four (meule) of 300 stères green = 2.7 tonnes dry (divide by 11) (2a) *1 meule = 1 camion (2c)* *1 meule = 9 "tas" (2c)*	**Yield of charcoal per kg of wood** 16% (Outchoun 1983) to 30% of weight of raw material (drier wood yield = higher); low avg = 20% (other examples in doc) (3) **Energy yields per meule** (4) : Traditional meule = "18%" Casamance kiln = "30%" 3-stone cooker = "20%"	**QUINTAUX** ▪ ******Quintaux = "100kg" = "2 sacks" (4) ▪ ******Quintaux/Tonne = 11 (4) ▪ *2.5 quintau/m3 (2c)* ▪ *150 quintaux/camion* ▪ 1 quintaux = 100 kg DRY (2a) ▪ 10 quintaux =**1 tonne dry wood** = (2a) ▪ *100 quintaux = 6m radius kiln (2c)* ▪ 150 quintaux=1camion (2c)

TABLE SOURCES

(1) Nygard, R., L. Sawadogo, and B. Elfving. 2004. Wood-fuel yields in short-rotation coppice growth in the north Sudan savanna in Burkina Faso. *Forest Ecology and Management* 189 77-85. Elsevier B.V.

(2) Visites de terrain a. Kaolack 2005 b. Missirah 2006 c. *Tamba- Koulor -Nétéboulou 2007*

(3) Keita, J.D. Undated. Article presenting a comparison of energy balance for fuelwood and for charcoal. 6 pages. See very interesting sections on economics of transport: it is shown that charcoal with a 28% thermal energy equals the price of its transport by old truck at a distance of 1000 km.

(4) FAO Documents 1 and 5 on Consommation en Charbon de Bois au Senegal: Dept des Forêts Rapport d'étude sur les Données du Bois-Energie au Sénégal", and "Etude sur les Ressources Forestières et les plantations Forestières au Sénégal".

(5) C.T.F.T. 1989. Mémento Forestier. Ministère de la Coopération et du Développement, Paris. (Out of print)

Example of conversion factors used with SIEF output and annual quota

The SIEF output gives cubic meters. The annual quota is in quintaux. Let's say that according to the PAF written with the help of SIEF, a parcel has 1,000 cubic meters available.

___ Convert to quintaux: 1,000 m3 x 2.5 quintaux per m3 = **2,500 quintaux**

___Convert to quintaux via stères:

(1,000 m3 x 2 stères/m3 x 130kg wood/stère) /(100kg/quintaux) = **2,600 quintaux**

___Convert to quintaux via coefficient d'empilage and stères:

((1,000m3) / (.65m3/stère)) X ((130kg/stère)/ (100kg/quintaux)) = **2,000 quintaux**

This example shows how the various coefficients used can allow the estimated cubic volume allocated as sustainable cut to turn into various possible true volumes coming out. Bearing in mind that a single quintaux can be worth 10,000 FCFA ($20) on the market, an estimate that is off by 500 quintaux can result in a windfall or a loss to someone of 5,000,000 CFA or $2,000.

Thus, in spite of all the careful measurements on the plots and all the computerized calculations of the inventory data, there is a broken link between the inventory data and the potential profit because the inventory data are converted at the last step.

Example of conversion factors used with PAF and area of production

Remember that the PAF volume tables are supposed to be half of what the SIEF software outputs. This is a manual conversion that has no means of verification because it is a step undescribed in the manual. Then, since half the stems are left to grow during the rotation time of 8 years, one can assume that the "rotation age" of cut stems is really more than 8 and less than 16, with a midpoint of 12 years.

The management plan gives cubic meters. Let's say that according to the PAF, a parcel has 1,000 cubic meters available. How many meules should be built to reach this 1,000 cubic meters, and how many hectares will be required to make this 1,000 cubic meters into charcoal? Let's take the 1,000m3 to be 2,500 quintaux from calculation above.

From the tables describing productivity per hectare, one finds that a typical estimation of productivity based on rainfall gives a value of 0.5 m3/ha/yr. If the ostensible rotation age is 12 years, then each hectare should be producing an allowable cut of (12 X 0.5 =) 6.0 m3 after 12 years.

How many quintaux are in the 6m3? By straight conversion, (6/1000 =) .006 X 2500 quintaux per 1,000 m3 = 15 quintaux. This means that each and every hectare in the parcel is supposed to yield 15 quintaux. If a meule of about 15m in diameter contains 150 quintaux in it (from table above), then you would need to build 10 meules of this same size on the entire parcel.

- Alternatively, you would need to count all the stères that are placed in the meules on the entire parcel, and make sure that they don't go beyond 1,538 stères (=1,000m3 divided by 0.65 coefficient d'empilage).
- Alternatively, you could measure volumes in all the meules constructed in a parcel, and stop when you reach the allowed 1,538 stères (as verified by measuring the cubic volumes measured as below).

Productivity of Casamance kiln versus traditional meule

The Senegalese Forest Service has a legal requirement that all charcoal production in community-managed areas be done in improved kilns or meules. The Casamance kiln is mentioned by name in arrêtés to this effect. In principle, the Casamance kiln when correctly used yields a higher percentage of the wood into charcoal, condenses toxic byproducts from pyrolization into usable liquids, and takes fewer days to produce the charcoal. More formal studies of these claims need to be carried out, since paying for, constructing, and hauling around the welded metal barrels that make up the chimney pose hardships for most subsistence producers, who would prefer to use traditional open-air kilns or meules. Some references that can assist in designing a study comparing the two types are given in the Annex at the end of this report.

Measurement of volume in a meule

The wood cutters that we visited were aware of the need to stack and measure the amount of wood removed in stères. In fact, they had a meter stick and demonstrated the proper procedure for measuring a stère, but admitted that they do not use the system in stères but rather in "tas" (piles): 9 tas make a meule. The specialists hired to build a meule and produce the charcoal rely on their own experience as to how much charcoal will be produced from a meule. A truck is assumed to carry 300 sacks of charcoal, but people acknowledge that additional sacks (up to 50 or more) are often stacked in the truck for a variety of reasons.

It is not known how careful the woodcutters are in keeping track of the number of stères that they cut. If they are diligent about their work, clearly it would be a significant amount of effort to cut the stems into 1 meter lengths, carefully stack them, and then keep accurate records of the number of stères cut.

Figure 10: Close-up of a traditional meule chimney, top view

It appears that the objective is to record the amount of removals from the land and to record the amount of charcoal in sacks or quintaux that the wood produces.

If the relationship between the number of stères and the sacks of charcoal can be established then there would be an option of measuring the number of stères, or just measuring the sacks of charcoal and converting the sacks of charcoal to stères or even back to cubic meters of wood. To test if this is feasible another approach is recommended that only involves measuring the **volume of the meule.** This method requires the use of a laser inclinometer. The steps are:

1. Fasten a stick vertically to the air vent or chimney located at the very top of the meule (Figure 10).
2. Use a tape from the vertical stick and measure out to a set distance on the ground. Slope distance is OK. Mark the same distance in each cardinal direction. Experiment on a distance that would be convenient. Set a tripod at one of these spots.
3. Measure the distance to the meule at regular angles moving up the slope of the meule with the laser inclinometer. Record both the angle and the distance to the base of the meule as well as the distance to each point along the side of the meule (Figure 11).
4. Repeat at each cardinal direction but be sure that the tripod is exactly the same distance from the center stick.

Figure 11: Meule with tripod to measure volume

The more recordings, the finer the volume of the meule will be calculated. Any vertical distance can be extrapolated from the two closest measurements by using a straight line interpolation.

The meule can be sliced into disks which are actually truncated cones. The volume of each truncated cone can be calculated and summed. One thing to consider is whether the center vent does not have the same dimensions through the meule. If it actually is larger at the base and tapers to the top, then this volume needs to be estimated and deducted from the total volume. The necessary formulas and Excel spreadsheet for this research can be provided by USFS if WN decides to take it on.

This procedure will allow a relationship between stacked wood volume and sacks of charcoal to be determined. There will still be a need for establishing other links between meule volume and the forest area in hectares required to produce the meule and the resulting sacks of charcoal, for purposes of verifying compliance with the management plan and validating what the plan said was available to cut.

INVENTORY AND PRODUCTIVITY OF SELECTED NONTIMBER FOREST PRODUCTS

(Note: We decided to drop the bamboo inventory component of the original terms of reference, since it is a product of lower priority and is not yet a market chain being targeted by WN.)

Recommendation for Inventory and estimation of productivity of the Mbepp Gum Tree (Sterculia setigera)

The tree *Sterculia setigera* produces karaya or mbepp gum (Figure 12), an important commodity for export that is used in world-wide in cosmetics, food, and pharmaceutical industries. During the period of 1982 through 2002, Senegal's production has fluctuated from a low of approximately 350,000 kg in 1999 to nearly 2,500,000 kg in 1989 (Johnson et al. 2005). Although much has been written on the production and value of mbepp gum, little has been published on the number of gum trees in the population. At least one study by Mbaye et al. (2005) only covered a 300-hectare area.

Figure 12: Demonstrating gum harvest technique

Fortunately, all the inventories conducted by PROGEDE included the species *Sterculia setigera*. A review of the database shed light on whether the existing plot design would be adequate for estimating the number of trees within a given area (Appendix A Tables 1&2). It appears that within the Tamba-Kolda inventory area, the tree is represented reasonably well: 26% of the plots had at least one tree recorded, and there are approximately three stems in plots where the species was present. These numbers indicate that while the stem density is not high, the density is sufficient to consider only using SIEF's existing plot design. This is a practical decision. A specifically designed inventory would probably result in a larger plot, but the existing inventory already identifies the gum species and records associated attributes such as diameter and height reasonably well. The only attribute that needs more explicit mention is the state of the trees; it would be interesting to see the evaluation of the health by size class, since the future productivity will depend on it. Momar Mbaye performed such an assessment but it has not been used in management planning yet.

This inventory would give the user an average number of stems per hectare. Once the variability of the existing data is calculated, the production per tree (which we were told is on the order of 2.5 kg of gum per tree per year) can be multiplied by the stems present and the annual potential can be inferred. Ideally, the appropriate statistics (confidence interval) indicating the minimum and maximum potential should be worked up at the same time and based on specific target areas.

We recommend that the available inventory data on *Sterculia setigera* be evaluated, and then the need for further information assessed and prioritized as compared to the need for information on other non-wood products.

How to inventory the Baobab and estimate its productivity

Baobab trees have numerous uses. The leaves are an ingredient in sauces, the branches are cut for forage, the strips of bark are used for short rope cords, and the fruit's flesh is edible and even exportable as a condiment and also as cream of tartar. Wula Nafaa is primarily concerned with estimating the quantity of marketable fruit produced so that contracts can be signed with processors and exporters.

We presumed that the diameter (age) distribution of trees is linked with the quantifiable supply of fruit.

A review of the frequency of occurrence of the baobab recorded in the SIEF inventory shows that this species is relatively rare on the landscape (Appendix A Tables 3&4). In addition, it is well known that this tree occurs in clumps or 'parks' (see Figure 13).

Figure 13: Baobab Park

While unbiased estimates of the number of trees within the areas covered by the existing inventories can be calculated, the simple random design, or even a stratified random design with a low correlation of the stratification to the attribute of interest, is an inefficient sampling strategy. Also, it is clear from casual observations of the spatial arrangement of the trees that a plot significantly larger than 20 meters in radius should be used. For areas the size of a classified or community forest, the existing inventories will only provide marginal information for managing this species or for estimating the quantity of fruit. Several sampling strategies will be proposed depending on the availability of aerial photography and the ability to discern baobab trees on the photographs.

If aerial photographs are available

The objective is to test the use of aerial photographs to identify the presence of baobab parks. PROGEDE has 1-meter panchromatic photography for the regions of Tambacounda and Kolda. There are 3- and 9-meter photos also available, but it is important to use the highest resolution photography to assess the validity of this approach. The steps are:

1. Locate and GPS some baobab parks across the area where there are photos. The baobab parks should include ranges of sizes of the parks, diameters of the trees, and land uses. Not all baobab parks should be in agricultural fields. Also, locate and GPS groups of other large tree species that are found scattered in the area.
2. Bring the photo interpreter(s) to these areas with a lap top computer with the aerial photographs so that the photo interpreters can see the trees from the ground and see the trees on the photographs. Discuss the characteristics, if any, that can be used to distinguished the differences between the species.
3. Construct a blind test. GPS and locate on the photos about 6 baobab parks and 6 areas of large non-baobab trees. Give these locations to the photo interpreter(s) and ask them to identify which are baobab parks. Do not identify which of these areas have baobab trees or even say how many baobab parks are in the group. If there is more than one interpreter, be sure that they interpret the photos independently. Assess the results.

If baobab parks can be identified reasonably well on the photography:

It is assumed that the area to be inventoried is within either the Tamba-Kolda or the national inventory sample frame. Henceforth, both inventories will be called 'extensive surveys'. Now divide the landscape into two strata: baobab parks and everything else. The baobab stratum will be described below. The

existing SIEF inventory will be used to sample all areas outside of the baobab parks. The use of the existing inventory allows the estimation of baobab trees that have not been identified on the aerial photos.

Method for identifying the baobab parks: There are over eight hundred 1-meter resolution aerial photographs in the Tambacounda and Kolda regions. Only a sample of them will be interpreted for baobab. The basic steps are:

1. Divide the regions into square blocks by using UTM coordinates in a GIS layer.
2. Intersect the blocks with the aerial photo coverage and determine the portion of the photo that is within the block.
3. Randomly choose a relatively large number of blocks using a simple random sample without replacement.
4. Delineate all probable baobab parks within the chosen block; place blocks with any such parks into a "high" potential stratum and all remaining blocks into a "low" potential stratum.
5. Randomly choose a subset of the photointerpreted blocks using a simple random sample without replacement within the high and low potential strata; visit these blocks and record the baobab trees greater than XX cm in diameter at 1.3 meters above the ground. Sampling can be more intense for the high potential stratum and less in the low potential stratum.
6. For trees less than XX cm, randomly locate points within the parks delineated in step 4, and collect information on smaller trees and regeneration as desired on fixed-radius plots.
7. Count the number of fruits on each tree.

The size of the block to superimpose on photos in the GIS layer can be adjusted by piloting several possible grid sizes, and choosing one that has a reasonable chance of containing a baobab park but that is not so large that it will take a long time to interpret. Some suggested lengths of the sides are 100, 200, 400, and 800 meters; but any size can be used.

Here is a variation on the preceding design for visiting parks delineated on the photos:

It is simpler to adjust the size of the block and visit all of the parks than to sub-sample the parks, but sub-sampling is a legitimate sampling technique. Only some of the baobab parks are assessed on the ground on each photo. The parks to be assessed can be chosen by a number of methods but two methods will be described here.

- Select the baobab park with probability proportionate to the size of the park. Follow the steps described above at each one of the selected parks.
- If an approximate number of baobab trees greater than a certain diameter can be estimated from the photo, then a double sample could be constructed where a relatively large number of photographs are selected, the baobab parks identified and the number of trees estimated. A sub-sample of these parks is selected for ground measurement. This method assumes a linear relationship between the estimated number of trees and the actual number of trees. The advantage of this method is that if the relationship is strong between the estimated and the actual, then the estimate of the variance is reduced or fewer plots need to be recorded in the field. The big disadvantage is that if some of the 'parks' identified on the photos are not baobab, then there will be some positive estimate of baobab trees but zero recorded when the field crew visits the area. At the minimum, this will reduce the advantage of this method and at worst violate the linear relationship, producing biased estimates.

It is possible to measure diameters and count fruit on a sub-sample of the baobab trees and then model the number of fruit on trees by diameter class; but this procedure is not recommended when working with baobab parks. This would add to the complexity of the inventory, while a good estimate on large trees with many fruits is adequate.

One concern is that large trees vary significantly in the number of fruits they produce depending on whether the branches have been cut for forage or food by villagers. This added variability will decrease the effectiveness of modeling the fruit based on diameter, unless other factors are recorded such as classes for the size and health of the crown. But again, these other factors will further complicate the analysis.

The concern over varying fruit productivity will be relaxed when estimating fruit production outside of baobab parks, where no direct measurement of fruits is possible without return visits to the field.

In summary, it is recommended to use a simple survey strategy that relies upon few assumptions, at least for the first couple of forests to be inventoried. With additional information, more complex designs could be assessed for use later.

If there are no photographs of the area , or baobab parks cannot be identified reasonably well on the photography

Implement the first three steps under the heading for photography being available. The size of the blocks should be smaller than 200m since each block will be visited on the ground and the entire block surveyed for baobab trees. If the ground plot has a baobab tree, then sample the neighborhood of the plot using an adaptive sample design as discussed in Thompson and Sebe, 1996.* Do step 6 if information on smaller trees is desired.

*Thompson, Steven K., George A.F. Seber 1996. *Adaptive sampling*. John Wiley & Sons, Inc. New York 265p.

How to inventory Madd fruit vines and estimate productivity

Saba senegalensis is a vine that grows up and over the canopy of trees in search of sunlight and out of reach of herbivores. The fruit, called "madd", ripens from January to June and flowers in the late winter and early Spring (see Figures 14 & 15). Fruit ripens over two seasons. Ripe fruit and flowers may both be present at the same time.

Figure 14: Unripened madd fruit and blossom

Collected fruit is dried and converted into a powder form. The powder is mixed with sugar and produces a sweet, delicious drink that is usually consumed as a dessert.

There is some association between the presence of the madd vine and sufficient moisture. In the drier areas, madd is associated with riparian areas in the Kolda area but in the book *Vegetation et Flore, Parc Transfrontalier Niokolo Badiar* (1997), it states that madd also grows in savanna. This poses problems when developing an efficient inventory strategy. We did observe madd vines on our trip from Kolda to Tambacounda in the dry areas of the country. All the madd sites in savanna were in association with either an obvious source of intermittent water or a termite mound.

Out of the 126,000 records in the SIEF-2 database, there are only 13 records of the madd vine (see Appendix A Tables 5 & 6). This shows that the existing sample and plot design is not well suited for recording this species. There have been special studies for this vine in the past and if the need for this information is great, a special study is the only realistic way to obtain sufficient information to help identify the size of the population.

To design an efficient inventory, it is important to identify the objectives. In this case, we could estimate the amount of fruit that is currently going to an external market, amount of fruit harvested from the vine or the amount of fruit on the vine. These numbers are different and require different approaches. In discussions with Mr. Brook Johnson and Mme Bineta Coly Guèye of the Wula Nafaa project, they are interested in an estimate of the total amount of madd fruit that is grown in an area. With this information, they can estimate the maximum amount that is available for market analysis. Unfortunately, it is very difficult to estimate the total amount of fruit growing on the vines. Below we will discuss the amount of fruit that can be potentially harvested.

Figure 15: Measuring madd vine diameter

The current protocol measures the madd crown width at the longest and shortest diameters within a gallery canopy and takes the average to compute crown area in two dimensions. Stem diameter measurements are also taken, but it is impossible to distinguish between individual lianas once they reach sunlight and intertwine.

The crown measurement seems a reasonable approach to quantify the surface area of the plant when a madd patch is identified. It would be interesting to consider the height of the canopy as well since the volume of the canopy determines its outer surface available to leaves of the vines, and thus to their productivity. Unanswered are the relationship between the crown cover and the measured diameters; the productive capacity of the canopy; and a survey approach to estimate the amount of madd patches in the landscape. If WN wants to find the rapport between habitat characteristics and the amount of fruit produced, we recommend further exploring the volume of the canopy that supports the vines as a potentially highly-correlated variable; perhaps even more highly correlated when used with the diameter measurements.

Assuming that riparian zones or intermittently wet areas can be identified reasonably well on the photography

Areas of intermittent water can often be seen on the aerial photos associated with large trees (see Figure 16). The madd vine itself cannot be identified on the photos but since the presence of large trees are necessary but not sufficient for the madd vine, areas with large trees can act as a means of stratifying the landscape into two strata:

> *Stratum one:* Areas of relatively high probability of locating the madd vine.
>
> *Stratum two:* Areas of low probability of finding the madd vine.

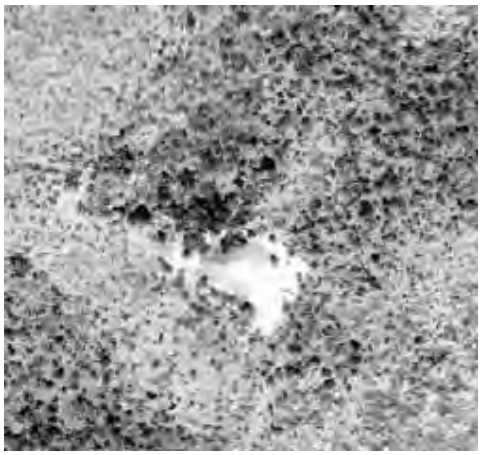


Figure 16: Area of potential madd vine seen on aerial photography

The areas of relatively high probability would include those portions of the valley bottoms where trees are present and not the total valley area. The same procedures for surveying for baobab trees could be used here. In fact, using the same photos selected for baobab would save time and money both in the photo interpretation and especially in the field data collection portion of the survey. Of course, the delineation of the baobab parks and the madd fruit areas must be kept separate by means of a different coding system.

There is no compelling reason to stratify the landscape into agricultural and non-agricultural areas. Baobab trees are found in the agricultural areas hence photos from across all lands will be selected. The amount of time to scan these photos for potential madd habitat in depressions containing trees will be very short and the survey will be more complete with these photos included within the madd sample frame.

Once at the site, measure the length , width, and height of the madd vine patch or patches. This will give you a surface estimate of the area covered by the leaves. Continue to measure diameters of individuals as before, in the hopes that eventually a relationship between diameter, crown, and fruit production can be found, even if it is with the total basal area of all the vines in the patch.

The most difficult part of this inventory is to estimate the fruit production. The operational challenges to count the fruit on the vine are large, and destructive sampling is not desirable and may even be illegal under Senegalese law. We have three recommendations:

1. Initially, go to villages where madd patches are nearby and solicit estimates of the annual production from the villagers. Measure the size of the patch using the above protocol, average the estimates from the villagers, and produce a yield of fruit per unit surface area. This figure will be applied to the hectares of madd patches found in the aerial photo exercise above.

   Repeat at villages spatially distributed across the area of the interest, choosing a range of madd patch sizes.

2. Locate madd patches with villagers nearby as in number 1, but have the village leaders select a responsible person to record the yield of the patch. The leaders, with the help of the Wula Nafaa project liaison, explain to the villagers the importance of informing or better yet, allowing the responsible person to count or weight the fruit. The amount of fruit will then be put into a relationship with the surface area that produced it. The results will be the same as option 1 with a yield of fruit per unit of surface area.

3. For small patches, especially in the savanna areas, it may be possible to directly count the fruit if the vines are growing on only one or maybe two trees exposing the sides of the tree to direct sight. Convert the numbers into kilograms or another marketing unit, then to a yield per surface unit area.

Use the same method as described above for baobab to estimate the amount of madd vines outside of the madd vine patches.

Literature Cited

Alegria, J. 1988. *Dry Weight, Volume and Growth Equations for Combretaceae in the Niamey Department.* US Agency for International Development/Forest Land Use Planning 58p. + Appendices.

Amadou Tidiane Bâ, Bienvenu Sambou, Finn Ervik, Assane Goudibaly, Ciré Camara, et Dauda Diallo, Juillet 1997. Vegetation et Flore, Parc Transfrontalier Niokolo Bariar. Institut des Sciences de l'Environnement

Arbonnier, M.; Faye, B., 1988 - Etude de la Forêt Classée de Koumpentoum. République du Sénégal. Ministère de la Protection de la Nature. Direction de la Conservation des Sols,

Dakar et Centre Technique Forestier Tropical (CTFT-France), fascicules 1, 2 et 3 (62, 77 et 70p.).

Centre Technique Forestier Tropical (France*)* 1990. *Memento Du Forestier,* Edited by Ministère De La Cooperation, Paris

Dieng, Cheikh 2006. *Tree Species Diversity Assessment and Utilization of Biodiversity Indices in the South East Forests of Senegal*. Cuvillier Verlag, Göttingen. ISBN 3-86537-760-2.

Dieng, Cheikh, and P Lennertz 2001. *Mise en place d'un Système d'Information Ecologique, Forestier, et Pastoral (SIEF),* Presentation du SIEF by the Unité de Coordination du PROGEDE.

" " :Travaux réalisés de 2000 à 2004 dans le cadre d'un Contrat de prestations de services de Consultants entre le PROGRAMME DE GESTION DURABLE ET PARTICIPATIVE DES ENERGIES TRADITIONNELLES ET DE SUBSTITUTION (PROGEDE) et DFS Financement: Dons des Pays Bas et du FEM (PowerPoint slide presentation)

Diop, Sidiky D. June 2002. *Tarifs de cubage et tables de volume pour les principales espèces forestières des forêts de Tambacounda et Kolda*. Programme de Gestion Durable et Participative des Energies Traditionnelles et de Substitution (PROGEDE) p29.

Johnson, Anne Dudte, Malick Sada Sy, and Matar Gaye. *Frame Étude de cas sur les produits naturels le Laalo Mbepp au Sénégal*, November 2005. International Resources Group for United States Agency for International Development.

Mbaye, Momar, Samba Thiapato Dia, Babacar Dione, Niang Top, and Jacques Diêne Sarr. June 2005. *Résultats d'inventaire forestier de 300 ha de la gommeraie de Koussanar pour la mise en place d'une Banque de données*. République du Sénégal, Ministère de l'Environnement et de la Protection de la Nature Direction des Eaux Forêts Chasse et de la Conservation des Sols.

Schreuder, H.T., and J. Alegria 1995. *Stratification and Plot Selection Rules: Misuses and Consequences.* USDA Forest Service, Research Note RM-RN-536, Ft. Collins, CO

Thompson, Steven K., George A.F. Seber 1996. *Adaptive sampling*. John Wiley & Sons, Inc. New York 265p.

Appendix A: SIEF-generated stem tables for non-wood product trees

Table 1: Occurrence of *Sterculia setigera*

Survey	Number of Stems	Number of Plots	Percent of Inventory Plots with Trees
National	193	91	7.4
Tamba-Kolda	975	333	26.0
Pre-national	130	61	12.9

Table 2: Diameter distribution of *Sterculia setigera* trees

	Diameter in centimeters												
Survey	<1	1-2	3-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50+
National	1	0	5	12	17	19	17	15	7	14	8	13	65
Pre-national	0		0	5	7	6	5	6	11	5	7	12	64
Tamba-Kolda	348	7	15	24	34	36	43	55	51	46	61	44	211

Table 3: Occurrence of *Adansonia digitata*

Survey	Number of Stems	Number of Plots	Percent of Inventory Plots with Trees
National	24	16	1.3
Tamba-Kolda	5	5	0.4
Pre-national	15	8	1.7

Table 4: Diameter distribution of *Adansonia digitata* trees

	Diameter in centimeters												
Survey	<1	1-2	3-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50+
National	0	0	2	0	1	0	1	0	0	0	1	1	18
Pre-national	0	0	0	0	0	3	1	1	0	0	2	0	8
Tamba-Kolda	0	0	0	1	0	0	0	0	1	1	0	0	2

Table 5:Occurrence of Saba senegalensis

Survey	Number of Stems	Number of Plots	Percent of Inventory Plots with Trees
National	9	2	0.2
Tamba-Kolda	1	1	0.1
Pre-national	0	0	0

Table 6: Diameter distribution of Saba senegalensis vine

	Diameter in centimeters												
Survey	<1	1-2	3-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50+
National	1	0	2	4	2	0	0	0	0	0	0	0	0
Pre-national	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamba-Kolda	0	1	0	0	0	0	0	0	0	0	0	0	0

Appendix B. Steps to incorporate data from PROGEDE'S SIEF National inventory into forest management plans and maps

(Taken from the Manual used for training PAEFK Forestry project in Kolda funded by Canadian International Development Agency, 2006)

SHORTLIST

1. CREATE THE NECESSARY DIRECTORIES AND SUBDIRECTORIES
2. CREATE A NEW PROJECT IN ARCVIEW
3. GET DATA FROM EXISTING THEMES: Forest boundaries, Roads, Hydrology, Villages, Inventory plot locations, Occup Sol, Mares; Clip all to one forest boundary and make a map
4. MAKE THE 3 SERIES OUT OF THE BASE MAPS: Agriculture (from OccupSol); Protection (Mares + Hydrol with buffers); Production (ForetClaire + Savanes Arbustive/Arborée/Boisée + jachères)
5. ANALYZE, SUMMARIZE AREA AND LENGTH DATA FROM SERIES MAPS
6. DISPLAY VARIOUS INVENTORY PLOT CHARACTERISTICS THAT DESCRIBE THE TERRAIN
7. MAKE A 1-HECTARE GRID FOR THE BLOCK AND PARCEL CALCULATIONS
8. DRAW OUT DATA ON YOUR FOREST FROM THE SIEF AND SAVE OR WRITE DOWN THE DATA TO ADD TO ACCESS: Stems/Basal area/volume per hectare living and dead; no. of plots; Total for forest and for utilization type especially Bois d'énergie
9. SYNTHESIZE AND INCORPORATE DATA BY STRATUM INTO FOREST POLYGON TABLES (for later estimation of stems, basal area, and volume in the forest, the blocks, and the parcels)
10. EXTRACT AND GROUP DATA FROM FOREST POLYGON TABLES BY FOREST, BY STRATUM
11. DO CROSS-ANALYSES IN ACCESS TO GET STEMS/BASAL AREA/VOLUME BY DIAMETER CLASS AND BY STRATUM -- PER HECTARE, PER UTILIZATION
12. CREATE BLOCKS WITHIN FOREST BOUNDARY BY CLICKING 1-HA SQUARES AND APPLYING THE AVERAGE "SERIE PRODUCTION" VOLUME TO EACH (based on one criterion: total of forest volume of bois d'énergie divided by the number of blocks)
13. CONSTRUCT PARCELS SIMILARLY BASED ON BOIS D'ENERGIE VOLUME IN EACH BLOCK DIVIDED BY NUMBER OF PARCELS (=8 in Tamba; =12 in Kolda); MAP THE SEQUENCE OF EXPLOITATION WITH COLORFUL POLYGONS

SUMMARY OF IMPROVEMENTS FOR FUTURE USE OF THE SIEF

- Perform a verification of the plot locations in relation to Yangambi (veg type) classes they represent. (During some mapping exercises, we found that some plots seem to fall outside predicted polygons)
- Define in more detail how it is decided whether more plots are needed to improve the sample, and how they are incorporated into the calculations once "borrowed" or measured in the field (Steps 3, 8); include a chapter on adding all new plots for a forest heretofore unsampled.
- Exclude substeps that produce graphs and maps not needed for the management plan (Steps 5, 6, 12)
- Include a buffer of at least 2km around forests so that roads, villages, and adjoining forest types can be linked to PAF activities inside the boundary. (Step 3)
- Add automatic report-producing modules in the Access portion of SIEF so that transferring data and tables between Access and Excel can be minimized (Steps 8, 9, 10, 11, 13)
- Clarify the meaning of-- and use in the PAF volume estimates -- the error calculations provided in SIEF's Paramètres Dendrométriques (step 8).
- Consider omitting the Thiessen square grid procedure for adding up volumes in blocks and parcels, in favor of drawing boundaries by eye together with village participants. The same inventory data can be applied to the Yangambi polygons thus enclosed, with more realistic results (steps 7, 12, 13).

DETAILED PROCESS IN 13 STEPS

NOTES: "save .shp" means to save as a shapefile in ArcView

No. (pg) is the STEP NUMBER and (*page number)* in 2006 PAEFK - CIDA training manual

The theme "OcSol" is an *existing* map of the Yangambi strata of Senegal (forêt claire, 4 savane types, and others)

SW is the software used for the step: W=Windows, AV=ArcView, Ac=Access, Ex=Excel, S=SIEF

No. *SW*	OBJECTIVE	SUBSTEPS	OBSERVATIONS
1 *(p7)* W	CREATE NECESSARY DIRECTORIES AND SUBDIRECTORIES	C:\Amenag\[forest name]\ Subdirectories: \FichierAccess\ (for TraitemtCarto.mdb) \FichierDbase\ (for .dbf files) \FichierDoc\ \FichierExcel\ \FichierGIS\ (for \bloc\, \grille\, \parcel\	It is an excellent beginning to require setting up a good directory system right from the start.
2 *(p8)* *AV*	CREATE A NEW PROJECT IN ARCVIEW	Add Extensions Geoprocessing, ArcTrace, and Thiessen	Could combine this step with the next one.
3 *(p9)* *AV*	GET DATA FROM EXISTING THEMES: Forest boundaries, Roads, Hydrology, Villages, Inventory plot locations, Occup Sol, Mares; Clip all to one forest boundary and make a map	▪ Add Senegal all forest boundaries ▪ Select this forest, save .shp, ▪ Add, clip to forest, & save as .shp: Routes, Hydro, Placettes (locations XY from national inv), OcSol, Mares (select & save separate from OcSol) ▪ Villages near the forest have to be selected by hand (those participating in the PAF) ▪ Combine .shp's to make forest map	(1) All steps from now on deal only with resources within forest boundaries, not immediately outside them. This makes boundary demarcation more important and ignores resources that straddle boundaries. (2) If there are no plots from the National Forest Inventory here, they must be "borrowed" from other areas. Dr Dieng of PROGEDE has the knowledge of how to do this.
4 *(p16)* *AV*	MAKE THE 3 SERIES OUT OF THE BASE MAPS: ▪ Agriculture (= from Occup Sol); ▪ Protection (= Mares + Hydrol with buffers); ▪ Production (= Foret Claire + Savanes + jachères)	▪ PROTECTION: Buffer mares with 100m, watercourses with 50m; union these themes; save .shp; calc areas. ▪ AGRICOLE: Select and save .shp the OcSol "agricole" stratum. Calc areas. subtract out Protection overlapping polys. ▪ PRODUCTION: Add themes FC, Savanes, jachères from OcSol; subtract out overlapping Protection polys (save .shp). Make buffer 1m of Routes; save .shp. Union these two and subtract out overlapping routes. Save .shp. ▪ Put all series on one map.	(1) THE AGRICULTURE LAND USE CATEGORY CANNOT BE REMOVED FROM THE ANALYSIS EVEN IF IT FALLS INSIDE THE FOREST BOUNDARY. Therefore if you want to exclude agricultural areas from the PAF, a special alternative procedure will have to be developed. (This is because the SIEF uses an established Yangambi land use classes for Senegal) (2) This step should be re-verified because in the manual the areas in the final map added up to more than the hectares in the forest. (a typo, or a result of a wrong procedure?)

No. *SW*	OBJECTIVE	SUBSTEPS	OBSERVATIONS
5 *(p23)* *Ac* - *Ex*	ANALYZE, SUMMARIZE AREA AND LENGTH DATA FROM SERIES MAPS FOR PRESENTATION	▪ Import data in .dbf from GIS themes forêt, hydro, vgs, mares, routes, ocsol, plac_for, and the 3 series o Sum lengths of watercourses, roads o Calc area of mares o Sum polygon areas by Yangambi stratum, convert to hectares o Sum polygon areas by Series, in ha ▪ Export sum tables to **Excel graphs**	(In the manual, the sums of areas in Yangambi strata are wrong) Displaying the point data as points with differentiated legend is truer to life (if points are properly registered to the polygons). Most of the summed data in this step have little use for the PAF as graphics (though they may be useful in other biodiversity applications).
6 *(26)* *Ac* - *AV*	DISPLAY VARIOUS INVENTORY PLOT CHARACTERISTICS THAT DESCRIBE THE TERRAIN (soil types/depth/texture, elevation, slope, erosion, veg cover %/ density, mean tree height)	▪ Copy Plac_for table from ArcView into Access; in design view, add fields from STATION table to Plac_for table and update with STATION data; export updated Plac_for.dbf to ArcView; use legend editor to display station **point-based** info on map. OR -- ▪ In ArcView, build Thiessen **polygons** with buffer %=10; add fields to the Plac_for table in Access as above, display polys by variable in legend editor	The Thiessen polygons are not based on natural features and are not really appropriate for presenting data such as elevation or soil type data taken at such wide spacing. Therefore this could be the point at which a simpler system which uses delineation of blocks BY EYE would diverge. The simpler process would then continue below in step 8.
7 *(p35)* *Ac* - *AV*	MAKE A 1-HECTARE GRID FOR THE BLOCK AND PARCEL CALCULATIONS	▪ Write max and min UTM coordinates for the forest. ▪ Run program "PointsGrille" in Access to create intersections of 100 distance apart. ▪ Export as coord.dbf; import the table into ArcView. ▪ In a new view, add Event Theme based on the x and y of coord.dbf. Convert to Grillept.shp. ▪ Add the forest boundary theme and edit the event them of Grillept.shp, deleting points outside, so that only points within the forest boundary remain. Work on small section of around 100 points at a time. ▪ Run Thiessen sub-program on selected point intersections. When program finishes this section, it will have drawn 1-ha squares connected by the point intersections. Delete the corner shapes which are not even squares. Save each section with the name Grilx.shp (x = successive no.) ▪ Cover the whole forest with subsets of points and Grilx.shp files. Group themes in geoprocessing assistant to make one GrilleS.shp.	THIS IS A "LONG AND DEMANDING STEP" IN THE PROCESS: CREATING THE 1-HA GRID REQUIRES HOURS. AT THE END, YOU HAVE A SERIES OF SQUARES THAT ARE COMPLETELY INDEPENDENT OF NATURAL BOUNDARIES BUT WILL BE USED TO CALCULATE BLOCK AND PARCEL BOUNDARIES. (It is proposed that this process be replaced by a "manual" (by eye) drawing of block boundaries together with forest management committees or other village representatives.) One should decide whether the size and location of each block should be relative to or independent of: - location and density of villages around the forest; - location and density of Sourgas and charcoal spp. inside and around the forest; - layout of roads and streams; - current land uses (zones amodiées, pasture corridors, fields, charcoal production areas)

No. *SW*	OBJECTIVE	SUBSTEPS	OBSERVATIONS
8 *(p40)* *S* - *Ac*	PULL OUT DATA ON YOUR FOREST FROM THE SIEF AND SAVE OR WRITE DOWN THE DATA TO ADD TO ACCESS: Stems/Basal area/volume per hectare and per stratum - FOR TOTAL FOREST - by UTILIZATION (bois d'Energie and bois d'oeuvre)	▪ TOTAL VOLUME: In SIEF-2, choose Afficher Données Détaillées - Inventaires Bassins d'approvisionnement et Tamba-Kolda - **Tous les D130** - Par Strate - Une forêt + Une strate - Param. Dendro, Données par Utilisation, and Quantif. Bois Mort. o Write down values for each of the 5 strata in the Série Production. o NOTE: When you choose the Param. Dendro option, ERROR CALCS ARE PROVIDED based on all plots within the forest within stratum. (SEE OBSERVATION) ▪	The error calculations provided in the "Paramètres Dendros" should be used in describing the confidence interval for volumes of fuelwood which are used in the PAF. The errors reported are called "Sampling errors" ("Erreur d'échantillonnage"), and there is a p=.05 written next to this. This may mean that what is being reported is 2xSampleError, in the format of a % of the mean. It would be better for the software to display this information properly. The error level described here for basal area per ha is the one that determines whether more plots should be added.
8 cont *(p44)* *S* - *Ac*		▪ BOIS D'ENERGIE: Repeat the above for **D130 between 10 et 25.** This will allow comparisons between the total population of trees and the subpopulations of fuelwood. ▪ BOIS D'OEUVRE: Repeat again for **Autre intervalles D130,** entering values 25 to 151. Then copy data for Type d'utilisation = menuiserie fine, ordinaire, and caisserie/coffrage	The process for adding more plots, either by "borrowing" from another area or by doing new fieldwork, is separate and needs to be described. Ideally, the SIEF program would report all these data automatically through a module for writing reports.
9 *(p47)* *Ac* - *AV* - *Ac* - *AV*	SYNTHESIZE AND INCORPORATE DATA BY STRATUM INTO FOREST POLYGON TABLES (for later estimation of stems, basal area, and volume in the forest, the blocks, and the parcels)	▪ Create table BD_DENDR.dbf under \FichierAccess\TraitemtCarto\. Codes for fields, formats, and comments on pg 47 of manual. o Add totals recorded in step 8 to appropriate columns ▪ Open New View in ArcView; intersect 1-ha grid (step 7) with Series Production (step 4); save ThFor.shp ▪ Compute Geometry; assign ID to each hectare square. ▪ Export ThFor.dbf to Access o Delete fields Buffer, ID_, Area_, Perimeter_, PRCNT_Tot; o Add fields V/BE/BED/MP_NHA, V/BE/BED/MG_VolHA, M_VHA ▪ Update ThFor.dbf fields from BD_DENDR.dbf (pre-stocked query converts m2 to ha and sums variables for all polys in a stratum: CstrMajForetGrilleExploitable) ▪ Export ThFor.dbf back to ArcView via \FichierdBase\ folder. The ThFor.shp theme's legend can be modified by variables in its new table.	THIS IS WHERE A COLUMN FOR ERROR /CONFIDENCE INTERVAL INFORMATION SHOULD BE ADDED AND USED IN THE PAF During the calculations of total areas in strata, a comparison should be made with a summarization of hectares by stratum taken directly from the OcSol theme. The hectares presented in the manual (page 26) do not match the area in this forest, thus the procedure needs to be verified. Suggest leaving all area values in the new table.
10 *(p54)* *Ac*	EXTRACT AND GROUP DATA FROM FOREST POLYGON TABLES FOR ENTIRE FOREST AND FOR EACH STRATUM	▪ All variables entered into ThFor.dbf from BD_Dendr are summed for the entire forest and per stratum (recall that BD_Dendr contains per-hectare, per-stratum values; ThFor contains stratum polygons)	If the 1-ha squares were dropped, then BD_Dendr values would be applied to the stratum polygons in the simplified block which is a subset of the Série Production theme. See in step 12 comments

No. *SW*	OBJECTIVE	SUBSTEPS	OBSERVATIONS
11 *(p55) Ac*	DO CROSS-ANALYSES IN ACCESS TO GET STEMS/BASAL AREA/VOLUME BY DIAMETER CLASS AND BY STRATUM -- PER HECTARE, PER UTILIZATION	▪ Make new database Traitspécifiq.mdb; import from SIEF the tables DREF_TOUT, ESPECES, RECHESSCLA, CODECLDIA; from TraitmtCarto, the table PLAC_FOR ▪ Change 10-cm classes to 5-cm classes (HOW?) ▪ Add a field named Classe to the Plac_for table; rename table Pl_for ▪ Do cross-analysis with query assistant ("wizard"): o Results desired: 2 tables of Espèces - totals (distributions of stems and volumes), by utilization and diam class o Line headings: Codetarif.Famille o Column headings: CodeUtil	(The 5-cm class may be due to the inventory design which had a plot design based on 10 to 20cm in one plot size. This requires that trees between 20 and 25cm diameter must be pulled out and treated separately so they can be added into the exploitable fuelwood utilization class.) THE PROCEDURE AND REASON FOR CHANGING TO 5-CM CLASSES ARE NOT CLEAR -- It should be noted that the word "Classe" leads to some confusion in the database and one should always be aware if one is talking about a Yangambi stratum, a Landsat stratification, a diameter class, or an explanation of code meanings.
11 cont *(p59) Ac*		▪ Pre-stocked queries in Access do the cross-analyses for distribution of stems by SPECIES - by utilization and diameter class ("ForetNombre"). NOTE: the forest sum for each species is divided by the number of plots done in the forest. ▪ Totals by species are further distributed by stratum ("Stratx_Nombre"). ▪ (Not clear why the average per plot is calculated here --pg 60) ▪ IF NO PLOTS OR NOT ENOUGH PLOTS, LOAD IN A TABLE FROM THE ZONE AND DO THE QUERY BASED ON THAT TABLE (how to choose plots?)	NOTE: The sum of each species divided by all plots in forest gives average species per hectare according to all plotwork in the forest regardless of whether it fell in or out of production series; thus its average describes all the series (prod, prot, agric). When you divide the 5 "production" stratum sums by the number of plots in the stratum, they are an average only for the production series. Thus the whole forest has 77 plots, while the production series has only 66. WHY CALCULATE THIS? (NOTE: NUMBER OF PLOTS IN THE MANUAL FIGURE PG 32 = 27; IN SIEF-2, TABLE PlacMaBa = 48)
11 cont *(p60) Ex*	PLOT SIEF RESULTS FOR SPECIES AND DIAMETER DISTIRIBUTION IN EXCEL; modify tables	▪ Copy table of stem distrib into Excel. o Sum Column 2 o Add a column before species code: Total stems in one species/ total of all species (format: integers) o Add row that sums by diam class o Add row below this for % represent. o Bring in species names from Access table Code ClDiam; transpose to match format. ▪ Do Graphs of species and diam distributions in Excel. ▪ Make table from a query to ThFor.dbf that shows Stratum, Area, Total stems, Total volume, Stems of Bois d'Energie, Volume Bois d'Energie, Stems of exploitable BE, Vol of exploitable BE, Vol of dead wood.	The Reporting format could be simplified by adding pre-designed reports in the Access part of SIEF, RATHER THAN DOING EVERYTHING BY HAND IN EXCEL. NOTE: Although no deduction of volume is made in the software, the manual says that one half the volume in the table will be taken. The exploitants are to follow the protocol of cutting only half the stems as described by service forestier: If they cut half the total stems but they are all the biggest stems, then they have cut more than half the volume.

No. *SW*	OBJECTIVE	SUBSTEPS	OBSERVATIONS
12 *(p68) Av*	CREATE BLOCKS WITHIN FOREST BOUNDARY BY CLICKING 1-HA SQUARES AND APPLYING THE AVERAGE "SERIE PRODUCTION" VOLUME TO EACH (based on one criterion: total of forest volume of bois d'énergie divided by the number of blocks)	▪ Divide total volume of BE_expl or BED_volha from ThFor.dbf (10-25 cm diam) by the number of blocks to be devised in your forest. ▪ Open Forest.apr of your forest, new view; load ThFor.shp and activate. ▪ Select 1-ha squares and keep summarizing (by the Sum.. function) the field containing volume per ha, until the quotient above is reached. ▪ Save the selected squares in shapefile BlGr1.shp. ▪	Recall that the regressions used to estimate volume per tree include all above-ground woody biomass, that is, the branches and stems. Thus the estimations for charcoal volume are overestimated by some 20% (see report text). If volumes are eventually adjusted, then this will affect current volumes per hectare. The manual has a different value for exploitable bois d'énergie on page 75 and on page 68. (Possibly they are displaying the "exploitable wood" in all series, not just Production?) Again, it is mentioned that half the volume in this table should be cut in the field, but the software does not calculate that. IF THE FOREST SERVICE IS ADAMANT ABOUT TAKING HALF THE VOLUME, then it should be calculated automatically in the software.
12 cont *(p70) Av*		▪ Repeat for all blocks (BlGrx.shp). ▪ Add a repeatable legend for each block.shp. o If All species' biomass is needed, then intersect GrilleS in step 9 with Foret.shp instead of with S_Prod.shp; use same block boundaries as in this step; clip OcSol by Block themes one by one -- manual pg 71 ▪ Aggregate each square-filled block into new .shp using geoprocessor on field ___. ▪ Sum values for the 5 Yangambi strata contained in each block by Aggregating on the field called "Class" in block .dbf. Group by "Premier de Nom_Strate" and save in Bx_Occ.shp. ▪ Apply same legend as that for S_Prod map. ▪ Find exploitable wood volumes for each block and stratum in the BlGrx.dbf tables.	If the 1-ha square grid is omitted, then one would - select all the Yangambi strata polygons within defined blocks/parcels with natural/ village-drawn boundaries, and save them into their own .shp; - apply the BD_DENDR per-hectare stratum-based data to the block's polygons; - calculate total volumes, Basal area, and stems within blocks and parcels by summing the values for [(applicable variable per hectare) X (hectares in the poly)] The substep (page 72) of overlaying the OcSol layer onto the block is moot, because the block has already been delimited by using average volume/ha applied to many 1-ha squares.

No. *SW*	OBJECTIVE	SUBSTEPS	OBSERVATIONS
13 *(p75) Av*	CONSTRUCT PARCELS SIMILARLY BASED ON BOIS D'ENERGIE VOLUME IN EACH BLOCK DIVIDED BY NUMBER OF PARCELS (=8 in Tamba; =12 in Kolda); MAP THE SEQUENCE OF EXPLOITATION WITH COLORFUL POLYGONS	▪ The steps are the same as constructing blocks, but only use the Series Production. ▪ Load BlGrx.shp and select squares until sum of BED_Volha = (total block volume) divided by (number of parcels); save each **Px.shp**. ▪ Before going to a second block's parcels, in the current block's parcel's .dbf, add column for Bloc No. and Parcel No.; fill in. ▪ After all blocks are covered, Regroup parcels by block (Geoprocessor: agréger/group themes - **recapBx.shp**) o Combine files from this grouping by aggregating based on (parcel no. field); sum the other fields. o Result: ParcelNo. = heading, underneath are sum_V_NHA etc ▪ Export ParcBx.dbf to Access	
13 cont *(77) Ac*		▪ Modify ParcBx.dbf by o Change names to be more descriptive (manual pg 77) o Add field EXP to refer to year of exploitation to be assigned on map ▪ Export back to ArcView ▪ Combine ParcBx.shp with **recapBx.shp** for all blocks into Parcel.shp. ▪ It is possible to make OcSol by Parcel, using the **Px.shp** and aggregating entities by classe or nom_strate. ▪ Make a map of Exploitation years attached to Parcels within blocks. "Only Criterion is: the parcels that are cut in the same year cannot be contiguous (avoid human problems associated with proximity of cuts)". Attach the number of the year of exploitation to the parcel in the field "EXP" in the Parcel.dbf table.	The alternative procedure, wherein blocks are drawn by with input from local residents, would be similar in that parcels could consist of equal subdivisions within blocks to match the proposed rotation. (8 years were used in Missirah; 12 years in the Kolda training example for the Forêt Classée of Mahon-Bakor.) Mapping and presentation procedures would be similar to what is presented in the training manual.

Appendix C. Calculations of proportions of wood volume in fagots

Species	Avg value for Proportion of Fagot Vol to Total Vol	Number of trees in calculation	St Dev of Proportions	Coefficient of Variation for the species
CHARCOAL				
Anogeissus leiocarpus	0.373	3	0.0299	8%
Combretum glutinosum	0.344	43	0.1494	43%
Combretum nigricans	0.619	1		
Hexalobus monopetalus	0.310	19	0.1232	40%
Piliostigma thonningii	0.362	10	0.1363	38%
Strychnos spinosa	0.662	9	0.1852	28%
Terminalia avicennioides	0.329	23	0.1346	41%
Terminalia macroptera	0.359	23	0.1427	40%
		131		
SAWTIMBER				
Bombax costatum	0.150	37	0.0777	52%
Cordyla pinnata	0.184	32	0.0940	51%
Erythrphleum guineense	0.167	23	0.1071	64%
Lannea acida	0.224	35	0.1445	65%
Pterocarpus erinaceus	0.231	35	0.1507	65%
Prosopis africana	0.188	20	0.0760	41%
		182		

N.B.: 125 cut trees had no "sections" to stack, only fagots. All trees had at least ONE fagot (up to 26 fagots, for sawtimber) to weigh.

Species	No. of trees in sample	Avg Stump Ht (cm)	StDev of Stump Ht	CV of Stump Ht	Avg Height (m)	Avg Length (m)
CHARCOAL						
Anogeissus leiocarpus	4	25	9.95	38.62%	9.63	9.78
Combretum glutinosum	73	16	7.99	47.90%	7.74	8.22
Combretum nigricans	2	11	5.66	51.43%	4.65	5.55
Hexalobus monopetalus	40	14	8.51	59.21%	5.82	6.24
Bauhinia thonningii	22	16	8.59	53.66%	5.68	6.15
Strychnos spinosa	31	10	4.58	41.90%	4.36	4.83
Terminalia avicennioides	40	16	8.06	49.81%	5.09	5.56
Terminalia macroptera	30	14.	6.90	49.64%	9.43	9.71
SAWTIMBER						
Bombax costatum	39	44	25.98	58.61%	12.85	13.29
Cordyla pinnata	35	30	14.97	48.38%	11.36	11.53
Erythrphleum guineense	23	28	17.14	59.29%	15.22	15.35
Lannea acida	38	19	10.37	52.82%	9.01	9.68
Prosopis africana	25	27	15.14	56.09%	11.56	11.32
Pterocarpus erinaceus	37	31	15.88	51.13%	12.34	12.62

Appendix D. Charcoal variables and conversions used in Senegal and the Sahel

CONVERSION FACTORS

Weights and volumes	**Source**
Dry stems conversion to m3 on basis of **0.67Mg/m3** or 670kg/m3 (DRY MASS TO FRESH VOLUME RATIO) Trunk dry mass to fresh volume ratio = species weighted basic density = 0.68 Mg/m3. Trunk + branch + stemlets = each 1/3 total Dry Mass Trunk + its bark = 32-44% of Dry mass Basic density of *Anogeissus, Combretum glutinosum, and C. nigricans* = 0.72-0.80 Mg/m3	1 Burkina Faso 620 to 785 mm rainfall
1 stère = 215 to 600 kg (twisted branches versus straight wood from thinning)	3
1 stère = 0.5 m3 = 130 kg green wood 1 m3 = 2 stères = 260 kg green 1 quintaux = 100 kg DRY = 2 big sacks of charcoal **1 tonne dry wood:** = 4 m3 = 8 stères = 10 quintaux = 20 sacks 1 truckload = 150-170 quintaux = 300-350 sacks = 40-50 stères 1 stère = 0.65 m3 = 2.5 sacks 1 m3 = 2.5 quintaux 9 tas = 300 sacks = 1 meule	Visites de terrain Kaolack 2005 Missirah 2006 Tamba 2007
Coefficient d'empilage south of 900mm rainfall (natural forest): stère/m3 = 3.5 (bois 3-6cm) stère/m3 = 2.2 (bois 7-12cm) stère/m3 = 1.7 (bois 13cm+) Tonnes/stère = 0.27 Density of wood T/m3 = 0.8 Density of charcoal = Density of kerosene = 0.79 **Sack of charcoal = "45kg"** **Sack of charcoal = .045T** **Quintaux = "100kg" = "2 sacks"** **Quintaux/Tonne = 11**	7
Coefficient of empilage: 0.45 to 0.8 m3 per stère (if all wood is round and of same diameter: = pi/4 = 0.785)	9
Yield of charcoal per kg of wood	
16% (Outchoun 1983) to 30% of weight of raw material (drier wood yield = higher); low avg = 20% (See other examples in doc)	3
Productivity per meule	
20m diameter kiln pile = 400 sacks (Casamance) 6m radius kiln = 100 quintaux 13m diameter kiln pile = 200 sacks 1 stère = 80 to 130 kg of charcoal 1 four (meule) of 300 stères green = 290 000 kg = 29 tonnes green, or 2.7 tonnes dry (divide by 11) 1 truckload = 150 quintaux = 300 sacks = 40-50 stères 1 meule = 1 camion = 300 sacks loaded in front of Service Forestier = 9 "tas"	Visites de terrain Kaolack 2005 Missirah 2006 Tamba 2007
Energy yields: Traditional meule = "18%" Casamance kiln = "30%" 3-stone cooker = "20%"	7 (these references are all sourced)

UTILISATION AND ECOLOGY

Dakar market	
100 000 tonnes/yr (1980)	3
300 000 tonnes of charcoal per year = 3 million quintaux	Visites terrain Kaolack 2005
(approx 10 quintaux per tonne) Thies at 70km from Dakar was a main exploitation zone from 1950 to 1966, producing up to 2/3 of the total for Senegal. Closed for charcoal making from 1983. St-Louis, 200+ km from Dakar, was prominent from 1970 to 1982 because of natural populations of Acacia nilotica killed off by drought. Kaolack (200+km from Dakar) was prominent from 1959 to 1987, with stands on each side of the railroad. (Senegal population 1976 = 5 million) Tambacounda, at 400-500 km from Dakar, took over in 1985, with a harvest on the order of **one million quintaux per year**. (Senegal population 1988 = 6.9 million) Kolda at 700km from Dakar from 1990 to 1999 has gone from 4% to 67% of the total charcoal production. (Senegal Population 1990 = 7.3 million, 2000 = 9.5 million) Quota proposed for 2000 was 60 000 tonnes plus 20,000 tonnes of reserves. 1994: Dakar ville charcoal consumption = 114,300 T, gaz = 40,300 T	7
Heat value	
(An estimation of 70% of standing stock as being acceptable for fuelwood other species for fruit and other uses, or not dense enough) -- "Results of this study indicate that the share of commercial fuelwood in **young successional** forest could be much lower when taking into consideration the multiple uses of these forests." "Nevertheless, the concept of commercial fuelwood depends on supply and demand and, with increased scarcity, less suitable fuelwood species will be used." Barkless wood preferred in Niger. On an area-based volume, excluding branches, stemlets, bark, and non-optimal species results in a use-able 25% of volume.	1 Burkina Faso (620-785 mm rainfall)
Dry wood: 4500 to 4770 Kcal/kg; Green wood: 3500 Kcal/kg X 0.08 = **280 Kcal/kg wood** (thermal E yield=8% or 5% on 3-stone stove) Charcoal: 7500 Kcal/kg X 0.2 char yield X 0.28 = **420 Kcal/kg wood** (Thermal E=28%) Petrol product: 10 000 Kcal/litre	3
tep = 42 Gjoules kWh = 3.6 Mjoules Pci of kerosene = 43.5 Mjoules/kg Pci of butane = 45.7 Mjoules/kg Pci of charcoal = 29 Mjoules/kg Pci of wood = 17 Mjoules	7
Productivity per area	
"If protected for 5 yrs after clearcutting, 0.6 to 3 m3/ha/yr" Devineau (1997) used repeated meas. to estimate increment at 0.7 m3/ha/yr (mature savanna) and 0.3 m3/ha/yr (12-yr fallow) Cameroun Regrowth @ 800mm rainfall = 0.5 m3/ha/yr, 3 yrs after clearcut. Botswana regrowth @ <1000mm rainfall on sandy soil = 0.9 Mg/ha/yr Burkina regrowth @ 1000mm rainfall = 0.7 m3/ha/yr in mature savanna Guinea regrowth @ 1300mm rainfall = 1.3 m3/ha/yr in savane arbust; 2.3 m3 in savane boisée	1
"Exploitable" =15 stères/ha green + 3st/ha dead (Dosso) *(Combretum micranthum, C. nigricans, Guiera senegalensis)- Maradi and Dosso*	2 Niger
11.3 m3/ha/year all species mixed = 2640 kg/ha/yr = 290 kg charcoal/ha/yr = 3 quintaux/ha/yr	Visites terrain Kaolack 2005 Missirah 2006 Tamba 2007
6 years of cultivation leads to 50% density loss and 14 years leads up to 80% loss.	6

Total production of 1 million quintaux in 1994, and of 1500000 in 1988 and 1993.	7
Productivity in Mg/ha/yr = .051 + 1.082(pluviom)^2 thus 600-800mm yields 0.4-0.7 m3/ha/yr. Protection: increase by 25%; Degradation: decrease by 25%	8, cited in 9
Regen info; rotation age	
"Short" (<20-yrs) coppice cut rotation recommended in Abbot and Lowore, 1999; Bellefontaine/Gaston/Petrucci 1997; Jensen 1995; Catinot 1994. Short rotation means a different proportion of bark and branchwood than older trees. This affects density although volume is the variable that is taxed and that is predicted in equations. Thus dry mass=more appropriate for evaluation of growth and fuelwood value. "If Burkina Faso Forest Service applied the same cutting criteria for firewood trees as was used in 1982, a rotation period of more than 30 years would be required for regrowth to the same volume." (Based on 29 to 70 m3/ha that were removed during clearcutting in 1982) -- i.e. woody Dry Mass in mature stand would be less than reported in other studies in same rainfall conditions. CVs compared between current study 2004 and the CV for harvested wood in 1982 are comparable (11 to 29% range for both). "Longer rotation periods may produce a larger proportion of commercial fuelwood and this option should therefore be investigated." (pg 84)	1 Burkina Faso (620-785 mm rainfall)
Annual cut allows 69% to 80% of the annual growth Allowable = >6m diam at 20cm ht, "taillis fureté" or selective removal of sprouts *(Combretum micranthum, C. nigricans, Guiera senegalensis)- Maradi and Dosso*	2 Niger
Wound the roots at moment of high nutrient reserves for Combretums and many other sahelian spp= drageonnage	4
Combretum/ Anogeissus forests as "pseudo-climax" remain in spite of decreasing rainfall and degradation because of ability of stumps to regenerate since 1950s (pg. 25)	5
Note: Cutting permits do not have an expiration date, so once they are granted, the wood can be cut any time. The quota system directs woodcutters to specific Regions by limiting quotas from each.	7

PRODUCTIVITY PER WORKER:

150 QUINTAUX PER SOURGA PER YEAR (Tamba 2007)

SOURCES

1. Nygard, R., L. Sawadogo, and B. Elfving. 2004. Wood-fuel yields in short-rotation coppice growth in the north Sudan savanna in Burkina Faso. *Forest Ecology and Management* 189 77-85. Elsevier B.V.

2. (c. 2003?) n.a. Résumé du Plan d'Aménagement forestier du massif de Baban Rafi Sud (Département de Madarounfa) 3 pages -- internet site

3. Keita, J.D. Undated. Article presenting a comparison of energy balance for fuelwood and for charcoal. 6 pages. See very interesting sections on economics of transport: it is shown that charcoal with a 28% thermal energy equals the price of its transport by old truck at a distance of 1000 km.

4. Bellefontaine, R, E. Nicolini, S. Petit. 1999. Réduction de l'érosion par l'exploitation de l'aptitude à drageonner de certains ligneux des zones tropicales sèches. Bulletin Réseau Erosion (IRD-Montpellier et CTA-Wageningen), no. 19, p. 342-352

5. Ba, M., A. Toure, and A. Reenberg. Mapping land use dynamics in Senegal. Case studies from Kaffrine Departments. Working paper 45.2004 for Sahel-Sudan Environmental Research Initiative, Institute of Geography, Copenhagen. 33 pages

6. Faye, E., D. Masse, and M. Diatta. 2002. Dynamique de la régénération ligneuse durant la phase de culture dans un système de culture semi-permanente du Sud du Sénégal. In Savanes africaines: des espaces en mutation, des acteurs face à de nouveaux défis. Actes du colloque, mai 2002. Marouna, Cameroun. 30 pages.

7. FAO Documents 1 and 5 on Consommation en Charbon de Bois au Senegal: Dept des Forêts Rapport d'étude sur les Données du Bois-Energie au Sénégal", and "Etude sur les Ressources Forestières et les plantations Forestières au Sénégal".

8. Clément, J. 1982. Estimation des volumes et de la productivité des formations mixtes forestières et graminéennes tropicales. B.F.T., No. 198, in CTFT Mémento Forestier page 507.

9. C.T.F.T. 1989. Mémento Forestier. Ministère de la Coopération et du Développement, Paris. Out of print.

Appendix E. Species information from SIEF tables

Blue shaded = charcoal species with a regression volume tariff; Black shaded = Sawtimber species with a regression volume tariff; *italic* = sawtimber species that need a regression volume tariff.

Utilisation:

a: Bois de menuiserie fine /artisanat
b: Bois de menuiserie ordinairel
c: Bois de caisserie et de coffragel
d: Bois de servicel
e: Bois d'énergie
f: Bois de déroulage
g: Fibres (cordage)
h: Tanninl
i: Pharmacopée - Cosmétiquesl
j: Alimentation (fruit)
k: Condiments
l: Fourrages: nl
m: Gommes - Résines
p: Aucune

Protection: *i= completely protected; p= partially protected; s= non-protected; v= unknown*

Genus	species	French	Wolof	Mindinguei	Peuhl	util	*prot*
Acacia	albida		Kad		Tièaki	l	*p*
Acacia	ataxacantha			Koss	Goubi	e	*s*
Acacia	macrostachya		Sam	Ouoko	Tchidi	e	*s*
Acacia	nilotica/ tomentosa	Gommier rouge	Gonaké		Patouki	d	s
Acacia	nilotica / adansonii		Neb neb		Gaoudi	h	*s*
Acacia	polyacantha		Garap			e	*s*
Acacia	raddiana		Seng			e	*p*
Acacia	senegal	Gommier blanc	Vérék		Delbi	m	*p*
Acacia	seyal	Mimosa épineux	Sourour		Boulbi	m	*s*
Acacia	sieberiana	Acacia de Sieber	Sandandour		Djelouki	e	*s*
Adansonia	digitata	Baobab	Gouye		Boki	j	*p*
Adenium	obesum	Baobab d. chacals				i	*s*
Afrormosia	laxiflora				Koukouli	e	*s*
Afzelia	*africana*	*Linké*			*Linkéyi*	*a*	*p*
Albizia	adianthifolia			Banéto		e	*i*
Albizia	chevalieri		Nété nèy			e	*s*
Albizia	dinklagei		M'blélod			e	*s*
Albizia	lebek					l	*s*
Albizia	zygia	Palissandre Sénég		Sankalama		e	*s*
Alchornea	cordifolia	Médicinier rouge	Lah			i	*s*
Allophylus	africanus	Copalier Zanzibar	Gèrnay			l	*s*
Alstonia	boonei	Emien				i	*i*
Anacardium	occidentale	Pommier cajou	Darkassou		Darkassouyi	j	*s*
Ananas	comosus	Ananas				j	*s*
Andira	inermis		Simbak	Keren duto		e	*s*
Annona	senegalensis	Pommier cannelle	Dougor	Sumkum	Dukumi	j	*s*
Anogeissus	leiocarpus	Bouleau d'Afrique	Nguédiane		Godioli	e	*s*
Anthocleista	djalonensis					i	*s*
Anthocleista	nobilis			Fafa		e	*s*
Anthonotha	crassifolia					e	*s*
Anthostema	senegalense		Roh	Mano		i	*s*
Antiaris	*africana*	*Tomboïro blanc*				*d*	*s*
Avicennia	africana	Mangle blanc	Samar			d	s
Azadirachta	indica	Lilas des Indes	Neem			i	*s*
Baissea	multiflora	Liane étoilée	Ndam tap			x	*s*
Balanites	aegyptiaca	Myrobolan d'Egypt	Soump		Muceteeki	j	*s*
Bauhinia	reticulatum		Ngigis	Farah	Farayi	d	s
Bauhinia	rufescens	Bauh. rougeoyant	Randa			l	*s*
Bauhinia	thonningii		Ngigis/bambuk	Faara	Thiékéyi	d	*s*
Bombax	costatum	Kapokier	Garap laobé		Dioyi	c	*s*
Borassus	aethiopium	Rônier femelle	Ron (male)		Doubbi (femaile)	d	*p*
Boscia	angustifolia/salicifolia	feuilles étroit Nues				d /l	*s*
Boscia	senegalensis	Boscia du Sénégal	Ndiandam			i	*s*
Bridelia	micrantha			Foulékir (diola)		i	*s*
Burkea	africana				Bignarabi	d	*s*
Cadaba	farinosa	Cadaba farineux	Ndébargé			l	*s*
Calotropis	procera	Pommier Sodome	Paftan			i	*s*
Canarium	schweinfurthii					c	*s*
Capparis	corymbosa	Caprier d'Afrique				e	*s*
Capparis	tomentosa	Caprier tomenteux	Kérèn			e	*s*
Carapa	procera			Touloucouna		i	*s*
Carica	papaya	Papayer				j	*s*
Cassia	siamea					e	*s*
Cassia	sieberiana		Sindièqn	Sindiangh	Samassindiangui	i	*s*
Cassia	tora		Ndur		Oulo	k	*s*

Blue shaded = charcoal species with a regression volume tariff; Black shaded = Sawtimber species with a regression volume tariff; *italic* = sawtimber species that need a regression volume tariff. *Protection: i= complete; p= partial; s= not; v= unknown*

Genus	species	French	Wolof	Mindingue	Peuhl	util	*prot*
Casuarina	equisetifolia	Filao				d	*s*
Ceiba	*pentandra*	*Fromager*		*Bentene*	*Bantangui*	*b*	*p*
Celtis	integrifolia	Micocoulier d'Afriq	Mbul		Gaki	j	*i*
Chlorophora	*regia*	*Tomboïro noir*				*a*	*p*
Chrysophyllum	*pruniforme*			*Enoukoul*		*b*	*s*
Chysobalanus	ellipticus					p	*v*
Cissus	populnea		Mbogoy			i	*s*
Citrus	limonum	Citronnier				j	*s*
Citrus	sinensis	Oranger doux				j	*s*
Cocos	nucifera	Cocotier				j	*s*
Cola	cordifolia		N'taba			j	*s*
Cola	nitida				Goroyi	j	*s*
Combretum	aculeatum			Sawat		i	*s*
Combretum	colinum or crotonoides					e	*s*
Combretum	fragans					p	*v*
Combretum	geitonophyllum			Diamba mousso		e	*s*
Combretum	glutinosum	Combrétum gluant	Rat	Diambakatang	Dooki	e	*s*
Combretum	lecardii		Kérindolo			g	*s*
Combretum	micranthum		Kinkéliba	Baro	Gougoumi	i	*s*
Combretum	molle			Diambakatanmusso		i	*s*
Combretum	nigricans		Tap	Koulounkalang	Dookigoré	e	*s*
Combretum	paniculatum		Kindindolo			i	*s*
Combretum	racemosum					i	*s*
Combretum	reticulata					p	*v*
Combretum	tomentosum		Sérèdèd			e	*s*
Commiphora	africana	Myrrhe africaine	Ngotot		Badi	e	*s*
Commiphora	pedunculata					e	*s*
Cordyla	pinnata		Dimb	Duto	Duki	a	*p*
Crateva	religiosa		Horel			e	*s*
Crossopteryx	febrifuga			Balenko		i	*s*
Cussonia	barteri					i	*s*
Dalbergia	boehmii	Kawey				d	*s*
Dalbergia	melanoxylon	Ebénier du Sénég	Dialamban			l	*i*
Dalbergia	sissoo					e	*s*
Daniellia	ogea			Santan-Foro		x	*i*
Daniellia	oliveri		Santan			c	*s*
Delonix	regia		Sèv durubab			c	*s*
Detarium	microcarpum		Dank			j	*s*
Detarium	senegalense		Detah			j	*s*
Dialium	guineense	Tamarinier noir	Solom	Kossito		j	*s*
Dicrostachys	cinerea	Mimosa clochette	Sinke	Kourloung	Bourli	e	*s*
Dicrostachys	glomerata		Sinth			e	*s*
Diospyros	ferrea		Sélah			d	*s*
Diospyros	heudelotii					d	*s*
Diospyros	mespiliformis	Faux ébénier	Alom		Koukoui	j	*i*
Dombeya	quinqueseta			Fuyu faya		e	*s*
Ekebergia	senegalensis		Khastoy			i	*s*
Elaeis	guineensis	Palmier à huile				j	*s*
Entada	africana		Batar	Gouling	Padapadi	d	*s*
Erythrina	senegalensis		Hundol	Dolingh	Ngarara	e	*s*
Erythrina	sigmoidea					i	*s*
Erythrophleum	africanum				Pelli	e	*s*
Erythrophleum	guineense		Tali			i	*s*
Eucalyptus	camaldulensis		Khotbutel			d	*s*
Euphorbia	sudanica	Euphorbe duSoudan				i	*s*
Euphorbia	unispina					i	*s*
Fagara	leprieurii					e	*s*
Feretia	apodanthera		Santer	Toungsouma		e	*s*
Ficus	capensis	Figuier du Cap		Adiana-Soto		i	*s*
Ficus	dicranostyla			Bouret(diola)		e	*s*
Ficus	exasperata			Bousass(diola)		e	*s*
Ficus	glumosa			Soto-Messeng		e	*s*
Ficus	gnaphalocarpa	Symocore d'Afriq	Gangue	Soto		j	*s*
Ficus	ingens					p	*v*
Ficus	iteophylla	Ficus étrangleur			Wardonnayi	i	*s*
Ficus	ovata		Dob djiné			e	*s*
Ficus	platyphylla			N'kobo		x	*s*
Ficus	sagittifolia					e	*s*
Ficus	thonningii		Dobali		Thiékéyi	e	*s*

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Genus	species	French	Wolof	Mindingue	Peuhl	util	*prot*
Garcinia	livingstonei					d	*s*
Gardenia	erubescens		Dibuton djigen			i	*s*
Gardenia	ternifolia				Dingali	i	*s*
Gardenia	triacantha			Tankana kodé		i	*s*
Gmelina	arborea	Gmélina				c	*s*
Grewia	bicolor		Kèl	Sambé	Kelli	i	*p*
Grewia	flavescens		Khorom radj			i	*s*
Grewia	lasiodiscus				Kelli baléyi	i	*s*
Grewia	tenax					i	*s*
Grewia	villosa		Khorom sap			i	*s*
Guibourtia	*leonensis*					*d*	*s*
Guiera	senegalensis		Nguer	Kankanang	Eloki	i	*s*
Hannoa	undilata					p	*v*
Harungana	madagascariensis	Arbre à sangdragon				d	*s*
Heeria	insignis				Kélel diéri	l	*s*
Hexalobus	monopetalus			Koundié		j	*s*
Holarrhena	floribunda	Hollarrhène Sénég				i	*i*
Hygrophila	auriculata		Sèber buki			i	*s*
Hymenocardia	acida		Koronkondo			e	*s*
Hymenocardia	lyrata					e	*s*
Indéfini	Indéfini					p	*s*
Isoberlina	*tomentosa*					*p*	*v*
Khaya	*senegalensis*	*Caïlcédrat*		*Jaloo*		*a*	*p*
Kigelia	africana	Saucissonnier	Ndjambal	Lamouko		i	*s*
Landolphia	heudelotii					j	*s*
Lannea	acida	Raisinier acide	Sonn	Bembo		j	s
Lannea	microcarpa	Raisinier		Kolo-Bembo	Thionoyi	j	*s*
Lannea	schimperi					p	*v*
Lannea	velutina	Raisinier velouté		Bembé-Ké		e	*s*
Lecaniodiscus	cupanioides					i	*s*
Lepisanthes	senegalensis		Khèver			i	*s*
Leptadenia	pyrotechnica					l	*s*
Leuceana	leucocephala					l	*s*
Lonchocarpus	cyanescens					x	*s*
Lonchocarpus	laxiflorus			Mo-Iro		i	*s*
Lonchocarpus	sepium					p	*v*
Lophira	alata					e	*s*
Lophira	lanceolata			Malanga		e	*s*
Maerua	angolensis		Khèd			l	*s*
Maerua	oblongifolia		Ngèn			i	*s*
Mallotus	oppositifolius					i	*s*
Mammea	africana					j	*s*
Mangifera	indica	Manguier				j	*s*
Manilkara	multinervis					e	*s*
Markhamia	tomentosa	Kasounkaress				e	*s*
Maytenus	senegalensis			Kasa boro	Guiel gotel	i	*s*
Melaleuca	leucadendron		Niaouli			d	*s*
Mezonevron	benthiamianum					i	*s*
Microdesmis	puberula					i	*s*
Mitragyna	inermis	Dioung	Hos		Koyli	e	*s*
Mitragyna	*stipulosa*	*Bahia*				*b*	*i*
Morinda	geminata		Vanda			i	*s*
Moringa	oleifera	Pois quenique	Nébéday		Neboday	j	*p*
Morus	mesozygia	Mûrier du Sénégal				i	*s*
Musa	sinensis					j	*s*
Nauclea	latifolia		Nandok	Korkondo		i	*s*
Neocarya	macrophylla					j	*s*
Newbouldia	laevis		Vosvosor			i	*s*
Oncoba	spinosa			Mur		e	*s*
Ormocarpum	bibracteatum					d	*s*
Ostryocarpus	stuhlmannii		Beur			e	*s*
Ostryoderris	chevalieri					e	*s*
Ostryoderris	stuhlmannii				Bardaneyi	i	*s*
Oxytenanthera	abyssinica				Kewe	d	*s*
Ozoroa	insignis				Kélél diéré	e	*s*
Pandanus	candelabrum					i	*s*
Parinari	curarellifolia	Pommier de cayor				d	*s*
Parinari	excelsa			Mampato		j	*s*
Parinari	macrophylla		Néw			j	*s*
Parkia	biglobosa		oul	Nété	Néré	j	*s*
Parkinsonia	aculeata	Parkinsonia				e	*s*

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Genus	species	French	Wolof	Mindingue	Peuhl	util	*prot*
Paullinia	pinnata		Képu nèy			i	*s*
Pavetta	cinereifolia					e	*s*
Pavetta	corymbosa					e	*s*
Pavetta	crassipes					e	*s*
Pentaclethra	macrophylla		Ulu nèy			e	*s*
Pericopsis	laxiflora				Koukouli	i	*s*
Persea	americans	Avocatier				j	*s*
Phoenix	dactylifera	Vrai dattier	Tandarma			j	*s*
Phoenix	reclinata	Dattier du Sénégal	Sor sor			j	*s*
Polyscias	guilfoylei					x	*s*
Pouteria	alnifolia		Gnakhagn	Bousser (diola)		d	*s*
Prosopis	africana	Prosopis d'Afriq	Ir		Thiélingayi	d	*p*
Prosopis	juliflora	Mesquite			Lalloyi	d	*s*
Pseudocedrela	*kotschyi*					*b*	*s*
Pseudospondias	microcarpa			Kounounou(diola)		i	*s*
Psidium	guajava	Goyavier				j	*s*
Pteleopsis	suberosa					d	*s*
Pterocarpus	erinaceus	Vène	Vèn	Keeno	Bani	a	*p*
Pterocarpus	lucens		Bèy bèy	Mousso keeno		d	*s*
Pterocarpus	santalinoides					e	*s*
Quassia	undulata		Kiéo	Kéko	Kékudié	e	*s*
Raphia	palma-pinus					d	*s*
Rhus	longipes		Takh			i	*s*
Ricinodendron	heudelotii					j	*s*
Saba	senegalensis		Madd			j	*s*
Salvadora	persica	Brosse àdents Ngao				i	*s*
Sapium	*ellipticum*					*c*	*s*
Schrebera	arborea			Bouyoupa (diola)		i	*s*
Sclerocarya	birrea	Prunier d'Afrique	Ber	Kountang		e	*p*
Securidaca	longipedunculata	Arbre à serpent	Fouf	Njuto	Diourou	i	*s*
Securinega	virosa		Kèng	Baram baram	Tiambel goré	i	*s*
Smeathmannia	laevigata					e	*s*
Sorindeia	juglandifolia					l	*s*
Spondias	mombin	Prunier icaque		Ninkon		d	s
Sterculia	setigera	Platane du Sénég	M'bepp			k	*s*
Sterculia	tragacantha			Diobi-Tabo		i	*s*
Stereospermum	kunthianum		Eti dema	Mor kela		d	s
Strophanthus	hispidus					i	*s*
Strophanthus	sarmentosus		Tokh			i	*s*
Strychnos	spinosa	Oranger debrousse	Temb	Keera		e	*s*
Swartzia	*madagascariensis*		*Dimbolé*			*e*	*s*
Synsepalum	pobeguiniana					d	s
Syzygium	guineense	Jambolan d'Afrique	Sédada	Boutoul (diola)		j	*s*
Tamarindus	indica	Tamarinier				j	*p*
Tamarix	senegalensis		Ngèdj			dol8i	s
Tectona	*grandis*	*Teck*				*a*	*s*
Terminalia	avicennioides		Reb reb	Wolo xoro		e	*s*
Terminalia	laxiflora			Wolo-Ba		e	*s*
Terminalia	macroptera	Badamier du Sénég		Wolosa		e	*s*
Terminalia	mantaly					e	*s*
Tetracera	alnifolia		Lala			i	*s*
Tetrapleura	tetraptera			Boussesseng(d)		j	*s*
Treculia	africana	Arbre à pain		Kobo		i	*s*
Trema	guineensis					i	*s*
Trichilia	emetica					i	*s*
Trichilia	prieureana			Foumba		i	*s*
Trichilia	roka	Rouquier				i	*s*
Uapaca	togoensis			Samo		e	*s*
Usteria	guineensis					i	*s*
Uvaria	chamae		Sédada			d	s
Vitellaria	parkii		Karité			j	*i*
Vitex	*doniana*	*Prunier noir*	*Lenge*	*Koutouboulo*	*Boummi*	*j*	*s*
Vitex	madiensis		Lung			j	*s*
Voacanga	africana			Soula ele balo		i	*s*
Ximenia	americana	Citronnier de mer	Ngolon		Tiéni	i	*s*
Xylopia	aethiopica		Djar			k	*s*
Zanthoxylum	leprieurii					e	*s*
Ziziphus	amphibia					j	*s*
Ziziphus	mauritania	Jujubier	Sedèm	Tomborong	Diabé	j	*p*
Ziziphus	mucronata	Jujubier de l'hyène	Sedèmi buki			i	*s*

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ANNEX: REFERENCES FOR A POTENTIAL STUDY COMPARING YIELDS OF THE CASAMANCE KILN VERSUS TRADITIONAL KILN

1. Document distributed by the Peace Corps (c. 1980s; date unknown)
2. ÉTUDE FAO: FORÊTS 41: Techniques simples de carbonisation FAO/ Rome, 1983
3. CTFT's MEMENTO DU FORESTIER 1989 (pages 951-966)
4. Le projet SIE-Afrique (c. 2005)
5. Lettre de Politique de Développement du Secteur de l'énergie (9 avril 2003)

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1. REFERENCES FROM A DOCUMENT DISTRIBUTED BY PEACE CORPS

Charcoal yield worksheet

The basic formula for determining the % yield of charcoal by weight is:

100 x (Wt. of charcoal)
[(Calculated oven-dry wood weight) -
(Weight of Brands)]

Brands [Poussier in French; cinders, residues) may be of two types: wet and oven-dry. Brand content of 2% or more by volume is an immediate indication of kiln inefficiency.

There are essentially four options in accounting for brands in yield calculations:

1) Subtract wet brands from wet wood, then calculate oven-dry wood weight.

2) Subtract dry brands after calculation of oven-dry wood weight.

3) Do both of the above (considered to be most accurate).

4) Ignore the brands in the calculation and list as X% yield with Y% of brands.

Sample problem:

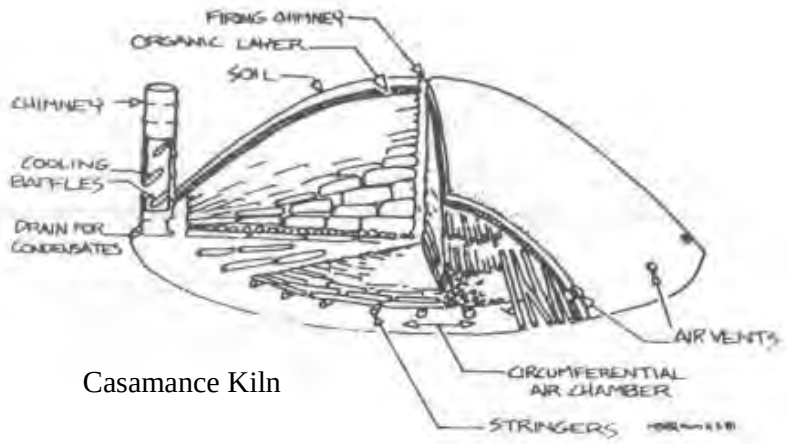
875 kg of charcoal

100 stères of wood at 350 kg/ stère

8 kg of wet brands

4 kg of dry brands

20% moisture content



Casamance Kiln

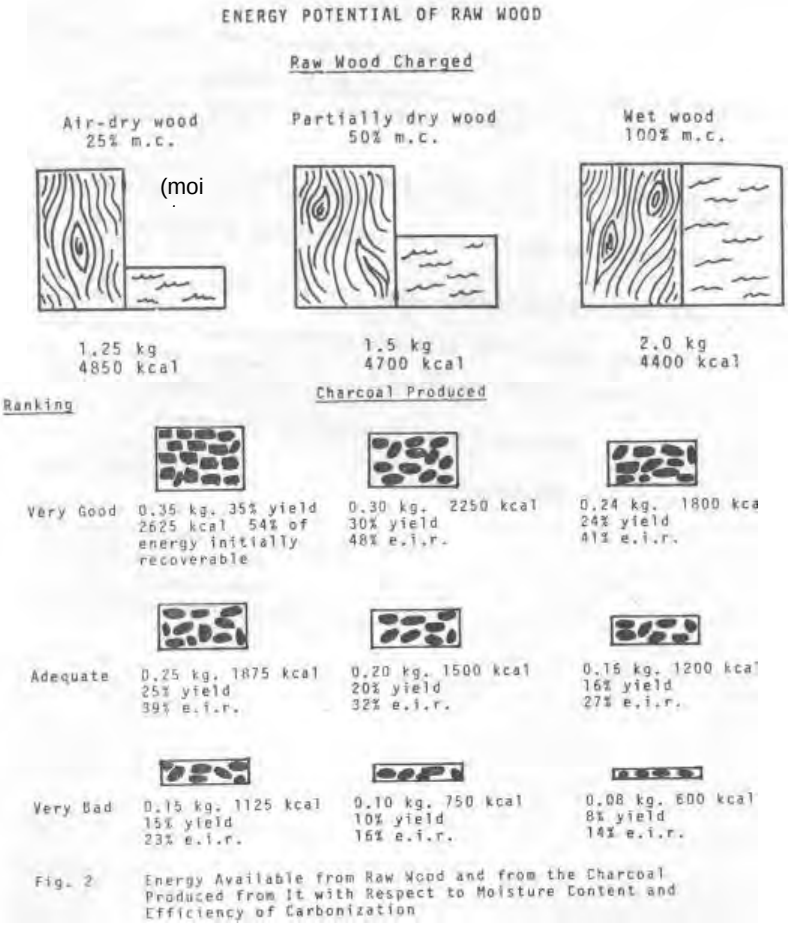


Fig. 2 Energy Available from Raw Wood and from the Charcoal Produced from It with Respect to Moisture Content and Efficiency of Carbonization

2. REFERENCES FROM FAO DOCUMENT 41: Techniques simples de carbonisation (1983)

(Sous-Division produits de l'industrie mécanique du bois, division des industries forestières, dépt des forêts)

Le principe de base de la carbonisation en meules est le même que celui de la charbonnière en fosse, à savoir que le bois à carboniser est enfermé dans un espace clos dont l'étanchéité [airtightness] est assurée par de la terre, matériau disponible partout où l'on trouve du bois. La charbonnière en meule est préférée à la fosse lorsque les conditions suivantes existent:

- le sol est rocheux, induré ou superficiel
- la nappe phréatique est trop proche de la surface
- on travaille dans les zones agricoles où les ressources ligneuses peuvent être disséminées
- il est souhaitable de faire le charbon de bois près d'un village ou autre installation permanente

A l'inverse la charbonnière en fosse est idéale lorsque

- le sol est bien drainé, profond, limoneux.

Les rendements en charbon varient selon l'habileté de l'opérateur, la siccité [dryness] du bois, et l'étanchéité à l'air de la meule [how well sealed off it is from air].

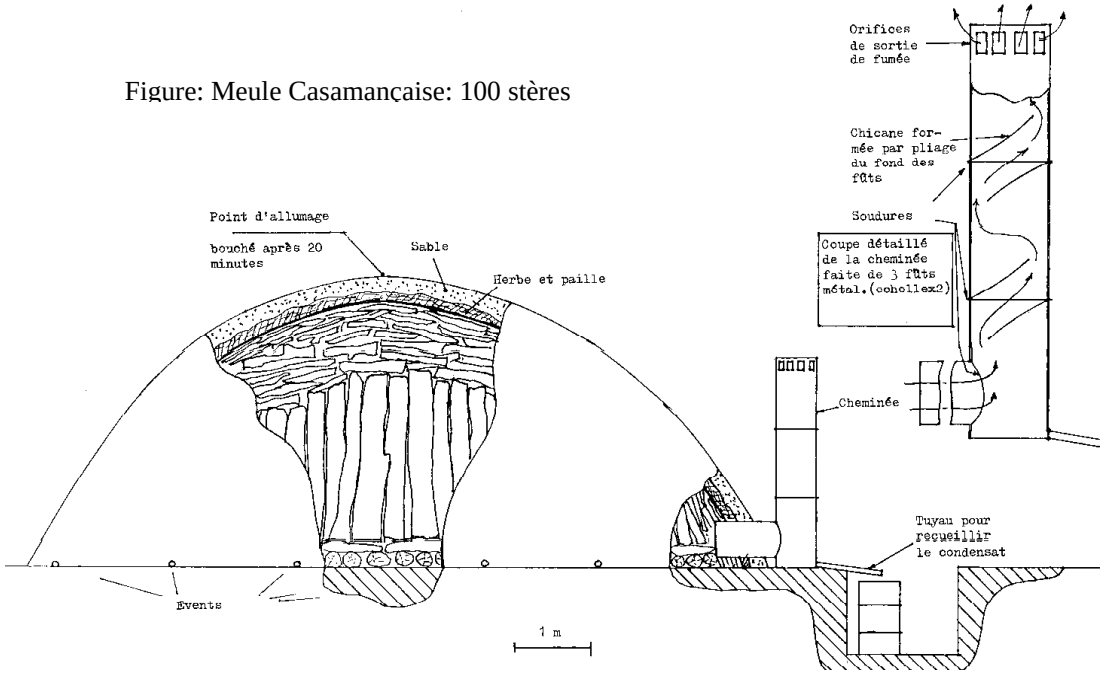
Un rendement de 1 tonne de charbon pour 4 tonnes de bois sec à l'air représente un bon résultat. Des rendements de 1 tonne pour 6 tonnes de bois sont plus courants.

La charbonnière type Casamance

Ce type de meule a été modifié par addition d'une cheminée faite de vieux fûts métalliques soudés ensemble. Des essais effectués au Sénégal avec ce système modifié ont montré de bons résultats. La cheminée améliore la circulation des gaz, ce qui réduit la proportion de fumerons et accélère la carbonisation. Du fait qu'il y a moins de fumerons, le rendement en charbon est amélioré.

La base de la meule est faite de deux couches de bois de petite et moyenne dimension. Pour la première couche, les bois sont disposés régulièrement, radialement autour du centre de la base, et pour la deuxième couche ils sont rangés tangentiellement, perpendiculaires à ceux de la première couche. Cette base joue un rôle important, car elle assure l'écoulement de l'air dans la meule.

Figure: Meule Casamançaise: 100 stères



Les couches composées de grosses billes (40 cm de diamètre) sont disposées à partir du centre jusqu'à 50 cm de la périphérie de la base. Elles sont entourées par des billes de moyen diamètre (20-40 cm), qui donnent de la solidité à la meule, et qui couvrent presque entièrement le reste de la base.

Le dernier anneau de la base est composé essentiellement de bois courts, de 20 à 40 cm de diamètre, disposés sur le pourtour de la base.

Le diamètre de la base varie en fonction du volume de la meule:

Pour une meule de 30 m^3 il faut une base d'au moins 3 m de rayon

" " " " 60m^3 " " " " " " 4 m " "

" " " " 100m^3 " " " " " " 5 m " "

La meule est couverte avec de l'herbe et des broussailles, puis du sable ou de la terre limoneuse. La cheminée est placée sur le pourtour, comme le montre le schéma ci-haut: l'ouverture à la partie inférieure étant en communication avec la base de la meule.

L'emplacement de la meule doit être nettoyé au râteau, et débarrassé des racines et des souches.

La carbonisation est terminée lorsque la fumée commence à diminuer et devient bleue. A partir de ce moment c'est le charbon lui-même qui brûle, d'où la nécessité d'enlever la cheminée et de fermer hermétiquement la meule.

...Le charbon qui vient d'être sorti de la meule doit être couvert de sable pour prévenir son inflammation. Cela évite une perte de qualité lorsqu'on l'éteint avec de l'eau. Seul le charbon en morceaux doit être ensaché, les fumerons [smut, soot] et le poussier [dust] étant écartés. Les sacs seront fermés avec une ficelle, à laquelle on attachera une étiquette de contrôle indiquant le poids du sac et le numéro de la charbonnière.

La meule Casamance est basée sur le principe du tirage inversé, c'est-à-dire que l'air entre par les évents de la base et que les gaz chauds, au lieu de s'échapper par le sommet, redescendent et passent par la cheminée, qui est reliée à la base de la meule. Au cours de la phase de décomposition exothermique, les sous-produits se condensent à la base de la cheminée, où ils sont recueillis; ce condensat est un mélange de goudron de bois et d'acide pyroligneux.

Récupération des goudrons avec la charbonnière Casamance

La récupération du condensat à la base de la cheminée dans la charbonnière type Casamance pose certains problèmes qu'il convient de ne pas perdre de vue. Le volume théorique qui peut se condenser est considérable, et se compose principalement d'eau sans valeur.

A partir de 100 stères de bois - soit une meule Casamance de grande taille - on peut obtenir environ 21 tonnes de condensat, qui demanderaient une centaine de fûts [barrels] de 200 litres pour les contenir. Ce condensat est formé essentiellement d'eau, qui est corrosive et contamine l'environnement en raison de sa teneur en acide acétique et autres acides voisins.

On peut recueillir en outre environ 2 tonnes de goudron, remplissant une dizaine de fûts, en supposant qu'il n'en soit pas brûlé une partie avant d'arriver à la cheminée. En pratique il est indispensable de **permettre à toute l'eau et aux substances acides de s'échapper normalement par la cheminée** sous forme de vapeur; leur dilution dans l'atmosphère diminue leurs effets polluants et irritants. On y parvient en **maintenant la cheminée chaude,** et en **évitant les vents froids**. On perd ainsi une partie du goudron, mais c'est inévitable avec un tel système simple, sinon le puisard de récupération [collection tank] déborderait, et la zone serait sérieusement contaminée par le condensat.

Lorsqu'on opère par temps froid, entraînant une condensation d'eau excessive, il faut isoler la partie inférieure de la cheminée, ou construire une cheminée en briques. En maintenant la cheminée chaude, c'est-à-dire aux environs de 100 C, on assure un tirage continu qui permet une circulation convenable des gaz dans la charbonnière, avec une bonne carbonisation, et on aura encore une condensation de goudron.

Prix de revient du charbon de bois produit avec la charbonnière Casamance (d'après l'expérience sénégalaise) NB: year = 1978

Coûts de production pour 12000 kg de charbon de bois

		% du total
Transport vers les principaux marches: (N.B. année = 1978)		
100 stères de bois à 550 FCFA/stère	55000	28,0 -
-- à Ziguinchor (1,81 F CFA/kg) 18,21 F CFA/kg		
Main-d'oeuvre, y compris ensachage	77040	39,2
-- à Dakar (8,00 F CFA/kg) 24,40 F CFA/kg		
Chargement des camions à la charbonnière à 250 F CFA/tonne	3000	1,5
Transport au dépôt principal	10449	5, 3
Déchargement au dépôt principal	2200	1, 1
Sacs	15000	7,6
Taxe à 1,50 F CFA/kg	18000	9,2
SOUSTOTAL	***180 689***	***91,9***
plus divers et imprévus 10% du coût hors taxe	16000	8,1
Coût du charbon de bois rendu au dépôt	**196 689**	**100%**

3.

- Les données se rapportent à une meule de 100 m^3:
- Les prix sont en francs CFA (en 1978 1 $US = 310 F CFA).
- 1 stère de bois donne 120 kg de charbon.
- Main-d'oeuvre: 3 charbonniers par meule.

= 16.40 F CFA/kg

REFERENCES FROM CTFT's MEMENTO DU FORESTIER 1989 (p.951-966)

Caractéristiques physiques du charbon

Le charbon de bois est caractérisé tout d'abord par sa densité. Sa masse spécifique peut varier de 0.2 à 0.6 t/m3, elle est fortement corrélée à celle du bois de départ, un bois dense donnant un charbon dense et un bois léger un charbon léger avec un coefficient massique de transformation de l'ordre de la moitié (ex: un bois de 0.6 de densité donnera un charbon dont la densité variera de 0.30 à 0.35), la perte en masse (70-75%) étant un peu compensée par le retrait (shrinking) enregistré pendant la carbonisation, retrait qui conserve toutefois dans le charbon la structure du matériau de bois.

Le pouvoir calorifique du charbon dépend de la technique de carbonisation et peut varier de 27.2 MJ/kj (charbon de meule) à près de 33.4 MJ/kg (charbon de cornue).

Le charbon est enfin plus ou moins friable et plus ou moins résistant, ces qualités dépendant de la nature de l'essence et de la technique de pyrolise. Il est aussi plus ou moins absorbant mais en tout cas, il l'est beaucoup plus que le charbon minéral.

Principaux usages

Les emplois du charbon de bois sont multiples et pour chaque utilisation les caractéristiques demandées sont différentes.

Emploi comme combustible ménager ou artisanal: avec le bois de feu, le charbon de bois reste l'un des principaux combustibles des pays en voie de développement. Il est utilisé partout pour la cuisine mais principalement dans les zones urbaines, dans les villages lacustres ainsi que dans les zones arides où il est plus rentable, **sur les distances excédant 60-70km**, de transporter du charbon plutôt que du bois, le premier se conditionnant mieux que le second et donnant à poids égal **un équivalent calorifique double**.

L'artisanat local (les forges par exemple) se sert également de ce combustible. On demande à ce type de charbon d'émettre peu de fumées et d'odeurs, désagréable, de bien "tenir" le feu, de donner peu d'étincelles (sparks) et de ne pas laisser des cendres. S'il doit être transporté sur des distances importantes, il ne doit pas être trop friable.

Les sous-produits de la carbonisation

Au cours de la pyrolyse, et a côté du charbon but de l'opération, d'autres composés sont formés constitués par des produits liquides condensables et par des gaz incondensables.

Les produits liquides: ils correspondent à 40-50% du poids du bois initial et sont appelés pyroligneux. Le pyroligheux est constitué tout d'abord par de l'eau (plus de la moitié de la totalité de liquidedpour des bois à 10-15% d'humidité), puis par de l'acide acétique et ses homologues propioniques et butyriques, de l'alcool méthalique, de l'alcool allytique, de l'acétone, quelques composés basiques (ammoniac, ammines) puis des goudrons.

Avec les résineux, le liquide receuilli se sépare souvent en deux phases, l'une comprenant le pyroligneux proprement dit de couleur jaune, l'autre les goudrons de couleur plus foncée. Pratiquemenet, il est parfois difficile, en particulier avec les bois feuillus, d'obtenir une séparation nette de ces deux phases et l'on a souvent affaire à un liquide brun ou jaune foncé dont le poids correspond à 10 à 20% du poid du bois, sur lequel surnagent quelques huiles légères.

Les goudrons des arbres feuillus ont une teinte foncée, allant du brun au noir. Ils sont principalement constitués par de la créosote avec de petites quantités de benzène, xylène, etc. Les goudrons de résineux, plus légers et de couleur plus claire, allant du jaune à l'orange, sont plus intéressants d'un point de vue chimique car ils contiennent des terpènes.

Les pyroligneux peuvent être séparés en leurs constituents par distillation fractionnée. Mais ce traitement étant assez compliqué, beaucoup d'unités industrielles préfèrent souvent réinjecter le pyroligneux dans le circuit comme source d'énergie.

Notons enfin que les goudrons sont également utilisés dans certains pays (tels le Brésil) comme fuel grossier de remplacement ou dans d'autres (le Sénégal) comme produit de préservation de perches...

En fait, les usines modernes de production de charbon de bois tournent pratiquement en circuit fermé du point de vue énergétique et n'ont pas besoin de faire appel à des sources extérieures.

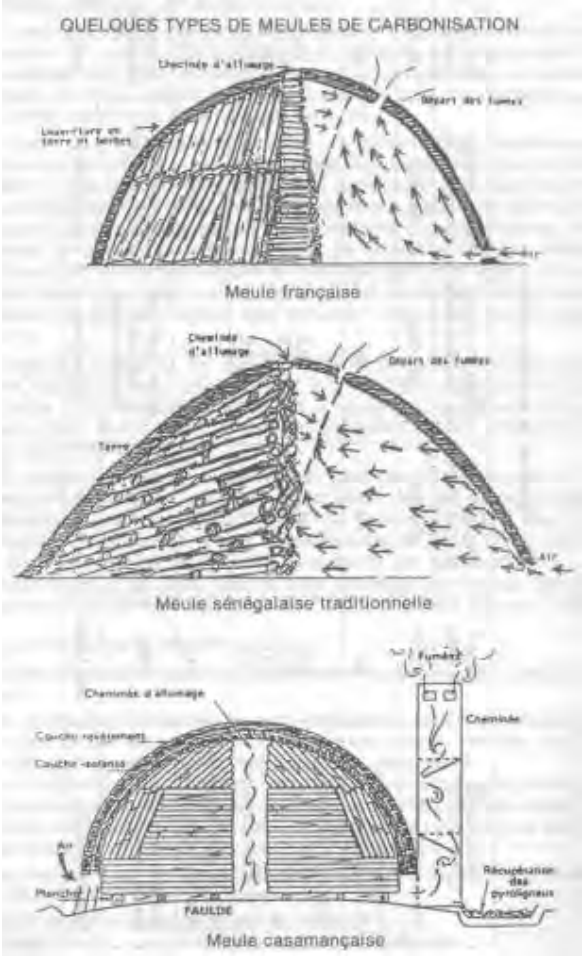
Ce n'est évidemment pas le cas des unités plus simples qui travaillent sans récupération, tands qu'au stade artisanat, la plus grande part sinon la totalité des sous-produits est perdue. Seuls les goudrons peuvent être récupérés avec certains fours en maçonnerie ou avec certaines meules améliorées.

Le pouvoir calorifique du bois D'un point de vue théorique, une notion importante en ce qui concerne le bois énergie est le pouvoir calorifique.

On appelle "pouvoir calorifique" d'un corps la quantité de chaleur dégagée par la combustion de l'unité de poids de ce corps. Le pouvoir calorifique s'exprime en joules/g, l'expression calories étant cependant tolérée du fait de l'habitude (1 cal. = 4.1855 J)….

Le pouvoir calorifique inférieur est le calcul du pcs en connaissant le nombre de molécules d'eau formée et la chaleur nécessaire au passage de l'état de vapeur d'eau à 100deg. C. à l'état liquide à 15 °C....

Le pouvoir calorifique d'un corps varie dans de fortes proportions suivant son degré d'humidité. La quantité de **chaleur fournie diminue quand la teneur en eau du bois augmente**.



Influence de la technique de suivie et de l'appareillage utilisé sur les rendements en charbon La technique de carbonisation influence nettement les rendements car il est bien évident que si la chaleur nécessaire à la réaction est fournie par le bois, le rendement final en charbon en sera diminué d'autant. C'est ce que l'on observe lorsque les carbonisations sont effectuées par des techniques artisanales rudimentaires (meules ou fosses) où l'on obtient des rendements très bas, d'autant que le bois étant toujours utilisé vert ou très peu séché, une quantité importanted d'eau doit être éliminée avant que commence toute pyrolyse. Or, il faut donc dépenser des calories (donc du bois) pour chauffer l'eau de l'ambiance jusqu'à 100 deg. C. (330 J/g d'eau) les carbonisations sont d'ailleurs d'autant plus longues.

A l'inverse, dans des appareillages industriels modernes, l'énergie est produite le plus souvent à partir des sous-produits de la carbonisation. Les pyroligneux sont brûlés ainsi que les gaz, ceux-ci servant d'abord au séchage du bois avant d'être envoyés aux brûleurs. L'usine tourne donc en circuit fermé...

A titre d'exemple, on donne ci-après quelques estimations faites pour la carbonisation de bois provenant de forêts tropicales hétérogènes africaines (densité moyenne des bois estimée à 0.7).

1 stère de bois de forêt naturelle = 0.7 m3 et environ 500kg de bois anhydre soit potentiellement 9.2 x mille MJ et pratiquement 7.5 x mille MJ (bois à 20% d'humidité).

Type de carbonisation	Artisanale rudimentaire	Fours métalliques	Industrielle
Rendement pondéral charbon/bois anhydre	10 à 15% soit environ 50 -75 kg charbon par stère	20 à 24% soit environ 100-120 kg charbon /str	30 à 33% soit environ 150-165 kg charb/stre
Equivalent calorifique du charbon	1.46 à 2.22 x 10^3 MJ	3.14 à 3.55 x 10^3 MJ	4.6 à 5.02 x 10^3 MJ
Rendement énergétique (p.r. au bois sec à l'air)	20 à 29%	42 à 47%	61 à 67%

On voit donc que de la technique retenue dépendront fortement les quantités de charbon produites et les rendements énergétiques qui sont très défavorables dans le cas des carbonisations artisanales des pays en développement. Toutefois, l'installation d'unités industrielles modernes... peuvent paraître onéreuses. C'est pourquoi... l'accent est mis soit sur l'amélioration des meules ou encore sur la construction sur place de fours les plus simples possibles...

Le projet SIE-Afrique (http://www.sie-energie.gouv.sn/spip.php?article1)

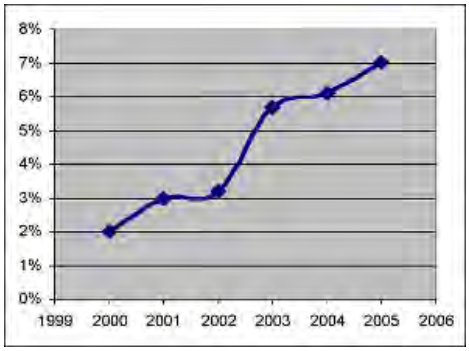
Le projet SIE-Sénégal s'inscrit à l'intérieur du projet SIE-Afrique qui appuie la mise en place de Systèmes d'Information Energétique (SIE) nationaux.

Objectif :Efficacité énergétique des charbonneries

Valeur en 2005 : 7 %

Evolution dans le temps : voir graphique

« Malgré la forte croissance de la part de la production de charbon qui est produite dans les meules casamançaises depuis 2000 (incitations financières de la DEFCCS), la technique améliorée reste peu diffusée au Sénégal. »



Pourcentage de la production contrôlée de charbon produite à partir de meules casamançaises

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Lettre de Politique de Développement du Secteur de l'énergie (9 avril 2003) (http://faolex.fao.org/docs/texts/sen60664.doc)

Arrêté fixant les modalités d'organisation de la campagne d'exploitation forestière 2005

4.4. Dans le sous-secteur des combustibles domestiques

69. Les préoccupations environnementales occupent une place importante dans la stratégie retenue par l'état dans le secteur des combustibles domestiques.

70. Ainsi le Gouvernement entend poursuivre l'objectif général défini en 1997, à savoir (i) valoriser de manière durable les ressources énergétiques issues des formations forestières; (ii) faire bénéficier aux collectivitiés locales et aux populations riveraines des ressources tirées de l'exploitation forestière; et (iii) promouvoir des combustibles de substitution adaptés aux modes de cuisson sénégalais.

71. Dans le cadre de l'amélioration de l'efficacité du sous secteur le Gouvernment a décidé l'introduction et la généralisation, dès le 1er janvier 2004, de **la meule casamance,** technique de carbonisation de loin plus performante que la meule traditionelle.

Le Ministre de l'Economie de l'Hydraulique
Abdoulaye DIOP

Le Ministre d'Etat, Ministre des Mines, de l'Energieet des Finances Macky SALL