



Manual for Forest Assessment Tool and Forest Simulator

v. 0.98

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**FAO-Finland Forestry Programme
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ABBREVIATIONS

AAC	Annual allowable cut
AG	Above-ground
AMR	Annual mortality rate
BEF	Biomass expansion factor
BG	Below-ground
C	Carbon
DBH	Breast height diameter
FAO	Food and Agriculture Organization of the United Nations
MAI	Mean annual increment
MS	Microsoft
MYRLIN	Methods of Yield Regulation with Limited Information
NTFP	Non-timber forest product
VBA	Visual Basic for Application
WD	Wood density

Table of Contents

ABBREVIATIONS	i
1 Introduction	1
2 Worksheets	2
3 Forest Assessment Tool	3
3.1 Description of the attributes	5
3.2 Calculation of forest assessment results	7
4 Forest Simulator	11
4.1 About simulation	11
4.2 Parameters for simulation.....	12
4.3 Simulation results	13
4.4 Determination of sustainable AAC	15
5 Models applied in Tanzania, Lindi Region	20
5.1 Models in VBA	20
5.2 Annual diameter increment	21

List of Appendices

Appendix 1 Reliability estimates.....	23
Appendix 2 Tally sheet for Tanzanian forest assessment for management planning	26

List of Tables

Table 1. Application’s worksheets.....	3
Table 2. List of static and dynamic tree functions	20

List of Figures

Fig. 1. Macros need to be enabled in order to run the program scripts	2
Fig. 2. List of Excel sheets in the program	2
Fig. 3. Data entry form ‘AssessmentData’	4
Fig. 4. General information about the inventory area	4
Fig. 5. Plot dimensions	4
Fig. 6. Main input data of the forest assessment	5
Fig. 7. Treeless plot in data (Plot No 3).....	6
Fig. 8. Areas of strata.....	7
Fig. 9. Grouping of species.....	8
Fig. 10. Filter tool in Excel 2007	9
Fig. 11. Sheet ‘PlotResults’	9
Fig. 12. Sheet ‘StandTables’, results by DBH classes (and input data for simulations)	10
Fig. 13. Sheet ‘StandTables’, results by DBH classes (tree utilization classes).....	10
Fig. 14. Sheet ‘StandTables’, results by tree use classes.....	10
Fig. 15. Sheet ‘SpeciesGroupParameters’: main interface for forest simulator.	13

Fig. 16. Sheet ‘Yield’: schedule of coupes.....	13
Fig. 17. Sheet ‘Fig1_Volume’. This simulation example is from Lao PDR.....	14
Fig. 18. Part of simulation results on sheet ‘Table1’	15
Fig. 19. More simulation results on sheet ‘Table1’	16
Fig. 20. Tree diameter increment according to Kuutti (2008) in Valkonen <i>et al.</i> 2008. Stand basal area for “sparse” where basal area = 5 m ² ha ⁻¹ , and “dense” where basal area = 14 m ² ha ⁻¹	21

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1 Introduction

This manual represents free software for forest assessment and planning, and it is the wish of the author that these tools can be potentially applicable for promoting sustainable forest management and wood production. These tools are a partial outcome by NAFORMA project (2009–2013) implemented in Tanzania with technical support from FAO and FAO-Finland Forestry Programme. These tools are shared under the FAO Open FORIS Initiative¹.

The program consists of two main modules:

- a) Forest Assessment Tool, and
- b) Forest Simulator.

The software is built on the top of MS Excel. Most of the program functionalities are built using MS Visual Basic for Application (VBA) language. Excel version to use this program should be 2007 or newer. These two main modules share some worksheets, as well as program code.

The main purpose of the Forest Assessment Tool is to provide a simple platform for storing forest assessment data collected from field sample plots and computing key results for this assessment. The assessment can take place on a single area or stratified area, in the latter case as for instance in forest management units.

Because this application was originally tailored into the tropics where the number of tree species can be high, the results are computed by tree species groups. This means that the user should predefine the principles how to group the species, and give species group names. It should be noted that an individual tree species can be regarded as its own group, if required: for example valuable *Dalbergia melanoxylon* (“mpingo”) can be regarded as one group.

The second tool, the Forest Simulator, is applicable for the projection of the forest development under different harvesting regimes. This module uses results from the assessment module as the input data. One of the main variables of interest is the Annual Allowable Cut (AAC) that can be determined both graphically and numerically. In the program version for Tanzania, the output tables are fixed to show simulation results for 2 x 10 years simulation periods (i.e. 20 years), although the simulator’s program code does not have such limitations.

The Forest Simulator is based on MYRLIN #3 model (Alder *et al.*, 2002) but it has been developed further for proving results for development of growing stock in terms of biomass and carbon. MYRLIN² is a freeware Excel application originally developed by a project undertaken by the Oxford Forestry Institute under the UK Forest Research Programme (1999 – 2002). This simulator can be potentially applicable tool towards more sustainable forest management, since as stated by Wright and Alder (2000), yield regulation is not sufficiently defined by the classical concepts of felling cycle and minimum felling diameter that is applied in many countries. Tropical forests are spatially and structurally diverse, and practically, mean annual increment (MAI) and annual allowable cut can only be estimated by simulation or stand projection.

The program’s VBA code is open, and it is not protected with any password. The main program sheet ‘*AssessmentData*’ may be protected, but there is no password either. The software is provided freely as a service towards improving the sustainable management of natural tropical forest. However, it is a condition of use that software is not incorporated in whole or in part into any

¹ <http://openforis.org/wiki>

² MYRLIN is an acronym for Methods of Yield Regulation with Limited Information.
See <http://www.bio-met.co.uk/myrlyn>

commercial product that is subsequently re-sold; and that reports, plans or presentations of information acknowledge this manual, as in case of the Forest Simulator to the MYRLIN website as the source too.

2 Worksheets

Open the Excel file and enable macros (Fig. 1):



Fig. 1. Macros need to be enabled in order to run the program scripts

The program contains 12 sheets, of which two are for visualizing of simulation results. Because the tables contain cross-references between the sheets and sheet names are also written into the VBA code, it is not advised to any sheet name. The list of sheets is presented in Fig. 2 and more description in Table 1.

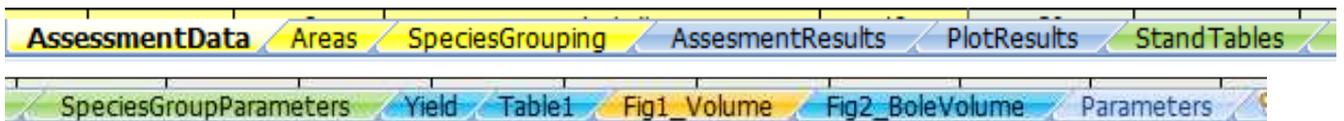


Fig. 2. List of Excel sheets in the program

Table 1. Application’s worksheets.

Sheet name	Tool	Purpose
<i>AssessmentData</i>	Forest Assessment	Main interface for Assessment Tool. Input data
<i>Areas</i>	Forest Assessment	Areas for strata
	Forest Simulator	Areas for strata Setting: Stratum can be harvested or not
<i>SpeciesGrouping</i>	Forest Assessment	For grouping of species to be done manually as the first cycle in computing assessment results
<i>AssessmentResults</i>	Forest Assessment	Results by strata and species groups
<i>PlotResults</i>	Forest Assessment	Results by sample plots
<i>StandTables</i>	Forest Assessment	Diameter class range limits. Results by strata, diameter classes and species groups
	Forest Simulator	Input data for simulation
<i>SpeciesGroupParameters</i>	Forest Assessment	List of species group names (max. 20). List of tree classes (max. 10).
	Forest Simulator	Main interface for simulations. Simulation parameters.
<i>Yield</i>	Forest Simulator	Results by year, strata and harvesting coupes
<i>Table1</i>	Forest Simulator	Results by year. Main result tables for determination of future yield, removal and AAC.
<i>Fig1_Volume</i>	Forest Simulator	Graph: Development of commercial bole volume, harvest drain and AAC
<i>Fig2_BoleVolume</i>	Forest Simulator	Graph: Development of bole volume
<i>Parameters</i>	Forest Assessment	Selections of dropdown lists in the program. Hidden sheet.

3 Forest Assessment Tool

The main program sheet of the Forest Assessment Tool is called ‘*AssessmentData*’ (Fig. 3). All assessment data is entered into this form. The form contains the following linkages:

- Region: list of regions in Tanzania (listed in sheet ‘*Parameters*’)³.
- Tree classes (optional): list of tree classes are given in sheet ‘*SpeciesGroupParameters*’.

The typical forest assessment data consists of tally tree data and sample tree data. The sample trees mean in this context the height sample trees. The current software can not automatically model the missing tally tree heights, so that should be done with some other application. The calculation of reliability estimates is described in Annex 1.

The field tally sheet for Tanzanian forest assessment for management planning is presented in Annex 2.

³ For tailoring this application to other countries, these regions can be changed to refer to provinces, zones, etc. as applicable.

Forest Assessment Tool v. 0.98		Region: Lindi		Plot dimension		Summary about data		1. Check input data and collect species names to group them		Method in computing means								
		District: Test district		Lower DBH limit Area (m ²)		Number of strata: 1		2. Compute results		<input checked="" type="radio"/> Weighted by basal area								
		Village: Test area		1 100.0		Number of plots: 63				<input type="radio"/> Arithmetic								
		Subvillage:		10 400.0		Number of tally trees: 867				<input checked="" type="radio"/> Calibrated by plot								
		Forest Reserve: Test area								<input type="radio"/> No calibration								
		Team: Village team																
		Date: 24.5.2013																
Stratum	Plot number	Tree number	Species name or code	DBH (cm)	Total height (m)	Bole height (m)	Number of stems	Timber	Medicinal	Fuelwood	Food	Pole						
Area1	1	1	mkuya	32	9					x		x						
		2	mkuya	18	9				x	x	x	x						
		3	ng'aja	55	14				x	x	x	x						
		4	ntandavala	7														
		5	nkolovonjo	2			4											
	2	1	ng'windi	31	23				x	x		x						
		2	ng'windi	18	22				x	x		x						
		3	njanda	11	11				x	x		x						
		4	ng'windi	13	9				x	x		x						
		5	ng'eeva	11	10				x	x		x						

Fig. 3. Data entry form ‘AssessmentData’

General information about the assessment can be filled on the top the form (Fig. 4). However, this data has no role in the result calculations.

Forest Assessment Tool v. 0.98 	Region	Lindi
	District	Test district
	Village	Test area
	Subvillage	
	Forest Reserve	Test area
	Team	Village team
	Date	24.5.2013

Fig. 4. General information about the inventory area

A sample plot can be rectangular or circular shape, and single area or nested plot. In both cases, the lower DBH limit applied in defined plot area is given (Fig. 5). For example as above, all trees with DBH greater than or equal to 1 cm are recorded on a plot with area of 100 m² (10 m x 10 m plot). In addition, all trees with DBH greater than or equal to 10 cm are recorded on a plot area or 400 m² (20 m x 20 m plot). Maximum of 4 nested plot sizes can be given. In case of a nested or concentric sample plot, enter all plot dimensions starting from the smallest plot size.

Plot dimension	
Lower DBH limit	Area (m ²)
1	100.0
10	400.0

Fig. 5. Plot dimensions

The tree data is entered into the form's grid (Fig. 6). The obligatory attributes are highlighted with light yellow back color, and optional attributes with light grey back color.

Stratum	Plot number	Tree number	Species name or code	DBH (cm)	Total height (m)	Bole height (m)	Number of stems	Timber	Medicinal	Fuelwood	Food
Area1	1	1	mkuya	32	9					x	
		2	mkuya	18	9					x	
		3	ng'aja	55	14				x	x	x
		4	ntandavala	7							
		5	mkolovonjo	2				4			
2	2	1	ng'windi	31	23				x	x	
		2	ng'windi	18	22				x	x	
		3	njanda	11	11				x	x	
		4	ng'windi	13	9				x	x	
		5	ng'eeva	11	10				x	x	
		6	shimbulele	10	9					x	
		7	shimbulele	15	10					x	
		8	mkolola	12	6				x	x	
		9	mkolola	44	23				x	x	
		10	ng'windi	16	16				x	x	
		11	mtumbati	35		8.0				x	

Fig. 6. Main input data of the forest assessment

3.1 Description of the attributes

A. OBLIGATORY ATTRIBUTES

Stratum [text]:

- In any case, even in single area assessment, give a stratum name.
- All plots belonging to the same stratum must be entered one after another.
- The number of strata is not limited. However, the maximum number of tree records in the current version is limited to 32 767.

Plot number [integer number]:

- Plot number must be given to first tree on the plot, but it is not necessary to repeat it for each tally tree.

Tree number [integer number]:

- The program automatically highlights the tree number 1 with yellow back color.

Species name or code [text]:

- Give species name or code. This can be a local name, scientific name, genus etc. (as agreed in the inventory design).
- This field must be always filled!

DBH (cm):

- Breast height diameter.

B. OPTIONAL ATTRIBUTES

Total height (m):

- Tree top height.
- Missing tree height is computed using a coded height model (see chapter 5.1).

Bole height (m):

- Tree commercial/technical bole height.
- In order to compute bole volume, this attribute should be given (if applicable). Missing bole height is not modelled.

Number of stems (integer number):

- Number of similar size stems.
- Can be left blank: the default value is 1.

Tree class attributes:

There can be maximum 10 user-defined tree class attributes. These attributes are used to compute frequencies of trees belonging to a certain user-defined class, as by usage classes as above. A tree can belong to multiple classes.

The tree class names are given on the sheet '*SpeciesGroupParameters*' and these names emerge automatically into the header row. Mark a selection with letter 'x' or 'X' when applicable.

Special cases and additional information

- Treeless plot: give *Plot number*, and for *Tree number* enter zero (0). Leave all other data blank. See the next figure where Plot 3 is treeless.

Stratum	Plot number	Tree number	Species name or code	DBH (cm)	Total height (m)	Bo
		19	shimbulele	7		
		20	ng'enjele	7		
	3	0				
	4	1	mtama	32		
		2	mpande	23		

Fig. 7. Treeless plot in data (Plot No 3)

- Do not leave a totally blank row into the table! The program stops reading input data into a blank row.
- Data on forest areas are given on the sheet '**Areas**' (Fig. 8). Give stratum name(s) and area in hectares. The maximum number of strata is currently 30. For simulator there is also a column '*Harvest order*' which is not yet fully applicable but reserved for the future version of the software. However, text '**N**' in '*Harvest order*' column can be used to prevent program of doing cutting simulations in that particular forest stand.
- Names of strata must be same as in the sheet *AssessmentData*. If you have just one forest area, you still have give name to that area (e.g. "*Areal*") in the assessment data and to give its area in hectares.

Forest management units or strata (max. 30 units)			
		Total	1800.0 ha
#	Stratum	Harvest order	Area (ha)
1	Area1	1	1 500.0
2	Area2	N	300.0
3			

Fig. 8. Areas of strata

- There are two alternative methods how the program computes the mean diameter and mean height on a plot. These are weighted method (by tree basal area) and arithmetic mean.

Method in computing means

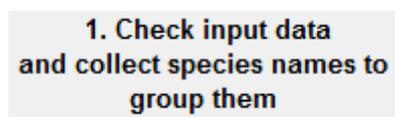
Weighted by basal area

Arithmetic

3.2 Calculation of forest assessment results

The calculation of results consists of two phases: 1) grouping of species, and 2) compiling of results.

The grouping of species is conducted with the following command button:



The program collects all individual species names from the input data. Then it gives the following message box:



If you answer YES, then the program cleans out all previous selections on the sheet 'SpeciesGrouping' and then you should manually link each species into its group.

If you answer NO, no cleaning of species list is done.

The list of species on sheet ‘SpeciesGrouping’ looks out as shown on Fig. 9. The grouping should be done manually⁴. If for some reason, there are too many cases meaning the same species but repeated because of typographical errors, then it is still possible to go back to the input data to clean it and run species grouping macro again. However, absolute correct species names are not required, because eventually all results are shown only by species groups!

	A	B	D
1	Set species groups correctly before computing the final results		
2			
3	Species name in input data	Species group	
4	mkuya	Medicine_Species	▼
5	ng`aja	Food_Species	▼
6	ntandavala	Pole_Species	▼
7	mkolovonjo	Firewood_Species	▼
8	nq`windi	Pole_Species	▼

Fig. 9. Grouping of species

The second calculation phase is not possible before all individual species belong to its certain group.

The calculation of the assessment results is conducted with the following button:



The program will reread the input data, species grouping data and diameter class range limits⁵. Then it computes forest assessment key results for each tally tree, sample plot (by species group and DBH class), and stratum. The results are written into three separate sheets: ‘AssessmentResults’, ‘PlotResults’ and ‘StandTables’.

In Forest Assessment, the missing bole height is not modelled. If a tally tree has no bole height, then it is not computed and that tree gets no bole volume either. Missing top tree height is always computed with a height model (see more in Chapter 4.3).

On sheet ‘AssessmentResults’ all result variables emerge into one table. In the same table there are results by hectare, and by stratum. Because the plain result table is not very readable, use FILTER Tool in Excel for browsing your variables of interest (Fig. 10). Then copy the result data row(s) into your reports.

⁴ The combo box lists of species group names are linked with species group names given on the sheet ‘SpeciesGroupParameters’. The selection indexes are written into (hidden) column ‘C’ on the same sheet.

⁵ Diameter class ranges are given on the sheet ‘StandTables’.

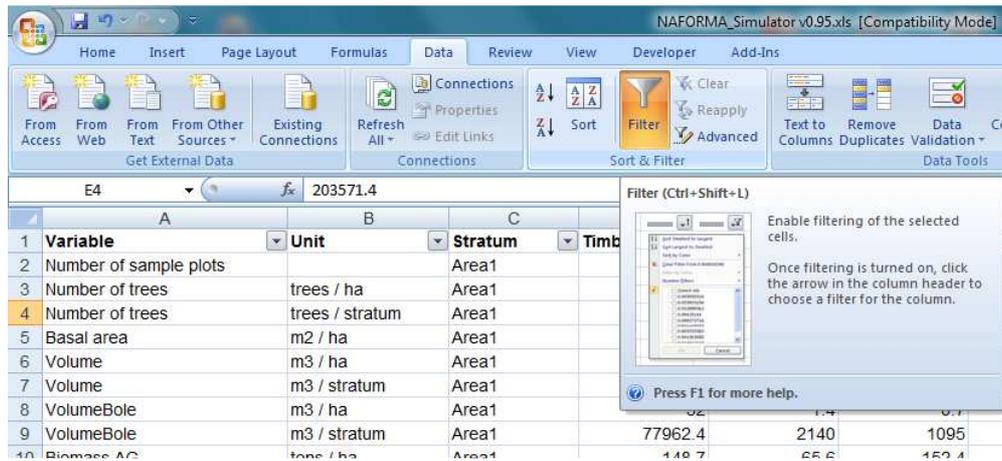


Fig. 10. Filter tool in Excel 2007

Sheet ‘PlotResults’ contains result data by sample plots (Fig. 11). Similarly as with the previous result table, use Excel Filter tool to browse through the results of interest.

	A	B	C	D
1	Variable	Stratum	Plot	Value
2	Number of tally trees	Area1	1	8
3	Number of trees/ha	Area1	1	575
4	Basal area (m2/ha)	Area1	1	9.1
5	Volume (m3/ha)	Area1	1	54.6
6	VolumeBole (m3/ha)	Area1	1	0
7	Biomass AG (tons/ha)	Area1	1	148.5
8	Biomass Total (tons/ha)	Area1	1	219.8
9	Carbon AG (tons/ha)	Area1	1	74.3
10	Carbon Total (tons/ha)	Area1	1	109.9
11	Number of tally trees	Area1	2	25
12	Number of trees/ha	Area1	2	1675
13	Basal area (m2/ha)	Area1	2	15.6
14	Volume (m3/ha)	Area1	2	112.1
15	VolumeBole (m3/ha)	Area1	2	13.1
16	Biomass AG (tons/ha)	Area1	2	304.9

Fig. 11. Sheet ‘PlotResults’

Sheet ‘StandTables’ contains various result tables, where results are frequency results (i.e. number of trees) are aggregated by strata, species group, and diameter classes. The first table (see Fig. 12) shows result data that is applicable input data for simulations. If required, the user can edit the diameter class limits, but in that case the calculation should be rerun in order to get the results.

Note: diameter class limits are given as text string, for instance ‘20-29’ (starting with Single quote). Look at Excel table’s cells to get acquainted with the markings.

Stratum	Species Group	For simulation: Frequency by diameter classes (trees/ha)								
		1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
Area1	Timber_Species	104.8	32.1	14.7	9.5	7.9	4	3.6	1.2	0.8
	Pole_Species	82.5	31	9.9	5.6	4.4	1.6	0.8	0	0
	Food_Species	36.5	7.9	2.4	2.4	0.8	0.4	0	0.8	1.6
	Medicine_Species	281	55.2	6.7	3.2	1.2	1.6	0	0	0
	Firewood_Species	41.3	19.8	15.9	2	0.4	0	0	0	0

Fig. 12. Sheet ‘StandTables’, results by DBH classes (and input data for simulations)

Diameter classes in the previous table were adjusted to fit for simulations but these may not be applicable for local reporting. Therefore there are also tables titled as ‘Utilization’ where DBH limits may be defined following the local reporting requirements set e.g. for different timber assortment classes, or equivalent (Fig. 13).

Stratum	Species Group	Utilization: Frequency by diameter classes (trees/ha)					
		1-3	4-7	8-14	15-29	30-49	50+
Area1	Timber_Species	33.3	71.4	23	23.8	17.5	9.5
	Pole_Species	15.9	66.7	18.3	22.6	9.9	2.4
	Food_Species	15.9	20.6	4	6.3	3.2	2.8
	Medicine_Species	79.4	201.6	36.9	25	4.4	1.6
	Firewood_Species	9.5	31.7	7.1	28.6	2.4	0

Fig. 13. Sheet ‘StandTables’, results by DBH classes (tree utilization classes)

The last table on ‘StandTables’ shows the frequencies of trees by strata and by timber use classes (Fig. 14). These timber use classes were given as attributes for each single tally tree, and one tree can belong into more than one class. Therefore it is possible the total sum of these frequencies may exceed the actual total number of trees in stratum. So, the total sum should not be computed and reported.

Stratum	Timber use: Frequency (trees/stratum)				
	Timber	Medicinal	Fuelwood	Food	Pole
Area1	95238.1	255952.4	452976.2	16666.7	198214.3

Fig. 14. Sheet ‘StandTables’, results by tree use classes

4 Forest Simulator

4.1 About simulation

The forest simulator is applicable for forecasting the future development of forest stands. It can be used to examine the development of forest under different harvesting regimes (with selective cuttings), or untreated. This module uses results from the assessment module as the input data. One of the main variables of interest is the Annual Allowable Cut (AAC) that can be determined both graphically and numerically. However, in the current program version, the output tables are fixed to show simulation results for 2 x 10 years simulation periods (i.e. 20 years simulation), although the simulator's program code does not have such limitations.

The harvesting model of the Forest Simulator is based on MYRLIN #3 simulation system⁶. It comprises a simple stand projection model that simulates growth and harvesting on coupes of equal areas. The objective of the MYRLIN model is to provide projections of sustainable harvesting that is possible, subject to:

- Species occurrence and distribution, indicated by the stand tables;
- Growth and mortality rate information;
- Logging damage levels;
- Harvesting prescriptions and rules, including diameter limit and felling cycle.

The harvested quantities from the model, by coupe and year, can form the basis of a management plan schedule.

The simulation program can

- Compute estimates for total bole volume and commercial bole volume;
- Grow trees using DBH increment model (see Chapter 5.2);
- Simulate mortality, ingrowth and transfer of trees to upper DBH classes;
- Split larger compartments into coupes;
- Calculate future yield and AACs (for two felling cycles);
- Visualize key results as graphs.

⁶ MYRLIN is an open-(VBA-)source Excel application originally developed by a project undertaken by the Oxford Forestry Institute. See more information about MYRLIN under Chapter 1.

4.2 Parameters for simulation

The simulation requires the following parameters (Fig. 15):

- Length of felling cycle. It determines the area of forest felled during any one period, and the return period to a given coupe. Default value: 10 years.
- Damage factor. Damage to remaining stand⁷.
- Time interval (i.e. step in simulation. Default in Tanzania: 1 year.
- Time limit (i.e. length of simulation). Default in Tanzania: 20 years.
- Area tolerance % (MYRLIN parameter to regulate relative variation in sizes of coupes)⁸
 - If no logging simulation, set Area tolerance to 100%.
 - If logging simulation with quite even size coupes, set 90%.
- Recruitment factor. The model assumes that each tree that dies or is felled will be a replaced by default at 1:1 (100%) recruits at the smallest measured size.
- First simulation year.
- Minimum DBH for a bole log.
- Parameters by species groups:
 - Annual DBH increment (Dinc), in cm/year:
 - 1) Blank: use programmed growth model;
 - 2) Numeric value: use constant increment rate.
 - Annual mortality rate (AMR), % of all trees.
 - Minimum diameter limit in harvest (Dlim).

Increasing the diameter limit will reduce the number of trees which may be felled, and will therefore directly reduce harvest drain.
 - Harvest intensity (of number trees exceeding the diameter limit to be harvested during the felling cycle). If this field is left blank, then that species group is not harvested in the simulation.
 - Average wood density (WD), in kg/m³. If this field is left blank then the default average wood density is applied.

⁷ The logging damage factor is a multiplier applied to the ratio of harvested volume over standing volume to calculate damage in each size class as a percentage of the number of stems. For example, if 20% of the stand volume is harvested, and the damage factor is 1 (or 100%), then 20% of each size class (after felling removals) will be assumed to die or be severely damaged during felling. The formula used in the model is as follows: $f = F \times Vh / Vst$ where f is the damage % applied to each size class, F is the damage factor entered as a model parameter, Vh is volume harvested, and Vst is volume before harvest.

According to MYRLIN Manual, a damage factor of 1 (100%) is suggested as an appropriate rule-of-thumb if no better information is available from local damage studies. Note that the damaged trees include non-commercial stems and smaller sizes classes, so the actual impact on advance growth of commercial species may be minimal.

⁸ The model will determine a coupe area based on the felling cycle. The area tolerance is the percentage deviation in coupe area that may be allowed in order to make coupes correspond as much as possible with forest blocks. By setting it to a value of around 5%, the model avoids dividing blocks into sub-blocks that are small slivers of forest of a few ha.

- Parameters to compute forest carbon stock results (applicable for all species):
 - Biomass Expansion Factor (BEF),
 - Root/Shoot conversion factor,
 - Carbon factor (to convert biomass to carbon),
 - Default average wood density, in kg/m³.

A	B	C	D	E	F	G	H
Simulation parameters		Biomass and carbon parameters				<u>Source</u>	
Felling cycle (yrs)	10		BEF	3.4		IPCC LUCF Sector Good Practice	
Damage factor	100 %		Root/Shoot	0.48		As above. TABLE 3A.8. p. 167. (1	
Time interval (yrs)	1		Carbon factor	0.5			
Time limit (yrs)	20		Aver. WD	800			
Area tolerance %	90 %						
Recruitment factor	100 %		Min. bole DBH	10 cm			
First simulation year	2013						
Allow to split coupe	Y					RUN SIMULATION	
Species or species group parameters (max. 20 groups)							
For species grouping in forest assesment and simulation.							
Species or group name		Dinc	AMR	Dlim	Harv%	WoodDensity	
Timber_Species	->		1.0%	20	10 %		
Pole_Species	->		1.0%	10	5 %		
Food_Species	->		1.0%				
Medicine_Species	->		1.0%				
Firewood_Species	->		1.0%	10	5 %		

Fig. 15. Sheet ‘SpeciesGroupParameters’: main interface for forest simulator.

4.3 Simulation results

The simulation results go into the sheets ‘Yield’ and ‘Table1’. Sheet ‘Yield’ shows a schedule of coupes produced by the simulation model. An example of this output is shown in Fig. 16.

A	B	C	D	E	F	G	O	P	Q
Year	Stratum	Area	VolTotalStanding	VolBoleStanding	VolBoleCommStanding	VolBoleHarvest	Basal Area	N_Trees_HA	N_TreesHarvest
0	Area1{0}	150	21 584.6	12 397.2	8 231.8	1 103.8	23.0	1 119.2	689.5
0	Area1	1350	194 261.4	111 574.8	74 086.0		23.0	1 119.2	
1	Area1{0}	150	19 290.1	10 993.2	7 079.5		20.6	1 013.3	
1	Area1{1}	150	22 053.9	12 672.5	8 376.3	1 119.7	23.6	1 119.2	701.6
1	Area1	1200	176 431.4	101 379.9	67 010.3		23.6	1 119.2	
2	Area1{0}	150	19 752.9	11 263.5	7 212.6		21.4	1 119.2	
2	Area1{1}	150	19 724.0	11 247.8	7 212.5		21.1	1 014.0	
2	Area1{2}	150	22 529.1	12 951.4	8 525.1	1 136.0	24.1	1 119.2	714.2
2	Area1	1050	157 703.4	90 659.8	59 675.6		24.1	1 119.2	
3	Area1{0}	150	20 222.0	11 537.7	7 350.3		21.9	1 119.2	

Fig. 16. Sheet ‘Yield’: schedule of coupes.

The column ‘D’ gives the total standing volume of the block, for all species and size classes in the model. The column ‘E’ shows the bole volume of all species before harvesting. The column ‘F’ shows the volume of commercial species, above the minimum felling diameter, before harvesting. Column ‘G’ shows the volume actually harvested. Within each time period, there is one line for each coupe, which also gives the coupe area in hectares. The model harvests a fixed area in each simulation period (see more in Alder *et al.* 2002, p. 32).

This table can be manipulated in various ways using standard Excel tools and functions to provide other information and graphs. For example, by sorting on the *Stratum* field, then on *Year*, the history of each block and its sub-divisions will be seen more clearly.

The graph on sheet ‘Fig1_Volume’ is presented in Fig. 17. The graph lines correspond to the columns on the worksheet ‘Table1’ (Fig. 18). The figures shown fluctuate from period to period because the MYRLIN#3 model controls felling on an area rather than a volume basis.

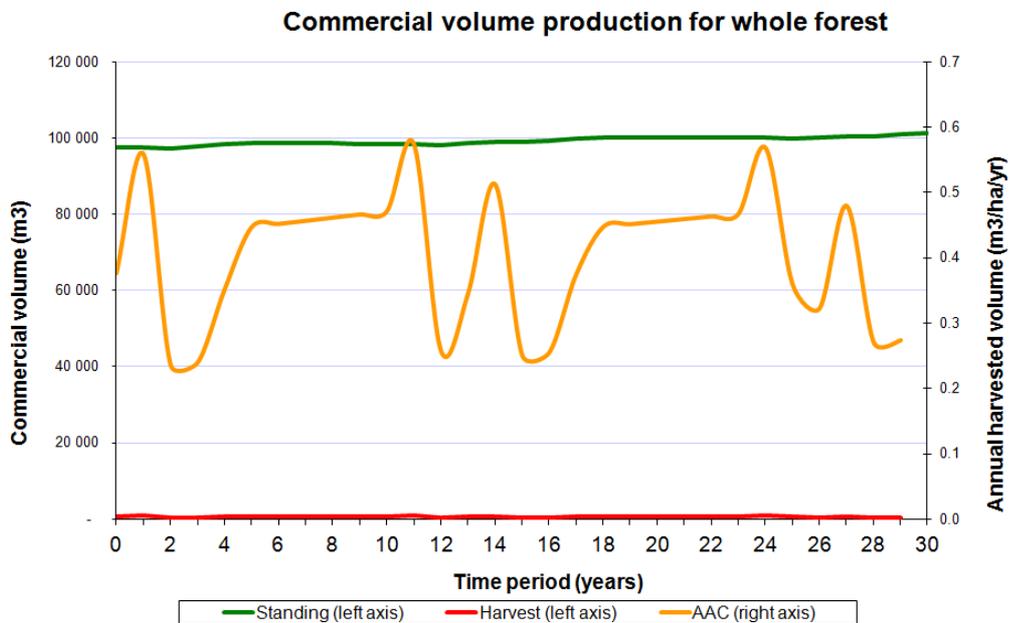


Fig. 17. Sheet ‘Fig1_Volume’. This simulation example is from Lao PDR.

Standing commercial volume is shown as a green line, read from the left axis, in total m³. This is the volume above the minimum felling diameter, for the species groups indicated as commercial.

Harvested volume is shown in red against the left axis, in m³. It shows the actual volume removed during each simulation period.

Annual allowable cut (AAC) is indicated by a yellow line. It is read from the right axis, and shows the harvest removed in terms of m³/ha/year.

	A	B	C	D	E	F	G	
Year	TVolHa	TBoleVol_HA	VolBoleCom	VolHarvest	AAC	C Standing Stock	C I	
0	144	82.6	82 317.8	1 104	0.7	434 455		
1	145	83.4	82 466.0	1 120	0.7	438 338		
2	146	84.1	82 625.8	1 136	0.8	442 231		
3	148	84.8	82 795.3	1 153	0.8	446 129		
4	149	85.5	82 972.8	1 170	0.8	450 025		
5	150	86.2	83 156.7	1 187	0.8	453 917		
6	152	87.0	83 345.3	1 205	0.8	457 798		
7	153	87.7	83 537.2	1 224	0.8	461 665		
8	154	88.4	83 730.7	1 242	0.8	465 512		
9	155	89.1	83 924.5	1 261	0.8	469 336		

Fig. 18. Part of simulation results on sheet 'Table1'

4.4 Determination of sustainable AAC

One of the most important aspects of yield regulation is the determination of the **Annual Allowable Cut (AAC)** or prescribed yield⁹. Allowable cut is the harvest corresponding to sustainable yield.

Allowable Cut	A clearly expressed specification of the average quantity of wood (or other product), usually in an approved management plan, that may be harvested from a forest management unit, annually or periodically over a specified period. Usually expressed as quantity per unit area.
Prescribed Cut	
Prescribed Yield	
Permissible Yield	

A simple criterion for securing sustainability of future timber yield is to examine development of growing stock, and AACs of two cycles. In briefly, future growing stock should be at least on the same level as current (inventory) stock, and AAC of felling cycle 1 should be less than or equal to AAC of felling cycle 2. In practice – depending of the forest structure, growth, and recovery rate of forest after felling – this goal is not achievable. In these cases it should seriously considered the recommending other management options than timber harvest, as planting, afforestation, protection, etc.

The results on sheet 'Table1' should be followed after running the simulation (Fig 19). The program shows AACs for both felling cycles, minimum annual harvest level, standing stock (of bole volume) and commercial volume at three time points: 0, 10 and 20 years, respectively. In addition, there is a table showing standing stock by tree species groups. The program also computes results for annual carbon stock, and there are results also for net carbon sequestration for two 10-years periods.

⁹ Yield usually implies standing volume commercial timber, but can include non-timber forest products (NTFPs). However, NTFPs are not included into this calculation system.

Area			
	1 500.0 ha		
AAC, during first 10 years cycle			
	0.8 m3/ha	(annual average)	
	7.9 m3/ha	in 10 years	
Total	11 801.6 m3	in 10 years	
AAC, during the second cycle			
	0.8 m3/ha	(annual average)	
	7.8 m3/ha	in 10 years	
Total	11 676.5 m3	in 10 years	
Minimum annual harvest			
Period	Harvest		
0-10	1 103.8 m3		
10-20	1 084.5 m3		
Standing stock (bole volume)			
Year	Volume		
0	82.6 m3/ha		
10	89.8 m3/ha		
20	98.5 m3/ha		
Standing stock (bole volume commercial)			
Year	Volume		
0	54.9 m3/ha		
10	56.1 m3/ha		
20	58.9 m3/ha		
Net carbon sequestration, first 10 years period			
Carbon	38 677.8 tons in 10 years		
Carbon	3 867.8 tons/year		
Carbon	2.6 tons/ha/year		
CO ₂	14 156.1 tons/year		
CO ₂	9.4 tons/ha/year		
Net carbon sequestration, second 10 years period			
Carbon	45 871.0 tons in 10 years		
Carbon	4 587.1 tons/year		
Carbon	3.1 tons/ha/year		
CO ₂	16 788.8 tons/year		
CO ₂	11.2 tons/ha/year		

Fig. 19. More simulation results on sheet 'Table1'

Next, three alternative forest treatment alternatives are presented with their outcomes. Data is got from Nachingwea District, Lindi Region, Tanzania:

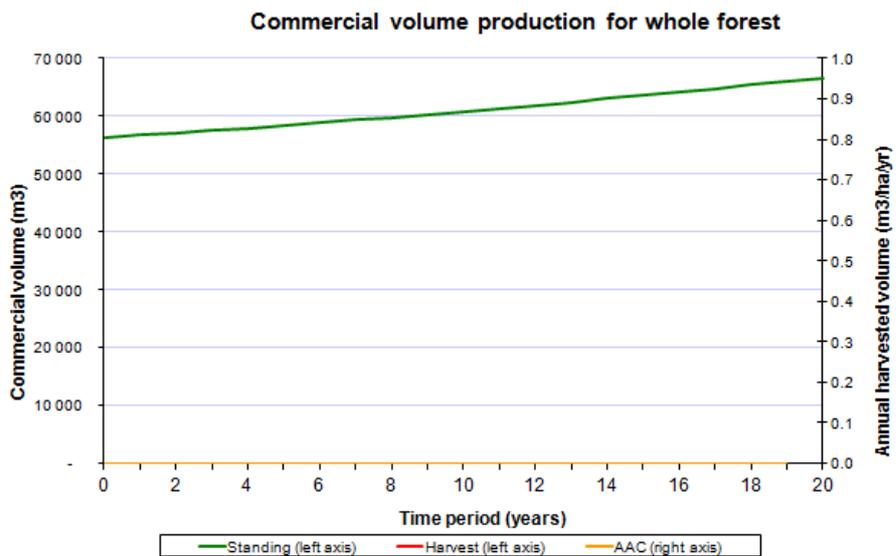
- A. Simulation with no felling,
- B. Simulation with high harvest intensity, and
- C. Simulation with sustainable the future yield.

Option A. Simulation with no felling,

Area tolerance set to 100% (= no felling simulated).

Area tolerance %

Outcomes:



AAC, during first 10 years cycle		
	0.0 m3/ha	(annual average)
	0.0 m3/ha	in 10 years
Total	0.0 m3	in 10 years
AAC, during the second cycle		
	0.0 m3/ha	(annual average)
	0.0 m3/ha	in 10 years
Total	0.0 m3	in 10 years

This alternative gives a growing stock, but not harvest drain could be got. This simulation can give estimates for future status of totally protected stands.

Option B. Simulation with high harvest intensity.

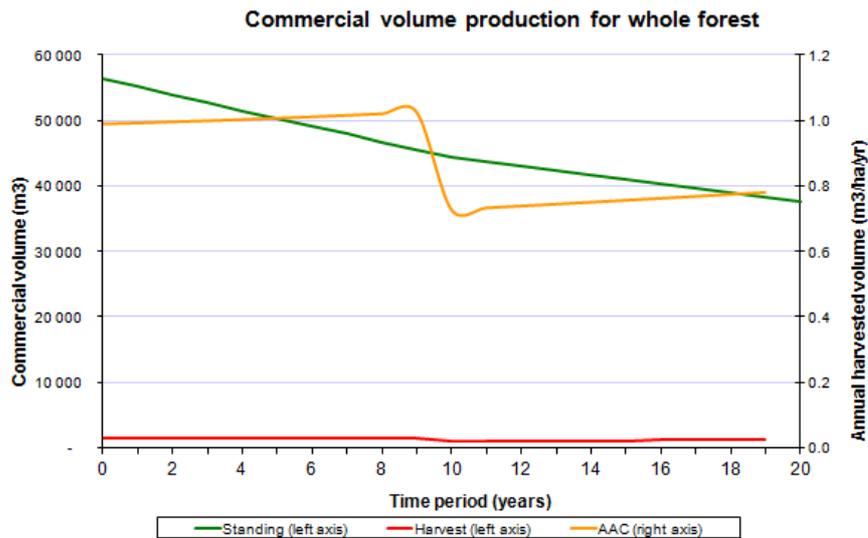
Area tolerance set to 90% (= equal size coupes).

Area tolerance %

Harvesting intensity is rather high: 20% of trees belonging to *Timber_Species* group are felled during a felling cycle.

Species or group name		Dinc	AMR	Dlim	Harv%
Timber_Species	->		1.0%	20	20 %
Pole_Species	->		1.0%	10	10 %
Food_Species	->		1.0%		
Medicine_Species	->		1.0%		
Firewood_Species	->		1.0%	10	5 %

Outcomes:



AAC, during first 10 years cycle		
	1.0 m3/ha	(annual average)
	10.0 m3/ha	in 10 years
Total	15 073.0 m3	in 10 years
AAC, during the second cycle		
	0.8 m3/ha	(annual average)
	7.5 m3/ha	in 10 years
Total	11 309.0 m3	in 10 years

This alternative gives a declining trend for future growing stock. Similarly, AAC in the second felling cycle will be less than during the first felling cycle, so forests' capacity to provide timber in the future will decline. This alternative will not provide basis for sustainable AAC.

Option C. Simulation with sustainable the future yield.

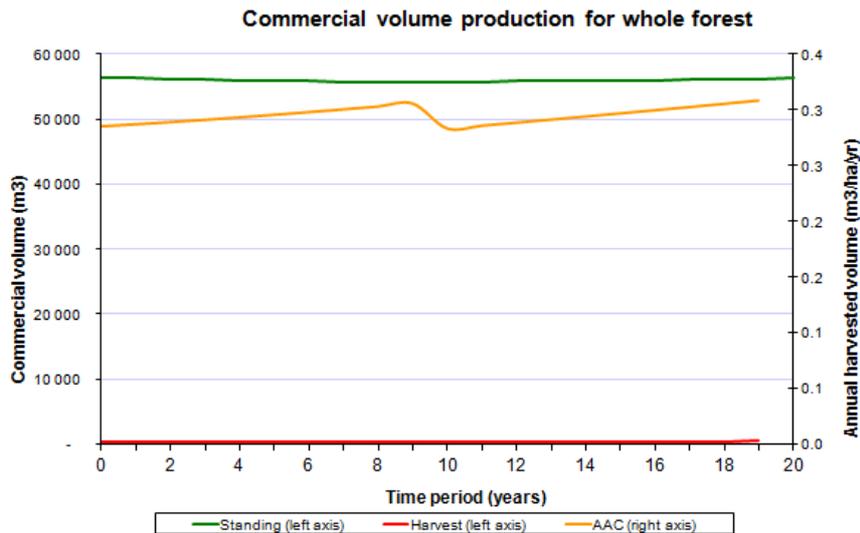
Area tolerance set to 90% (= equal size coupes).

Area tolerance %

Harvesting intensity is set so that AAC[Cycle1] is less than or equal to AAC[Cycle2]. This can be sought empirically.

Species or group name		Dinc	AMR	Dlim	Harv%	WoodDensity
Timber_Species	->		1.0%	20	4.0 %	
Pole_Species	->		1.0%	10	4.0 %	
Food_Species	->		1.0%			
Medicine_Species	->		1.0%			
Firewood_Species	->		1.0%	10	5.0 %	

Outcomes:



AAC, during first 10 years cycle		
	0.3 m3/ha	(annual average)
	2.9 m3/ha	in 10 years
Total	4 423.7 m3	in 10 years
AAC, during the second cycle		
	0.3 m3/ha	(annual average)
	3.0 m3/ha	in 10 years
Total	4 435.0 m3	in 10 years

This alternative gives a slightly growing trend for future (commercial) timber stock. Similarly, AAC in the second felling cycle will be about the same as during the first felling cycle, so forests' capacity to provide timber in the future will not decline. This alternative may provide basis for sustainable AAC.

5 Models applied in Tanzania, Lindi Region

5.1 Models in VBA

All models are coded in VBA language. These can be found through MS Visual Basic Editor in 'Module2'. The functions are in the subroutines (Table 2). When tailoring this application to new areas, these models can be changed into the program code.

Table 2. List of static and dynamic tree functions

Variable	Function name	Arguments	Remarks
Tree top height	<i>ComputeHeight</i>	SpeciesGroupIndex As Integer, DBH As Double	Height: in m; DBH, in cm
Bole height	<i>ComputeHeightBole</i>	SpeciesGroupIndex As Integer, DBH As Double	Only used in Simulator
Stem volume	<i>ComputeTreeStemVolume</i>	SpeciesGroupIndex As Integer, DBH As Double, HeightTotal As Double	Volume, in m ³ ; Height, in m; DBH, in cm
Bole volume	<i>ComputeTreeBoleVolume</i>	SpeciesGroupIndex As Integer, DBH As Double, HeightBole As Double	<i>As above</i>
DBH increment	<i>ComputeDBHIncrement</i>	SpeciesGroupIndex As Integer, DBH As Double, BasalArea As Double	DBH incr., in cm/year; DBH in cm; BasalArea in m ² /ha

Tree height model for Lindi Region was computed in 5/2013 using NAFORMA field data from Lindi Region¹⁰. The model's data comes from Woodlands vegetation type only.

$$Height = 1.3 + DBH^2 / (1.9233 + 0.2358 * DBH)^2$$

In Forest Assessment, the missing bole height is not modelled. If a tally tree has no bole height, then it is not computed and that tree gets no bole volume either.

In Simulator, the bole height is computed with the default model for Lindi Region, as follows

$$HeightBole = 2.6517 * \text{Log}(DBH) - 3.8352$$

¹⁰ These temporary models can be replaced when more applicable and tested models come available. Height models were created by FAO Consultant.

The total tree volume is computed with a form factor model, as follows:

$$\text{StemVolume} = \text{Pi} * 0.5 * \text{DBH}^2 / 40000 * \text{Height}$$

Similarly, the bole volume is computed as follows:

$$\text{BoleVolume} = \text{Pi} * 0.68 * \text{DBH}^2 / 40000 * \text{HeightBole}$$

5.2 Annual diameter increment

For projection of future yield, in all but the simplest of systems some estimate of the rate of growth of the forest is needed. However, in 5/2013 there were no applicable DBH increment functions in Tanzania for miombo forest lands¹¹. Therefore the system contains a temporarily adopted the growth curve presented by Kuutti (2008) in Valkonen *et al.* 2008 (see Fig. 18). An alternative method would be to use a static mean annual DBH growth rate for all sizes of trees (by species groups).

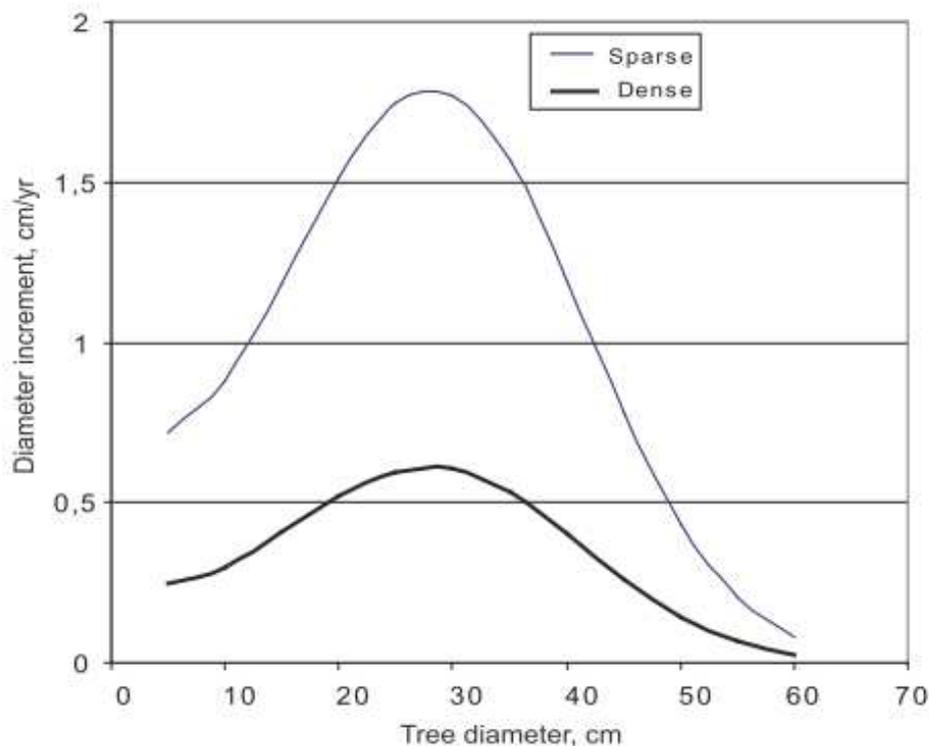


Fig. 20. Tree diameter increment according to Kuutti (2008) in Valkonen *et al.* 2008. Stand basal area for “sparse” where basal area = 5 m²ha⁻¹, and “dense” where basal area = 14 m²ha⁻¹.

The DBH increment curves were modelled and applied in the system. The maximum growth rate was set match with the upper curve (of “sparse stand”) presented in Fig. 20, and the minimum growth rate with the lower curve. Hence, the system first computes the estimate for the stand basal area, and then it computes annual DBH growth estimate according to tree’s diameter and stand basal area.¹²

¹¹ Prof. R. Malimbwi, Sokoine University of Agriculture (SUA).

¹² This model can be replaced when more applicable and tested models comes available.

References

- Alder, D; Baker, N; Wright, HL. 2002. MYRLIN: Methods of Yield Regulation with Limited Information. University of Oxford, Oxford Forestry Institute. Online publication. <http://www.myrlin.org>
- FAO. 1998. Guidelines for the Management of Tropical Forests, 1. The production of wood. FAO Forestry Paper 135. <http://www.fao.org/forestry/62268/en/>
- FAO. 2004. Simpler Forest Management Plans for Participatory Forestry. Forestry Policy and Institutions Service, Forestry Policy and Information Division, Forestry Department 68 p. <http://www.fao.org/docrep/008/j4817e/j4817e00.HTM>
- FAO. 2010. Guidelines on sustainable forest management in drylands of sub-Saharan Africa. Arid Zone Forests and Forestry Working Paper 1. 47 p. <http://www.fao.org/docrep/012/i1628e/i1628e00.pdf>
- Freese, F. 1962. Elementary Forest Sampling. Handbook No. 232, Forest Service, U.S. Department of Agriculture. USA. 91 p.
- IPCC. 2003. Good practice guidance for land use, land-use change and forestry The Intergovernmental Panel on Climate Change. IPCC/IGES, Hayama, Japan.
- IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use. IPCC/IGES, Hayama, Japan.
- Valkonen S., Elifuraha E. and Kiluma L. 2008. Application of modeling to study tree diameter growth in miombo woodland stands at Kitulangalo Forest Reserve, Tanzania. Working Papers of the Finnish Forest Research Institute 98. <http://www.metla.fi/julkaisut/workingpapers/2008/mwp098.htm>
- Wright, HL & Alder, D. [Ed.]. 2000. Humid and semi-humid tropical forest yield regulation with minimal data. Workshop proceedings, CATIE, Costa Rica, 5-9 July 1999. Oxford Forestry Institute Occasional Papers 52. 95 pp. Papers from <http://www.bio-met.co.uk/myrlin/A01a.htm>

Appendix 1

Reliability estimates

Here is the description of methods used to compute the statistical information by forest strata (see e.g. Freese, 1962).

Mean of the stratum.

$$\bar{X}$$

The mean of sample plots' volumes. In this program each sample plot has an equal weight in the stratum.

The standard deviation (s_x) is the basic measure of plot-to-plot variability.

$$\sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n - 1}}$$

where n = number of sample plots

The standard error (SE) in sampling without replacement is computed as

$$SE = \sqrt{\frac{s_x^2}{n} \left(1 - \frac{n}{N}\right)}$$

If $n/N < 0.05$ (in terms of areal sampling intensity), the program ignores the finite population correction and uses the shortened form as follows

$$SE = \sqrt{\frac{s_x^2}{n}} = \frac{s_x}{\sqrt{n}}$$

where s_x^2 = variance between plot volumes

n = number of sample plots in stratum

Coefficient of variation (CV).

$$CV = \frac{s_x}{\bar{X}}$$

Usually presented as percents (multiplied by 100).

Results for the total inventory area (in terms of volume)

The mean of the stratified sample is computed by:

$$\bar{X}_{ST} = \frac{\sum_{h=1}^L N_h * \bar{X}_h}{N},$$

where L = The number of strata

N_h = The size of stratum h (h = 1, 2, ..., L) in ha

N = The total size of the area in hectares $(N = \sum_{h=1}^L N_h)$

The standard deviation (SD) is computed as follows:

$$SD_{ST} = \sqrt{\frac{1}{W^2} \sum_{h=1}^L W_h^2 s_h^2}$$

The stratified **standard error** (SE_{ST}) of the mean volume (per hectare) is computed (in the short form) as follows:

$$SE_{ST} = \sqrt{\frac{1}{W^2} \sum_{h=1}^L \left[\frac{W_h^2 Var_h}{n_h^2} \right]}$$

where Var_h = variance in stratum h

n_h = number of plots in stratum h

W_h = area (ha) in stratum h

W = total size of the area in hectares

95% confidence interval¹³ for (cubic meter) volume per hectare:

$$\bar{X}_{ST} \pm t_{0.05, n-1} * SE_{ST}$$

where t = Student t-table value,

n - 1 = degrees of freedom.

¹³ The IPCC Good Practice Guidance (2003, 2006) suggests the 95%-confidence interval to quantify the uncertainty of estimates.

Appendix 2

Tally sheet for Tanzanian forest assessment for management planning

