DESIGNING NATIONAL LEVEL AND SUB-NATIONAL LEVEL FOREST INVENTORY FOR UN-REDD NATIONAL FOREST MONITORING SYSTEM OF MYANMAR

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ABSTRACTS: Geo-Informatics and Sampling Statistics play an important role in designing National Level and Sub-National Level Forest Inventory for National Forest Monitoring System of Myanmar to collect data spatial explicitly and generate the estimates of resource quantity at the desired level of accuracy at the affordable budget. This paper will discuss how integrated application of Geo-Informatics, Forestry and Sampling Statistics create National Level and Sub-National Level Forest Inventory System of Myanmar to achieve desired level of statistical accuracy. This paper will highlight the estimations of important statistical parameters from existing forest inventory data for designing forest inventory and resource quantity at the Plot Level, Per Hectare Level, and Study Area Level. Then this paper will demonstrate how to apply these parameters for designing National Level and Sub-National Level Forest Inventory for UN-REDD National Forest Monitoring System to achieve the desired level of accuracy at the affordable budget.

STUDY AREA

Myanmar is endowed with rich natural resources and biodiversity, with 45% of its land area covered by forests. Myanmar has the second largest forest cover and some of the most ecologically intact forest remaining in South-East Asia, with globally significant biodiversity resources. The forestry sector has traditionally played a critical role in the development and economic transformation of the country but, over the years, extractive operations have become more intensive. The country has relied heavily on natural forests, teak and other valuable species, to boost export revenue, provide energy, forest products and livelihoods for its population.

In principle, the forestry sector of Myanmar has potential for generating value-adding and diversifying production and exports. This has not yet happened and, instead, forest resources have been utilised unsustainably through over-cutting driven by revenue targets, illegal logging and trade, planned agri-business conversions, shifting cultivation and fuelwood extraction.

It is important to develop the National Sampling Framework for creating Forestry, Environment and Ecological data reliably, harmoniously and scientifically. It is important to fill the data and information gaps which will positively impact the quality of research and projects in relation to forestry, environment, ecology and biodiversity of the Nation.

It is recognized that the Multipurpose **N**ational **F**orest **I**nventory/**N**ational **F**orest **M**onitoring **S**ystem (NFI/NFMS) is required in order to fill the data, information and knowledge gap in relation to **S**ustainable **F**orest **M**anagement (SFM), Reducing Emission from Deforestation and Forest Degradation (REDD) and carbon emissions.

This paper discussed the Sampling Intensity, Sampling Errors, Sampling Cost and their relationships to design the National Sampling Framework for development of NFI/NFMS Myanmar.

OBJECTIVES

The main objective is to develop statistically robust and financially affordable flexible National Sampling Framework**s** which will produce reliable estimates on timber and non-timber quantities, forest biomass, forest carbon, biodiversity and ecological health indicators for NFI/NFMS Myanmar.

METHODOLOGY

Sampling with Fixed Area Plots

According to the theory of Sampling with Fixed Area Plots, the following statistical proration are derived and implemented in R statistics. (Gregoire et.al 2008)

"A" denotes the Area of study area such as a country, reserved forest, forest compartment or plantation etc. A contains m sample plots. The "**a**" denotes the area of a plot. The "y_i" denotes the measurement of individual quantity such as volume, biomass, and basal area of individual tree in the plot.

The population total T_y is derived as $\sum_{i=1}^{n}(yi)$ at the plot level.

The population mean per unit area is $\lambda_i = \sum_{i=1}^{n}(yi)\,/A$.

Inclusion probability (π) of a tree to a sample plot is derived as a/A. Inclusion zone has the same area of plot but orientation is different. The inclusion zone of circular plots and rectangular plots are straight forward. Therefore circular plots and rectangular plots are more common than other shapes like a star or an ell or a hexagon.

Each cluster plot can provide the independent estimate of population total $T_{y.}$ Therefore, inclusion probability of individual tree is $\pi_i = a_i/A$.

For the S^{th} plot, the independent estimate of population could be denote as $\hat{T}_{y\pi s}$ and the estimator is

$$\hat{\tau}_{y\pi s} = \sum_{U_i \in s} \frac{y_i}{\pi_i}.$$

Substituting $\pi_i = a_i/A$ into $\hat{\tau}_{y\pi s}$ yields $\hat{\tau}_{y\pi s} = A \sum_{U_i \in s} \frac{y_i}{a_i}$, which, barring edge trees, is identical to

$$\hat{\tau}_{y\pi s} = \frac{A}{a} \sum y_i = A\left(\frac{\text{plot total } y_i}{a}\right)$$

where the parenthesized term is the amount of the resource observed on the plot *prorated* to a per unit area (per acre, or per hectare, etc.) basis.

The $\hat{T}_{y\pi s}$ values varies from one plot to another provide the direct empirical evidence of how much the resource varies from one place to another with the study area A.

As there is m of these independent estimates $\hat{T}_{y\pi s}$ where s = 1, 2….m from m plots, average them together to get the unbiased estimator of T_y which will be denoted as $\hat{T}_{y\pi,\,rep.}$

$$\hat{\tau}_{y\pi,\text{rep}} = \frac{1}{m} \sum_{s=1}^{m} \hat{\tau}_{y\pi s}$$

Sample variance values among the $\hat{T}_{y\pi s}$ will be similar to the sample variance S^2_y of other context and it could be derived as follow.

$$s_y^2 = \frac{1}{(m-1)} \sum_{s=1}^{m} (\hat{\tau}_{y\pi s} - \hat{\tau}_{y\pi,\text{rep}})^2$$

As the plots are allocated at the simple random sample framework or systematically sufficient far apart to each other that there is no correlation between neighboring plots, the systematic layouts of plots is essentially equivalent to simple random sampling of plots. Therefore unbiased estimator of variance is derived as follow.

$$\hat{v}(\hat{\tau}_{y\pi,\text{rep}}) = \frac{s_y^2}{m} = \frac{1}{m(m-1)} \sum_{s=1}^{m} (\hat{\tau}_{y\pi s} - \hat{\tau}_{y\pi,\text{rep}})^2$$

For Per Unit Area (density) estimation $\lambda_{y,}$ the amount of y per unit area is denoted and estimated as follow.

$$\widehat{\lambda}_{y\pi,\text{rep}} = \widehat{\tau}_{y\pi,\text{rep}}/A$$

The variance is estimated as follow,

$$\widehat{\mathrm{v}}(\widehat{\lambda}_{y\pi,\text{rep}}) = \frac{1}{A^2}\widehat{\mathrm{v}}(\widehat{\tau}_{y\pi,\text{rep}})$$

Then the usual statistics is applied to derive the percent coefficient of variation (%CV), standard error percent (%SE), Margin of Error % (%MERR), upper limit estimate and lower limit estimate based on the $\widehat{T}_{y\pi,\text{rep}}$, S^2_{y}, $\widehat{\lambda}_{y\pi,\text{rep},}$ $\widehat{V}(\widehat{\lambda}_{y\pi,\text{rep}})$ and $\widehat{V}(\widehat{T}_{y\pi,\text{rep}})$. R statistics package is applied to implement the plot sampling statistics for National Forest Inventory and Forest Resources Assessment.

The relationship between %CV, %MERR and Sample size is the imperative in order to determine the sample size which will define the sampling intensity.

Estimation of Anticipated Number of Sample Plots and Proration of % Margin of Errors

Statistically, **the number of required sample plots (n)** could be estimated to achieve the **desired %MERR** based on the following statistical relationship. (Gregoire et. al 2008)

$$\boldsymbol{n_0=(t^2 \times r_y^2)/d_r^2}$$

n_0 = Preliminary Number of required sample plots
t = t value at 90% or 95% Confidence Interval based on very large sample number such as 10000
r_y = % Coefficient of Variation (Note: Percentage value)
d_r= desired % Margin of Error (Note: Percentage value)

$$\boldsymbol{n=(t^2 \times r_y^2)/d_r^2}$$

n = Final Number of required sample plots
t = t value at 90% or 95% Confidence Interval based on sample number n_0
r_y = % Coefficient of Variation (Note: Percentage value)
d_r= desired **%** Margin of Error (Note: Percentage value)

The sample size equation $\boldsymbol{n = (t^2 \times r_y^2)/d_r^2}$ based on the %CV and desired %MERR could be rearranged as follow to prorate the **%** Margin of Error if the expected number of samples (**Anticipated n**) is known for a Nation such as Country or Sub-Nation such as county, state, division, canton, district, county, township and village tract. Normally, spatial analyses functions of the Geographic Information System (GIS) could be applied to estimate the Anticipated n.

$$\boldsymbol{d_r = (t \times r_y)/\sqrt{n}}$$

n = Anticipated n or expected number of sample plots in each District or State & Division
t = t value at 90% or 95% Confidence Interval based on Anticipated n
r_y = % Coefficient of Variation (Note: Percentage value)
d_r= Prorated % Margin of Error (Note: Percentage value)

DATA

Spatial Data

The following data sets are selected to estimate the expected number of samples (Anticipated n) for each State, Division and District of Myanmar at the sampling distance of 1km, 2km, 3km, 4km, 5km, 6km, 7km, 8km, 9km, 10km, 11km, 12km, 13km, 14km, 15 km and 16 km sampling intervals throughout the Myanmar.

(1) National Boundary of Myanmar
(2) State & Division Boundary of Myanmar
(3) District Boundary of Myanmar
(4) Forest Cover data (2015) derived from Landsat Data

Forest Management Inventory Data

In order to estimate the %CV, %MERR, %SE of different forest types of Myanmar, the following recent available Forest Management Inventory (FMI) Data were analysed using the R Statistics based on the Sampling with Fixed Area Plots theory.

Table-1: FMI Data

Sites	Area (Ha)	Plot Size (Ha)	Number of Plots	Sampling Intensity	Remark
Shwebo	1,495,034	1	175	0.0117%	Large Plot Size
Katha	1,586,230	1	666	0.0420%	Large Plot Size
Taungoo	308,982	0.7854	569	0.1446%	Large Plot Size
Monywa	347,568	1	190	0.0547%	Large Plot Size
Dawei	1,378,218	1	109	0.0079%	Large Plot Size

The tree table of each data set contains the attributes of each tree. The important attributes for this study is species, genus, diameter at breast height (DBH), and height (H) and basal area (BA) of each tree. The volume of each tree is estimated based on the "Tree Volume Equations for Myanmar by J.W.Leech, Aung Kyaw Myint, Shwe Kyaw and Htun Lynn, Yangon March 1990". "Trees Volume Equations of Myanmar" provided the polynomial regression parameters for estimation of timber volume (cubic meter) from Diameter at Breast Height (DBM in cm) for different group of species at different region of Myanmar. This study found that the tree volume equations of Myanmar have the weakness due to **the multicollinearity of DBH** repeated many times in the same equation. This study applied the number of trees (frequency) and basal areas of the trees as the target parameters for the designing purpose although tree volumes are also calculated.

IMPORTANT RESULTS

Analyses of Forest Management Inventory Data

In order to study the important statistical parameters to estimate the sampling intensity (%SI), %Margin of Errors (%MERR), %Coefficient of Variation (%CV), Variance and Estimated Variance, mean, lower limit, and upper limit at 90% Confidence Interval for each diameter classes at plot level, 1 hectare level, per hectare level and study area level based on the Forest Management Inventory (FMI) data of Katha district, Shwebo district, Taungoo district, Dawei District and Monywa district (Table-1 FMI Data).

The CV% and variance of these FMI data is important to estimate the required number of sample plots at the desired % Margin of Error, which subsequently estimate the required sampling intensity at the desired % Margin of Error. Moreover, it will provide required area of cluster plot or plot. The analyses is accomplished based on the sampling theory outlined for Sampling with Fixed Area Plots in Sampling Strategies for Natural Resources and the Environment (2008) (Gregoire et. al 2008).

The following table provides the summary of important statistics based on (1) total number of trees, (2) total basal area and (3) total volume of all trees together for designing the NFI/NFMS.

FIA Data	Total Area (Ha)	Target Parameter	%MERR	%CV	Number of Plots	Plot Size (Ha)	Sampling Intensity %	%MERR
Shwebo	1495034	Trees	6.55	52.5	175	1	0.0117	7
	1495034	**Basal Area**	**10.68**	**85.42**	**175**	**1**	**0.0117**	**11**
	1495034	Volume	11.1	88.47	175	1	0.0117	11
Katha	1586230	Trees	2.22	37.75	666	1	0.0420	2
	1586230	**Basal Area**	**3.53**	**55.29**	**666**	**1**	**0.0420**	**4**
	1586230	Volume	4.02	62.97	666	1	0.0420	4
Taungoo	308982	Trees	4.14	59.94	569	0.7854	0.1446	4
	308982	**Basal Area**	**6.37**	**92.25**	**569**	**0.7854**	**0.1446**	**6**
	308982	Volume	7.32	106.01	569	0.7854	0.1446	7
Monywa	347568	Trees	3.07	25.58	190	1	0.0547	3
	347568	**Basal Area**	**4.9**	**40.87**	**190**	**1**	**0.0547**	**5**
	347568	Volume	5.39	44.93	190	1	0.0547	5
Dawei	1378218	Trees	9.4	59.17	109	1	0.0079	9
	1378218	**Basal Area**	**11.54**	**72.64**	**109**	**1**	**0.0079**	**12**
	1378218	Volume	13.28	83.55	109	1	0.0079	13

%MERR = % Margin of Error %CV = % Coefficient Variation

Note: Basal Area is the target parameter for designing purpose of NFI

The important statistics are %Coefficient of Variation (%CV), % Margin of Error (%MERR) and Sampling Intensity % (%SI). Plot Size is 1 Ha in FMI Data except the FMI Data of Taungoo where the plot size is 0.7854 Ha.

Estimating Number of Sample Plots based on desired % Margin of Sampling Error

Based on the following aforestated relationship $\boldsymbol{n} = (\mathbf{t}^2 \times \mathbf{r_y}^2)/\mathbf{d_r}^2$, the required number of sample points or plots (**n**) could be estimated to achieve the desired %MERR ($\mathbf{d_r}$).

Achieving the 10% margin of error (%MERR) for the estimates of forest resources quantities (e.g number of trees, basal area, volume, forest biomass, forest carbon etc.) for the district level forest management planning is optimal.

The following Table-2 illustrates the required number of samples to achieve the 10% MERR at the District level based on the aforestated FMI Data of Katha district, Shwebo district, Taungoo district, Dawei district and Monywa district.

Table-2: Required Sample Plots to achieve 10% Margin of Error

FIA Data	Total Area (Ha)	Target Parameter	%MERR	%CV	Number of Plots	Plot Size (Ha)	Sampling Intensity %	%MERR	Desired %MERR	Required Plots (n)	New SI%	New SI% 2 Digits
Shwebo	1495034	Trees	6.55	52.5	175	1	0.0117	7	10	77	0.005116	0.01
	1495034	**Basal Area**	**10.68**	**85.42**	**175**	**1**	**0.0117**	**11**	10	199	0.01333	**0.01**
	1495034	Volume	11.1	88.47	175	1	0.0117	11	10	213	0.01429	0.01
Katha	1586230	Trees	2.22	37.75	666	1	0.0420	2	10	41	0.002555	0.00
	1586230	**Basal Area**	**3.53**	**55.29**	**666**	**1**	**0.0420**	**4**	10	85	0.005334	**0.01**
	1586230	Volume	4.02	62.97	666	1	0.0420	4	10	109	0.006883	0.01
Taungoo	308982	Trees	4.14	59.94	569	0.7854	0.1446	4	10	99	0.025191	0.03
	308982	**Basal Area**	**6.37**	**92.25**	**569**	**0.7854**	**0.1446**	**6**	10	232	0.059001	**0.06**
	308982	Volume	7.32	106.01	569	0.7854	0.1446	7	10	306	0.077762	0.08
Monywa	347568	Trees	3.07	25.58	190	1	0.0547	3	10	19	0.005709	0.01
	347568	**Basal Area**	**4.9**	**40.87**	**190**	**1**	**0.0547**	**5**	10	47	0.013565	**0.01**
	347568	Volume	5.39	44.93	190	1	0.0547	5	10	57	0.016271	0.02
Dawei	1378218	Trees	9.4	59.17	109	1	0.0079	9	10	97	0.007011	0.01
	1378218	**Basal Area**	**11.54**	**72.64**	**109**	**1**	**0.0079**	**12**	10	145	0.010495	**0.01**
	1378218	Volume	13.28	83.55	109	1	0.0079	13	10	191	0.01384	0.01

%MERR = % Margin of Error %CV = % Coefficient Variation

Note: Basal Area is the target parameter for designing purpose of NFI

The Table-2 describes the required number of sample plots to achieve at 10% Margin of Sampling Errors and indicating that it could save sampling costs by collecting the data only at the required number of sample plots to achieve the desired % margin of sampling error. The target parameter for designing Myanmar NFI/NFMS is basal area.

%Coefficient of Variation indicates how the plots are similar and dissimilar. The lower value of the %CV indicates that the target resources in the plots are similar (less heterogeneous) to that of the other plots. The higher value of the %CV indicates that the target resources in the plots are dissimilar (more heterogeneous) to that of the other plots. In the aforestated table, the highest %CV is 106.01% for the volume estimate.

%MERR indicates the reliability of estimated values. The lower value of %MERR indicates the estimated values are more reliable. The higher value of %MERR indicates the estimated values are less reliable. The %Margin of Error of NFI/NFMS is generally targeted to achieve 10% to 20% at the State and Division level.

The sampling intensity % (%SI) relates to the %MERR. Higher %SI indicates lower %MERR. Lower %SI indicates higher %MERR. %SI could be calculated based on the number of sample plots (n) required to achieve the desired %MERR.

Estimating the Anticipated Sample Plots based on Sampling Distance and Prorating the % Margin of Errors

By using the Geographic Information System functionalities, the sample plots are laid out at 1km, 2km, 3km, 4km, 5km, 6km, 7km, 8km, 9km, 10km, 11km, 12km, 13km, 14km, 15 km and 16 km sampling intervals throughout the Myanmar. Then the number of sample plots that are completely within each District or State and Division are derived as the anticipated n.

Then prorated % Margin of Error for each State, Division and District is calculated based on the aforestated relationship $\mathbf{d_r = (t \times r_y)/\sqrt{n}}$ using the %CV (r_y) as 110% to maximize the variability. The total number of sample plots and prorated % Margin of error for each State, Division and District for each sampling interval are estimated.

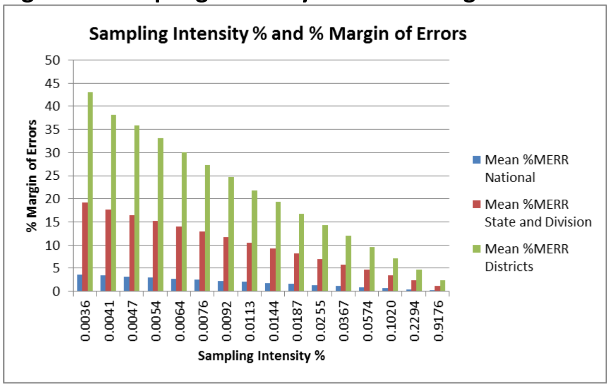
The following table (Table-3) provides the summary of prorated mean % Margin of error at National, State&Division and Districts at the sampling distance of 1 Km to 16 Km for the **1 Ha Plot** design of existing FMI of Forest Department. Although 1 Ha Plot size is exceptionally big, this study has to apply it for the initial design parameter estimation which will lead to create the optimal design of Myanmar NFI/NFMS.

Table-3: The Sampling Intensity % and % Margin of Errors based on **1 Ha Sample Plot** Design

Sampling Distance (KM)	Number of Plots in Myanmar	Plot Size (Ha) @ 1 Ha	Mean %MERR National	Mean %MERR State and Division	Mean %MERR Districts	Myanmar Study Area (Ha)	SI% @ 1 Ha Plot
16	2416	1	**3.68**	**19.12**	**43.11**	67657791	**0.0036**
15	2766	1	3.44	17.64	38.18	67657791	0.0041
14	3174	1	3.213	16.51	35.804	67657791	0.0047
13	3667	1	2.99	15.27	33.04	67657791	0.0054
12	4310	1	2.76	14.07	30.07	67657791	0.0064
11	5136	**1**	**2.53**	**12.86**	**27.34**	67657791	**0.0076**
10	6212	1	2.3	11.71	24.64	67657791	0.0092
9	7665	1	2.067	10.5	21.84	67657791	0.0113
8	9725	1	**1.83**	**9.32**	**19.31**	67657791	**0.0144**
7	12662	1	1.6	8.17	16.81	67657791	0.0187
6	17270	1	1.38	6.98	14.37	67657791	0.0255
5	24804	1	1.15	5.815	11.94	67657791	0.0367
4	38810	1	0.92	4.65	9.52	67657791	0.0574
3	68990	1	**0.69**	**3.49**	**7.13**	67657791	**0.1020**
2	155186	1	**0.46**	**2.32**	**4.75**	67657791	**0.2294**
1	620801	1	0.229	1.16	2.37	67657791	0.9176

The following figure presents the graphical forms of the table. The National Forest Inventory (NFI) and National Forest Monitoring System (NFMS) should target to achieve 20% Margin of Error at the State and Division level. The Forest Management Inventory (FMI) should target to achieve 10% ~ 20% Margin of Error at the District level.

Figure-1: Sampling Intensity % and % Margin of Error



Generally, the NFI/NFMS design should target to achieve 20% Margin of Error at the **State and Division** level. Therefore, the Sampling Intensity % (SI %) should be at least 0.0036% of the Area of Myanmar in order to achieve reasonable accurate resource estimate for reporting. However, 0.0036% SI will not provide good information for district level forest management planning because of 43.11% Margin of Sampling Errors for the **Districts**.

However, for the sustainable forest management planning, the countries desire to achieve 10~20% Margin of Sampling Errors at **the District** level. Therefore, the best sampling intensity of Myanmar for the district level forest management planning is 0.01% to 0.0574% based on the Table-3. The question is (1) “Is it affordable for data collection at 0.01% to 0.0574% sampling intensity in Myanmar?” and (2) What is the optimum Plot size to be practical and effective for field data collection instead of using the exceptionally large 1 Ha Plot Size?

Cluster Plot Design

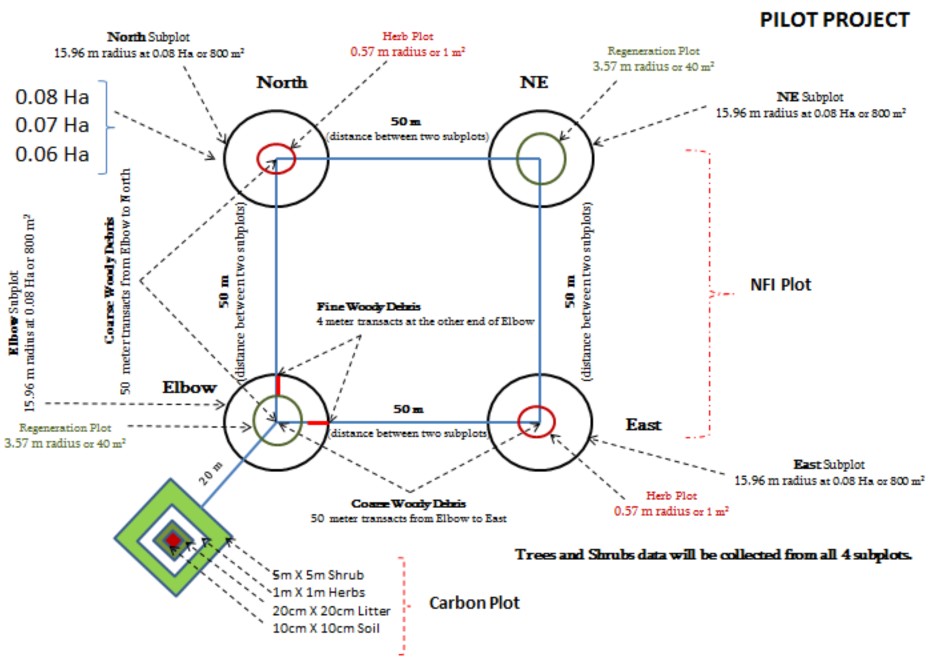
In the light of pros and cons of Strip Cruising (The Forest Measurements (Page 214 and 215) by Avery and Burkhart), the Myanmar NFI/NFMS proposed Cluster Plot Design. Moreover, the Carbon Plot will be introduced to estimate the carbon of soil, organic litter, shrubs and herbs. Line Intersect Sampling (LIS) will be introduced to estimate the biomass and carbon of fine woody debris and coarse woody debris on the forest floor.

Optimum Plot and Sub Plot Size

Comprehensive studies have been carried out to estimate the Optimum Subplot by the paper on "Optimum Subplot the National Forest Inventory of Burma" Leaflet No.20/81-82 by Dr. Kyaw Tint and Htun Lynn. It is the great comprehensive study and their findings contribute to the present study for designing the NFI/NFMS for Myanmar. According to the paper (page-19) *"the experience of the crew leaders indicated 0.10 ha was too big. Crew leaders preferred either 0.06 or 0.08 ha subplots. Statistical analyses of the field data have now shown the superiority of 0.08 ha-unit among those tested. It was most efficient and thus optimum. In addition, it had the least tree location errors, and the least CV%. In the light of these results of statistical analyses, and the experience of the crew leaders, the subplot type .08 ha is considered most appropriate for the NFI System, although subplot types 0.07 ha and 0.06 ha could also be acceptable."* The size of the single plot or subplot is bigger than 0.1 ha, it is too big based on the experience of crew leaders and the previous studies.

Proposed Cluster Plot Design for Myanmar NFI/NFMS

In the light of previous studies, literature support and requirement of estimating forest biomass, forest carbon and soil carbon by the UN-REDD, the Cluster Plot Design was proposed. The Cluster Plot for Myanmar NFI/NFMS will contain 4 subplots (0.08 ha) for trees and shrubs data collection, two line intersects of 50 m for coarse woody debris data collection, two line intersects of 4 m for fine woody debris data collection, two regeneration subplots ($40m^2$), two herbs subplots ($1m^2$). The Carbon Plot will be added to estimate the carbon of soil, organic litter, shrubs and herbs. The design of the Carbon Plot is similar to the operational design of Bhutan NFI/NFMS. During the pilot project of present NFI/NFMS designing, the optimum subplot size will be reconfirmed based on the statistical analyses and field data collection experience.



NFI/NFMS Preliminary Cluster Plot Design for Myanmar (Pilot Project)

During the Pilot Project, 0.08 ha subplots will be applied in order to estimate the resource quantity, reliability of estimates and %CV at 0.06 ha, 0.07 ha and 0.08 ha subplots. It will also examine the 4 subplots or 3 subplots required to achieve the required reliability of estimates.

Final Cluster Plot Design will be proposed as the Applied Design based on the statistical analyses of Pilot Project Data. **Therefore, it is important to carry out the Pilot Projects which represent the different ecosystem of Myanmar.**

Sampling Intensity and Cluster Plot Size

The Sampling Intensity % is calculated as follow.

SI% = (n * s)/A)) * 100

SI% = Sampling Intensity %
n = Anticipated number of Sample plots within the Area
s = Plot Size in Hectare
A = Area of Nation or State, Division or District in Hectare

The following table (Table-4) provide the summery of (1) total number of sample plots (Anticipated n) at 1 km to 16 km Sampling Distance and Sampling Intensity % for the plot sizes of 1 Ha, 0.15 Ha, 0.24 Ha, 0.28 Ha and 0.32 Ha.

Table-4: Sampling Intensity at different cluster plot size and different sampling intervals

Sampling Distance (KM)	Number of Plots in Myanmar	Plot Size (Ha) @ 1 Ha	SI% @ 1 Ha Plot	Plot size (H) @0.05 ha * 3 0.15 H	SI% @ 0.15 ha Plots	Plot Size (H) @ 0.06 H * 4 0.24 H	SI% @ 0.24 ha Plots	Plot Size (H) @0.07 H * 4 0.28 H	SI% @ 0.28 ha Plots	Plot Size (H) @0.08 H * 4 0.32 H	SI% @ 0.32 ha Plots
16	2416	**1**	**0.0036**	0.15	0.0005	0.24	0.0009	0.28	0.0010	0.32	0.0011
15	2766	1	0.0041	0.15	0.0006	0.24	0.0010	0.28	0.0011	0.32	0.0013
14	3174	1	0.0047	0.15	0.0007	0.24	0.0011	0.28	0.0013	0.32	0.0015
13	3667	1	0.0054	0.15	0.0008	0.24	0.0013	0.28	0.0015	0.32	0.0017
12	4310	1	0.0064	0.15	0.0010	0.24	0.0015	0.28	0.0018	0.32	0.0020
11	5136	1	0.0076	0.15	0.0011	0.24	0.0018	0.28	0.0021	0.32	0.0024
10	6212	1	0.0092	0.15	0.0014	0.24	0.0022	0.28	0.0026	0.32	0.0029
9	7665	1	0.0113	0.15	0.0017	0.24	0.0027	0.28	0.0032	0.32	0.0036
8	9725	1	0.0144	0.15	0.0022	**0.24**	**0.0034**	**0.28**	**0.0040**	**0.32**	**0.0046**
7	12662	1	0.0187	0.15	0.0028	0.24	0.0045	0.28	0.0052	0.32	0.0060
6	17270	1	0.0255	0.15	0.0038	**0.24**	**0.0061**	**0.28**	**0.0071**	**0.32**	**0.0082**
5	24804	1	0.0367	0.15	0.0055	0.24	0.0088	0.28	0.0103	0.32	0.0117
4	38810	1	0.0574	0.15	0.0086	**0.24**	**0.0138**	**0.28**	**0.0161**	**0.32**	**0.0184**
3	68990	**1**	**0.1020**	0.15	0.0153	0.24	0.0245	0.28	0.0286	0.32	0.0326
2	155186	**1**	**0.2294**	0.15	0.0344	0.24	0.0550	0.28	0.0642	0.32	0.0734
1	620801	1	0.9176	0.15	0.1376	0.24	0.2202	0.28	0.2569	0.32	0.2936

It is essential fundamental and significant to compare the Table-3 and Table-4 in order to find the equivalent sampling intensity % of different Plot and Cluster Plot Size.

Comparing the two tables, the following important fact could be determined.

(1.) **16 KM** Sampling Distance with **1 Ha** sample plot size design (SI% 0.0036%) is equivalent to **8 KM** Sampling distance with **cluster plot** size 0.24 Ha or 0.28 Ha or 0.32 Ha (SI% 0.0034%, 0.0040% and 0.0046%). The total number of plots at **8 KM** sampling distance with cluster plot size 0.24 Ha or 0.28 Ha or 0.32 Ha (SI% 0.0034%, 0.0040% and 0.0046%) is **9725 plots**. It is assumed that 50% of the plots (4863 Plots) will be completely within the forests and another 50% of the plots (4863 Plots) will be completely within the non-forest region.

(2.) **8 KM** Sampling Distance in **1 Ha** sample plot design (SI% 0.0144%) is equivalent to **4 KM** Sampling distance with **cluster plot** size 0.24 Ha or 0.28 Ha 0r 0.32 Ha (SI% 0.0138%, 0.0161% and 0.0184%). The total number of plots at **4 KM** sampling distance with cluster plot size 0.24 Ha or 0.28 Ha 0r 0.32 Ha (SI% 0.0138%, 0.0161% and 0.0184%) is **38810 plots**. It is assumed that 50% of the plots (19405 Plots) will be completely within the forests and another 50% of the plots (19405 Plots) will be completely within the non-forest region.

(3.) **11 KM** Sampling Distance in 1 ha Sample plot design (SI% 0.0076%) is equivalent to **6 KM** sampling distance with **cluster plot** size 0.24 Ha or 0.28 Ha 0r 0.32 Ha (SI% 0.0061%, 0.0071% and 0.0082%). The total number of plots at **6 KM** sampling distance with cluster plot size 0.24 Ha or 0.28 Ha 0r 0.32 Ha (SI% 0.0061%, 0.0071% and 0.0082%) is **17250 plots**. It is assumed that 50% of the plots (8635 Plots) will be completely within the forests and another 50% of the plots (8635 Plots) will be completely within the non-forest region.

Although it is not obligatory, it will be more convenient to select the even number of sampling distance of multiples of 2 such as (2 Km, 4 Km, 8 Km, 16 Km, 32 Km) because the additional sample plots could be added conveniently between the two existing sample plots at the mathematically precise even sampling distance for some priority areas where higher reliability of estimate is required such as priority districts for management planning. Moreover, additional plots could be added systematically and conveniently between the existing plots of the National sampling frame.

Alternatively, **6 Km sampling distance** sampling frame is also attractive with the possibility of adding additional plots at 3 Km and 1.5 KM sampling distance.

Preliminary estimates for the cost of Sampling

Based on the preliminary costing for data collection and regional experience of NFI/NFMIS data collection, the preliminary cost of sampling per plot is estimated as 500$ for the forest plots and 250$ for the non-forest plots. The final costing will be accomplished after the pilot project.

The following table (Table-5) presented the cost of sampling in relation to different sampling intensity % based on the proposed Cluster Plot Designs with subplot sizes ranging from 0.06 ha to 0.08 ha.

Table-5: Cost of Sampling at different Sampling Intensity

Plot Size (H) @ 0.06 H * 4 0.24 H	SI% @ 0.24 ha Plots	Plot Size (H) @0.07 H * 4 0.28 H	SI% @ 0.28 ha Plots	Plot Size (H) @0.08 H * 4 0.32 H	SI% @ 0.32 ha Plots	Sampling Distance (KM)	Number of Plots	Forest Plots	Non-Forest Plots	Cost/Forest Plot (USD)	Cost/Non-Forest Plot (USD)	Cost for Forest Plots (USD)	Cost for Non-Forest Plots (USD)	Total Cost (USD)
0.24	0.0009	0.28	0.0010	0.32	0.0011	16	2416	1208	1208	500	250	604,000	302,000	906,000
0.24	0.0010	0.28	0.0011	0.32	0.0013	15	2766	1383	1383	500	250	691,500	345,750	1,037,250
0.24	0.0011	0.28	0.0013	0.32	0.0015	14	3174	1587	1587	500	250	793,500	396,750	1,190,250
0.24	0.0013	0.28	0.0015	0.32	0.0017	13	3667	1834	1834	500	250	916,750	458,375	1,375,125
0.24	0.0015	0.28	0.0018	0.32	0.0020	12	4310	2155	2155	500	250	1,077,500	538,750	1,616,250
0.24	0.0018	0.28	0.0021	0.32	0.0024	11	5136	2568	2568	500	250	1,284,000	642,000	1,926,000
0.24	0.0022	0.28	0.0026	0.32	0.0029	10	6212	3106	3106	500	250	1,553,000	776,500	2,329,500
0.24	0.0027	0.28	0.0032	0.32	0.0036	9	7665	3833	3833	500	250	1,916,250	958,125	2,874,375
0.24	**0.0034**	**0.28**	**0.0040**	**0.32**	**0.0046**	**8**	**9725**	**4863**	**4863**	**500**	**250**	**2,431,250**	**1,215,625**	**3,646,875**
0.24	0.0045	0.28	0.0052	0.32	0.0060	7	12662	6331	6331	500	250	3,165,500	1,582,750	4,748,250
0.24	**0.0061**	**0.28**	**0.0071**	**0.32**	**0.0082**	**6**	**17270**	**8635**	**8635**	**500**	**250**	**4,317,500**	**2,158,750**	**6,476,250**
0.24	0.0088	0.28	0.0103	0.32	0.0117	5	24804	12402	12402	500	250	6,201,000	3,100,500	9,301,500
0.24	**0.0138**	**0.28**	**0.0161**	**0.32**	**0.0184**	**4**	**38810**	**19405**	**19405**	**500**	**250**	**9,702,500**	**4,851,250**	**14,553,750**
0.24	0.0245	0.28	0.0286	0.32	0.0326	3	68990	34495	34495	500	250	17,247,500	8,623,750	25,871,250
0.24	0.0550	0.28	0.0642	0.32	0.0734	2	155186	77593	77593	500	250	38,796,500	19,398,250	58,194,750
0.24	0.2202	0.28	0.2569	0.32	0.2936	1	620801	310401	310401	500	250	155,200,250	77,600,125	232,800,375

Based on the cost, the SI% (0.0034%, 0.0040%, 0.0046%) are financially affordable and achievable at the cost of **3.65 Million** USD for 5 years project. In this sampling intensity %, the District level % Sampling Error is approximately **45%,** the State & Division level % sampling error is approximately **20%** and the National Level % sampling error is approximately **3.6%.** The % Sampling Error at Districts (45%) could be reduced by adding the additional sample plots at the priority district through the Forest Management Inventory Operation of Forest Department.

Based on the cost, SI% (SI% 0.0061%, 0.0071% and 0.0082%) are financially affordable and achievable at the cost of **6.48 Million** USD for 5 years project. In this sampling intensity %, the District level % Sampling Error is approximately **27~28%**, the State & Division level % sampling error is approximately **12~13%** and the National Level % sampling error is approximately **2~3%.** It is **financially reasonable affordable project** and the data produce from the project could be applied to District Management Planning after stratification of the plot data according to the forest types of districts, estimate the resource quantity and emission factors by the forest types.

Based on the cost, SI% (0.0138%, 0.0161%, 0.0184%) are financially reasonably expensive and achievable at the cost of **14.6 Million** USD for 10 years project. In this sampling intensity, the District level % Sampling Error is approximately **20%,** the State & Division level % sampling error is approximately **10%** and the National Level %

sampling error is approximately **2%.** It will still be **the reasonably expensive NFI** and the data produced from the project could be **readily applied to District Management Planning**.

For the **comparison purpose**, SI% (0.1%) of NFI (1980/81) at 1.05 Ha L-Shape Strip Plot at 3 KM sampling distance design will cost approximately **25.87 Million** USD Nationally. In this sampling intensity, the District level % Sampling Error is approximately 7~8%, the State & Division level % sampling error is approximately 3~4% and the National Level % sampling error is approximately less than 1%. It is very expensive NFI and it could be one of the reasons the NFI (1980/81) could not achieved nationally.

For the **comparison purpose**, SI% (0.2294%) of present Forest Management Inventory (FMI) at 1 Ha Plot at 2 KM Sampling distance design will cost approximately **58.19 Million** USD Nationally. In this sampling intensity, the District level % Sampling Error is approximately 4~5%, the State & Division level % sampling error is approximately 2~3% and the National Level % sampling error is less than 1%. It is very expensive version of NFI.

RECOMMENDATION

In the light of Acceptable % Margin of Error for **National Level UN-REDD Reporting**, **State and Division Level In-Country Reporting**, District level Sustainable Forest Management Planning and Cost of Sampling, this study has recommended – **(Option-1)** 8 KM Sampling Interval - the SI% (0.0034%, 0.0040%, 0.0046%) at the field sampling cost of 3.65 Million Sampling Cost and **(Option-2)** 6 KM Sampling Interval – the SI% (0.0061%, 0.0071% and 0.0082%) at the field sampling cost of 6.48 million USD. Both options will provide the optimal results with the acceptable % Margin of Error for the National, State and Division level UN-REDD Reporting and Sustainable Forest Management Planning.

The 6-KM Sampling Interval option **(Option-2)** will provide reasonably optimal result for the district level reporting especially for large districts. It is necessary and recommended to intensify the additional cluster plots at every 3 KM within the Small Districts and priority districts in order to achieve the acceptable % Margin of Sampling error at the District level.

The 8-Km Sampling Interval Option **(Option-1)** will be required to intensify the sampling plots at every 4 KM in order to achieve the acceptable % Margin of Error for District level forest management planning. It is recommended to intensity the additional Cluster plots at every 4 Km at the priority districts to achieve the acceptable % Margin of Error at the District level.

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