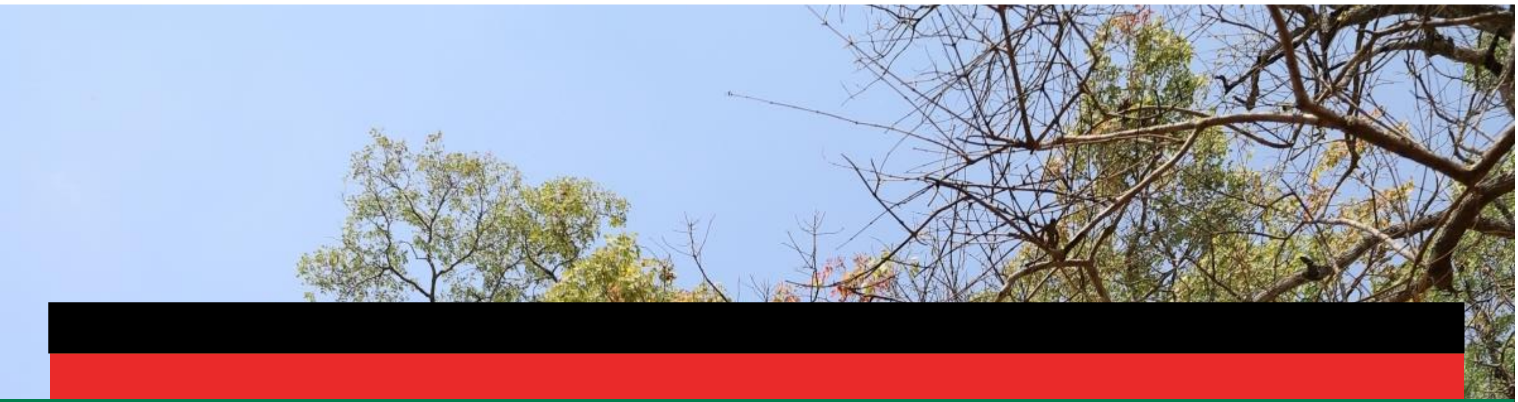

REPUBLIC OF MALAWI

The Ministry of Natural Resources, Energy and Mining

NATIONAL FOREST INVENTORY

2018 Analysis Report

FOREWORD

This publication was produced by the Government of Malawi through support from the United States Agency for International Development (USAID)-funded Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) activity. The views expressed in this publication do not necessarily reflect the views of USAID or the United States Government.

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TABLE OF CONTENTS

ACRONYMS & ABBREVIATIONS

AA	Accuracy Assessment
AGB	Aboveground Biomass
BGB	Belowground Biomass
CI	Confidence Interval
DBH	Diameter at Breast Height
DoF	Department of Forestry
GHG	Greenhouse Gas
GIS	Geographic Information System
GIZ	German International Development Agency
GoM	Government of Malawi
JICA	Japan International Cooperation Agency
MLULCCS	Malawi Land Use/Land Cover Change Classification Schema
MRV	Monitoring, Reporting and Verification
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
PA	Protected Area
PERFORM	Protecting Ecosystems and Restoring Forests in Malawi
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SADC	Southern Africa Development Community
SOP	Standard Operating Procedure
UNFCCC	United Nations Framework Convention on Climate Change

USAID	United States Agency for International Development
WAG	Wildlife Action Group
WG	Working Group

1.0 INTRODUCTION

This report presents an analysis of several forest inventories that have been undertaken over the past ten years, by the Government of Malawi (GoM) with financial and technical support from different international donors and actors. This includes data recently collected with support from the USAID/Malawi-funded Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) project.

The report includes the background on these inventories and presents the sampling design for the data collected in the first ever National Forest Inventory (NFI) conducted in 2018 by the GoM, with support from PERFORM. Also included is an analysis of the 2018 NFI data as well as data from the consolidated, previously-conducted inventories. This analysis provides estimates on national biomass and carbon stock figures for Malawi's Miombo woodland landscape. As a compilation of forest inventories done in Malawi, this report offers the nation, and the Malawi Reducing Emissions from Deforestation and Forest Degradation (REDD+) Program (MRP), the foundation for a consistent, standardized, and systematic approach to future forest inventories and monitoring, reporting, and verification (MRV) campaigns and serves as an important component of Malawi's National Forest Monitoring System (NFMS).

1.1 BACKGROUND ON PERFORM

Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) is a five-year project funded by USAID/Malawi and implemented by a consortium led by Tetra Tech ARD[1]. The objectives of the project are:

1. REDD+ (Reducing Emissions from Deforestation and Degradation) readiness is advanced
2. Low-emissions land use opportunities are increased in targeted geographies
3. Low-emissions development capacities are improved
4. Pathways for sustainability are instituted
5. CDCS (Country Development and Cooperation Strategy) priorities of integration and institutional strengthening are advanced

PERFORM is a core component of environment programming under USAID's Development Objective Assistance Agreement with the Government of Malawi (GoM) and is the flagship implementation vehicle for the low-emissions partnership between the United States Government and the GoM. PERFORM was designed to align with Malawi's mid-term Growth and Development Strategy (MGDS) and to promote the more efficient, equitable, and sustainable use of Malawian forests and soils.

The services that Miombo woodlands provide to Malawians are numerous—including food, water, and fuel. However, these woodlands are decreasing at one of the highest rates in southern Africa due to Malawi's unsustainable use of wood fuels (charcoal and firewood), poor agricultural practices, limited economic choices, and high population growth. PERFORM's support to the GoM

[1] Key consortium members include Total LandCare (TLC), Winrock International (Winrock), Michigan State University (MSU), World Resources Institute (WRI), and the Center for Environmental Policy and Advocacy (CEPA).

and its partners, on REDD+, works to tackle these interrelated issues and to quantify their impact on Malawi's forest stocks through an NFI.

1.2 PURPOSE OF THIS ANALYSIS

Before 2018, Malawi had never completed an NFI. Although localized inventories have been conducted in the over the last decade, the results of these smaller-scale efforts were never aggregated, and these efforts did not cover the extensive forested areas in the north or south of Malawi and alone were unable to provide a representative data set of the ecological condition, biomass stocks or biodiversity distribution of the country's forests. Furthermore, without an NFI or an analysis thereof, Malawi has been unable to make defensible estimates of forest stocks which are critical for forest carbon or forest biomass change estimates.

A national field based forest inventory, or NFI, was identified by the GoM as a key milestone to establishing the NFMS, and was thus earmarked by the DoF and the MRP as a priority for the country. This inventory was designed to give Malawi a nationally-derived estimate of its forest stocks that can be used to inform management of the country's forest resources.

Furthermore, carbon stock values estimated from the NFI 2018 analysis found in this document can be used to develop emission factors for national greenhouse gas (GHG) emission estimate for national and project-scale monitoring and planning activities, including National Communications to the UNFCCC and MRV data for REDD+. This NFI analysis also provides information on non-carbon dimensions of forest conditions in Malawi such as species richness and canopy density that are of interest to a broad range of potential management objectives for natural and indigenous forests.

1.3 INVENTORIES TO DATE

Several site-based forest inventories have been conducted in Malawi over the past ten years by the GoM with support from various international donors and actors. These inventories have been done primarily to inform site-based forest management, or to inform the country's path toward REDD+ readiness. While many of these inventories have been successfully implemented and executed, their scope has been limited to specific geographies, typically in protected areas and forest reserves.

Following guidance from the Director of Forestry, PERFORM supported the GoM to develop an NFI that consolidated and built directly on these past site-based forest inventories. This complementary and comprehensive NFI effort was done to build national capacity, to advance Malawi's REDD+ readiness and to provide the fundamental information needed to estimate and report carbon stocks and fluxes of carbon stocks to the United Nations Framework Convention on Climate Change (UNFCCC) and to develop the scientific methods necessary to formulate targeted interventions and to support the solicitations of funding from potential bilateral and multilateral donors to address deforestation and forest degradation in Malawi. Specifically, data from four previous forest inventories in addition to supplementary data collected in 2018 was used to calculate the estimates of forest carbon stocks in Malawi[2]. Table 1 summarizes the characteristics of the forest inventories used in this analysis.

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[2] Note: Additional forest inventories were conducted during this time, most notably through the Kulera Landscape REDD+ Activity, but to date the collected data has not made available to the GoM, so could not be included in the NFI.

Table 1 | Summary of Past Forest Inventories Done in Malawi

Inventory Title	Year	Sampling Strategy	N Plots	Plot Design	Geographical Focus	Approach to Land Cover	Data Collected
JICA	2011 2012	Systematic Random Sampling	278	Nested circular, single plots (0.1ha)	17 Forest Reserves across Malawi	Plots established in pre-determined locations regardless of land cover type	DBH, tree height, clear length, crown diameter, species
SADC-GIZ	2013	Stratified restricted random sampling	137	Nested circular, t-shaped cluster plots (3 subplots, 0.38ha total)	Large horizontal band on land across central Malawi	If cluster center was not in a forested area, the plot was moved to an area entirely within a forested condition	DBH, tree height, species, deadwood (standing and lying)
USAID-PERFORM	2016	Random sampling	86	Nested circular, t-shaped cluster plots (3 subplots, 0.38ha total)	Three Forest Reserves: Liwonde, Ntchisi, and Perekezi	Plots established in pre-determined locations regardless of land cover type	DBH, tree crown, species, deadwood (standing and lying), litter, soil
WAG	2016	Random sampling	33	Nested circular t-shaped cluster	Thuma Forest Reserve & Dedza-Salima Escarpment Forest Reserve	Unknown	DBH

The first of the four inventories was the Forest Resource Mapping project sponsored by the Japan International Cooperation Agency (JICA) initiated in 2010, which among other tasks, produced land use, land use change, and forestry (LULUCF) and forest resource maps, and conducted a forest biomass field survey in seventeen forest reserves across Malawi. Data were collected from 278 nested circular plots to evaluate tree biomass following a systematic random sampling approach. This inventory collected necessary data to estimate forest carbon stocks according to the selected allometric equation. The data collected included: diameter at breast height (DBH), tree species and tree height recordings as well as tree crown diameter.

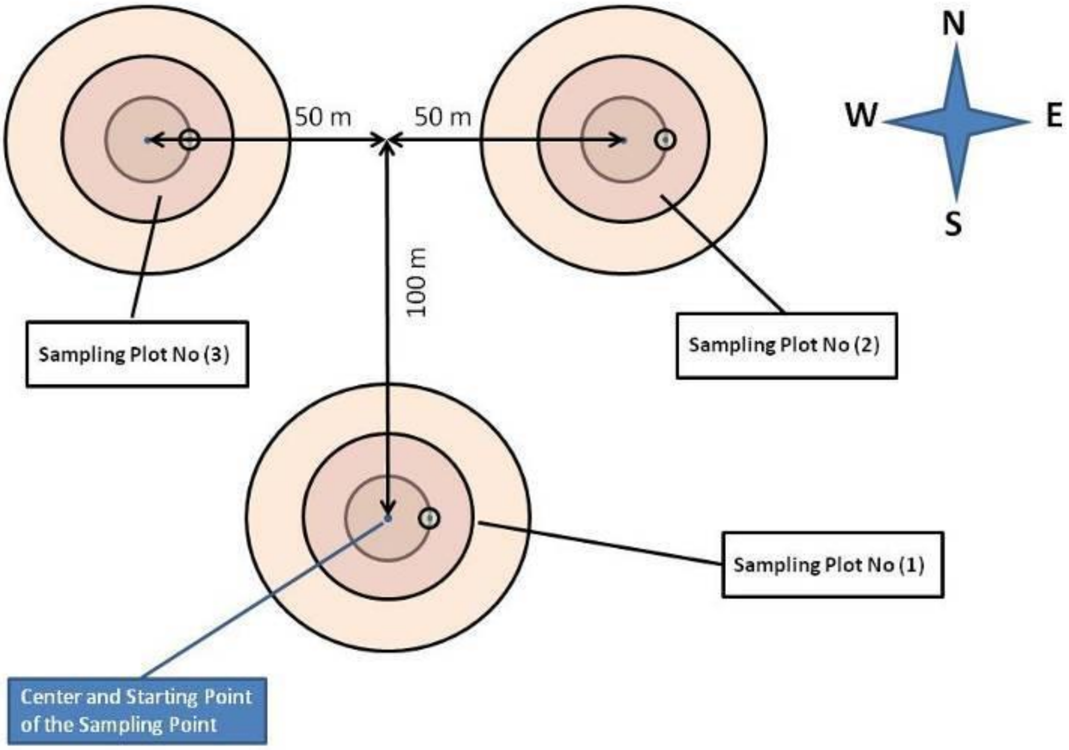

Figure 1 | T-Shaped Nested Cluster Plot Design

As shown in Figure 1, there were three nested plots for each cluster. In each plot of the cluster, trees were measured for aboveground biomass (AGB) and deadwood. The sampling point design was also applied in the field inventories under PERFORM to efficiently collect data on both large and small trees. During PERFORM inventories, the fixed radius plot was circular with concentric plots at the following radii:

- 06 m Radius Circular Plot – small trees 5 – 15 cm diameter at breast height (DBH)
- 12 m Radius Circular Plot – medium trees 15 – 30 cm DBH
- 20 m Radius Circular Plot – big trees > 30 cm DB

The second inventory was conducted under the Development of Integrated Monitoring Systems for REDD+ in the Southern African Development Community (SADC) program, sponsored by the German International Development Agency (GIZ). This inventory involved a transboundary field inventory carried out in Malawi and Zambia. In this inventory, a swath of land across the central part of Malawi and the eastern province of Zambia totaling 26,000 km² was surveyed through a stratified, restricted random approach.

In 2016, the GoM undertook site-based forest inventories in the Liwonde, Ntchisi, and Perekezi Forest Reserves through the support of PERFORM. As in the SADC-GIZ inventory, a t-shaped cluster plot design was followed with circular nested plots (Figure 1). A total of eighty-six clusters were established in which data were collected on DBH, deadwood (standing and lying), canopy cover, and litter. Soil samples were also collected for laboratory analysis.

Finally, in 2016, the Wildlife Action Group (WAG), working through the DoF, conducted forest inventories within the Thuma Forest Reserve and the Dedza-Salima Escarpment Forest Reserve. These inventories followed a random sampling approach that collected data from thirty-three t-shaped nested cluster plots (Figure 1). The Thuma and Dedza-Salima Escarpment inventories only recorded tree DBH.

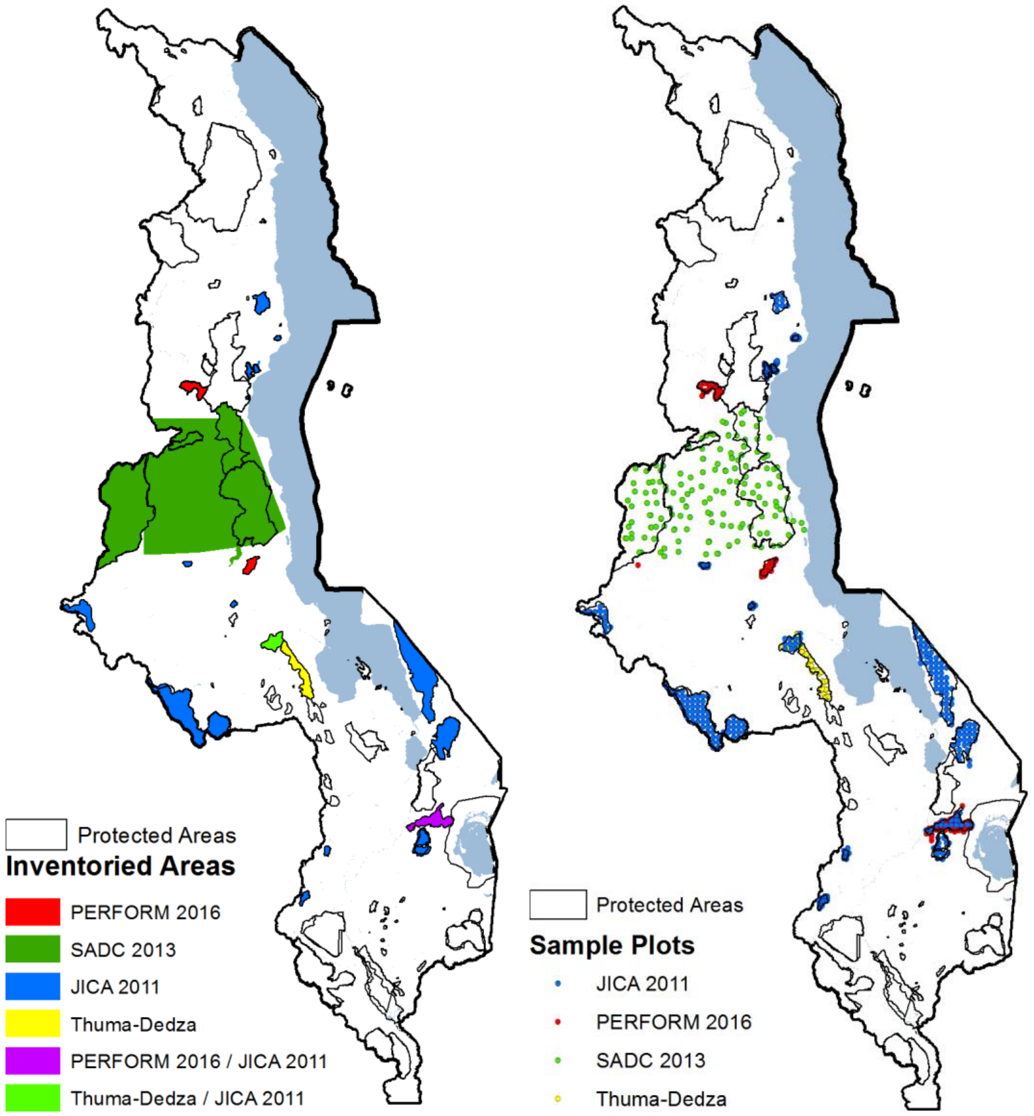

Figure 2 | Sampling Frames Associated with Past Inventory Efforts (left) and NFI 2018 Plot Allocations (right)

2.0 SAMPLING DESIGN PROCESS

This section details the steps taken to derive the sampling strategy used in the 2018 NFI, and includes the geographic distribution of plots, use of geographic stratification, estimation of required number of measurements, and ultimately, the plot allocation results.

The inventory was designed by a working group comprised endorsed by the Director of Forestry, which included personnel from the DoF (inclusive of FRIM and MCFW), as well as well as representatives from academia, and PERFORM. The team designed the NFI during extended working sessions on March 26-28th, and June 5-7th, 2018 (Annex 6.1).

2.1 Sampling Design Objectives

Several principles including cost effectiveness, minimal precision standards, and a desire to build on past inventory efforts informed the development of the 2018 NFI sampling design. Regarding precision, the inventory was designed to target the smallest number of inventory plots possible in order to achieve a biomass stock estimate with a half width of the 95% confidence interval equal or lower than the 10% of the mean.

This level of accuracy and certainty was deemed an appropriate starting point for the national inventory during the working group meetings. This random allocation of sampling units also allowed for the incorporation of prior inventories into the sample design and permitted augmentation of the sample at a higher level of intensity in the future, if needed. Key decisions made through the initial consultative design process are as follows:

- Focus on landscapes in Malawi where forests are more intact/dense, including Forest Reserves and customary land landscapes, identified by the working group
- Use of random sampling
- Use of t-cluster plots with same nest sizes as SADC-GIZ, USAID-PERFORM and WAG inventories
- Stratify forests based on anticipated canopy density using remote sensing-derived fractional cover maps

2.2 Summary of National Forest Inventory 2018 Sampling Approach

The overall process used to reach the final sampling strategy for the 2018 data collection is detailed below. It should be noted that after the initial stage of data collection, a second round was undertaken that used a modified sampling strategy to account for data shortcomings of the first round.

1. Collated past inventory data and coordinates and entered into a tabular form to create a consistent spatial projection
2. Converted tree-level measurements into plot-level measurements using consistent allometric equations for AGB and BGB (where tree-level measurements were available)
3. Selected a pilot sample from past inventory plots to use in calculating expected variance in each stratum (dense, medium, sparse forests)
4. Cleaned data by removing outliers and questionable coordinates
5. Experimented with several stratification approaches and applied a landscape-based approach that grouped lands into larger contiguous zones generally no smaller than 25km^2
6. Compared pilot samples to stratification and produced estimates of N required per stratum with an added 20% safety margin on target N
7. Distributed plot points within the sampling frame using the random stratified sampling design
8. Collected initial field data from targeted plots and evaluated initial results
9. Revised approach by no longer pre-stratifying and instead pre-screening target plots using Google Earth to avoid unnecessary field team travel to non-forest plots; collected remaining field data
10. Harmonized all data using post-stratification into forest and non-forest areas based on the 10% canopy cover outlined in the National Forest Definition, using visual imagery assessment on Google Earth

2.3 Inventory Consolidation and Standardization

Each prior inventory used as pilot data (Table 1) was converted from its stored format into a tree list containing the measurements of each unique tree, and a plot list containing measurements specific to each plot. For inventories using cluster plots, the plot list referred to subplots.

2.3.1 Data Cleaning

The following steps were taken to clean the data from previously conducted forest inventories:

1. Diameter/height plots were produced to check for unrealistic values of either. For instance, a stem recorded having a height of 150 meters, was corrected to have a 15 meter height.
2. Plots were mapped. Coordinates that were obviously incorrect were corrected in the following cases:
    a. When the x and y coordinates were reversed, they were corrected.
    b. When the coordinates for one plot in a cluster of three were dramatically different than the rest of the plots in the unit, the coordinates were revised to correlate with the other plots in the unit.
    c. When a plot was in an incorrect location, it was discarded.

2.3.2 Unit Summary

The unit (cluster of plots) was used as a conservative summary of the plot-level data in the cluster analysis and was used to create parity between the JICA inventory and the other inventory data. A unit-level summary of the plots was created by first summing the biomass of the trees calculated at the plot-level and then taking the average biomass as well as the x and y coordinates for each plot as the unit summary. Biomass outliers (greater than 1.5 times the 3rd quartile above the mean) were removed from the dataset.

2.4 Stratification

Stratification in an NFI is used to reduce the total number of measurements required to reach a target level of precision. Stratification is accomplished by spatially segmenting the landscape into categories based on any combination of factors related to ecological, biological, management, social, and proximity considerations of the landscape. Malawi's forests exhibit a wide range of conditions related to natural geographic variation and history of human utilization.

PERFORM supported the DoF, and more broadly the National Forest Monitoring System (NFMS) working group to explore several approaches to stratification. The approach ultimately selected used a landscape-scale stratification to develop the initial plot allocation for the 2018 NFI. However, when an opportunity was presented to collect additional data beyond the first plot allocation, stratification was abandoned as initial analysis did not did not reveal that stratification efforts were producing significantly improved precision.

The first stratification approach considered, but not adopted, was a 30-m pixel-based map of three forest types, derived from a "fractional cover" vegetation index applied to Landsat imagery (Figure 3, left). These class definitions were modeled on the proposed Malawi Land Use/Land Cover Classification Schema (MLULCCS), whereby, forests are segmented into Managed and Unmanaged, and Unmanaged Forests are further segmented by Dense, Moderate, and Sparse Forest (Annex 6.2). Thereafter, PERFORM led the Government of Malawi through a visual interpretation-based accuracy assessment exercise and found these fractional cover-derived stratification maps, when reclassified into MLULCCS classes of Dense, Medium and Sparse along cutoffs proposed by the United States Forest Service (USFS), accuracy was below the 90% threshold generally considered for forest maps under REDD+ programs.

The second approach built on the fractional cover map, but rather than considering each pixel individually, a spatial averaging technique using a moving 3-km radius window was undertaken in a geographic information system (GIS) software to produce a map of large contiguous "landscape" blocks with smooth borders. The GoM working group (WG), on June 5-7th, 2018, agreed that the landscape-scale stratification would be adopted. This stratification was then used as the basis for the initial plot allocation. This aggregation-based approach recognized that national-scale remote sensing in Malawi can convincingly identify the dominant land cover patterns of regions, but is not appropriate for pixel-by-pixel, high accuracy mapping. In the landscape-based stratification, class definition is intended to convey the fraction of the area of each stratum that meets the national forest definition, rather than any notion of the prevailing canopy cover of those forests that are in the stratum, and therefore, by design, include both forest and non-forest lands at the minimum mapping unit of a 0.5-ha parcel.

The NFI design was ultimately amended to remove references to map-based stratification and to simplify the sampling frame into a single homogeneous stratum.

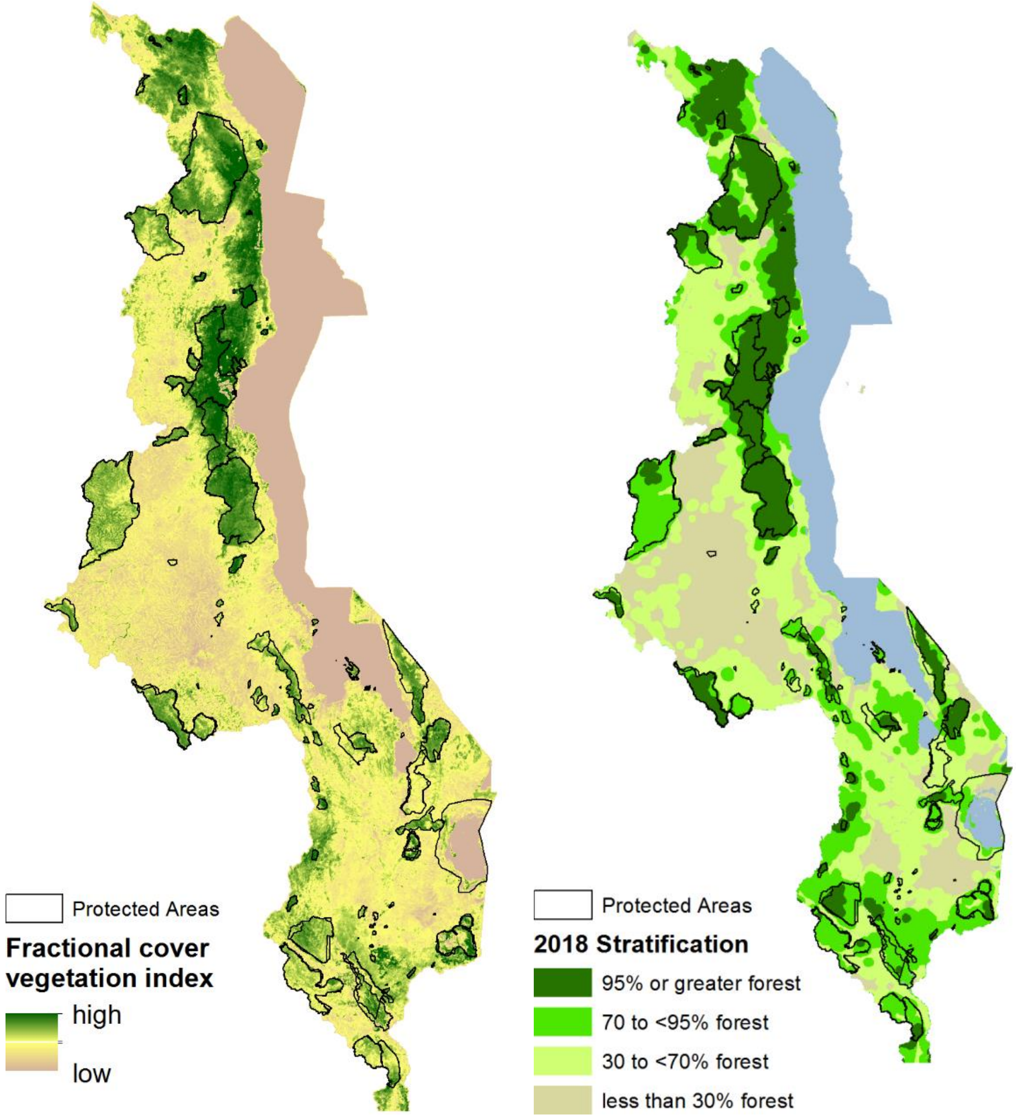

Figure 3 | The Original Cover Maps Produced for 2016 Using Fractional Cover Vegetation Index (left), and Map Stratified into Large-Scale Landscapes through a Moving-Window Spatial Average of Fractional Cover (right)

2.5 Design of Sample Frame

A forest inventory's sampling frame defines the areas that are eligible for measurement to take place, up to the entire land area of the country. However, for a number of reasons (including desires to: maximize limited NFI resources; focus on areas with the greatest emission reduction potential; etc.) the sampling frame was limited to a subset of the country (Figure 4).

WG consultations produced criteria to use in order to prioritize areas to be included in the NFI 2018 sampling frame. All protected areas (PAs) were included, because a focus on PAs was consistent with most previous forest inventories conducted in Malawi. PAs also encompass a disproportionate amount of Malawi's remaining forest cover. Government-managed plantations (including those within forest reserves) were specifically excluded, as these lands would be classified as Managed Forests and per MLULCCS should not to be comingled with Unmanaged Forests. Managed Forests can be better monitored through forest management records than through sampling. Certain areas of the landscape held in customary land tenure, especially in the northern region, contain important forest resources. Out of the WG's desire to capture these extensive non-Protected Area forests in the NFI, the WG hand-delineated boundaries around several northern region and one southern region customary landscape. These "forested customary landscapes" as defined by the WG were also added to the sampling frame.

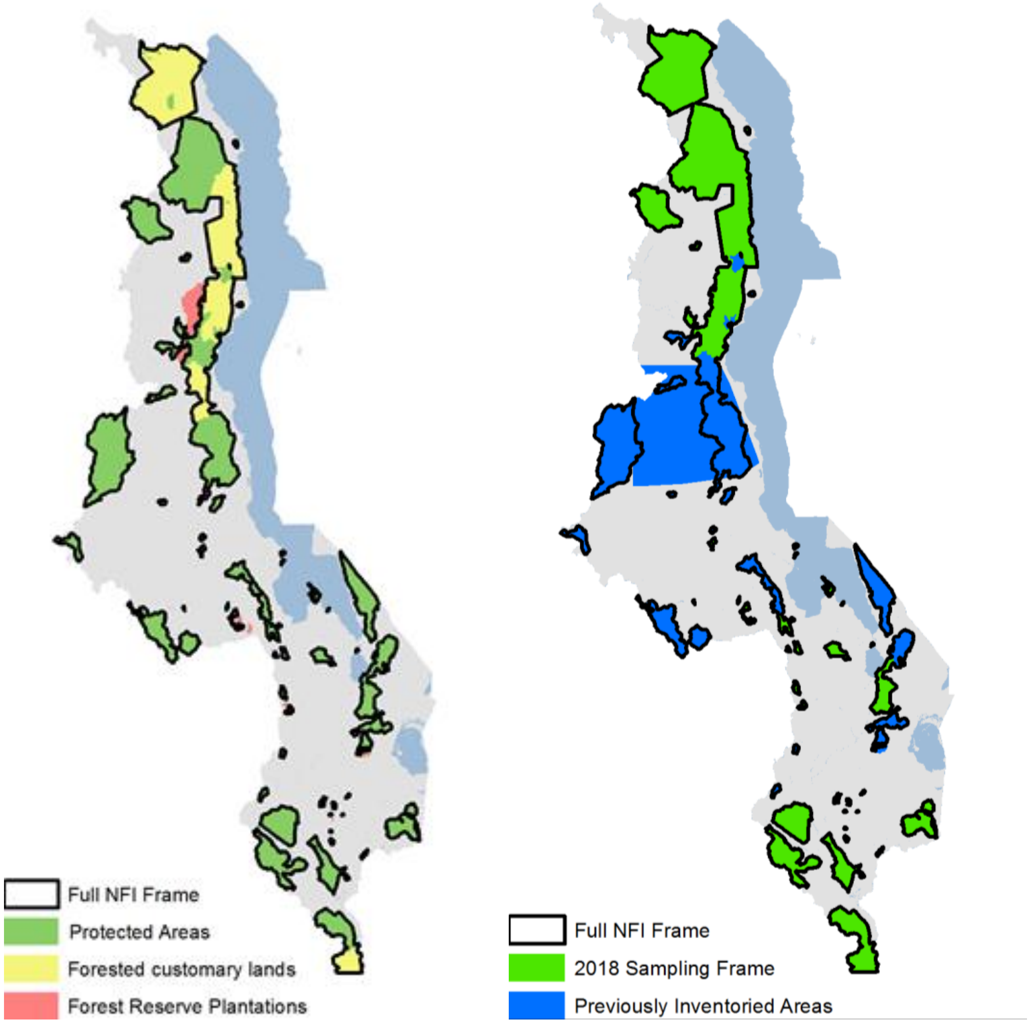

Figure 4 | The Full NFI Sampling Frame Including Protected Areas, Select Customary Landscapes, and Excluding Government Forest Plantations (left), and the NFI 2018 Sampling Frame Excluding Previously Sampled Areas (right)

The WG decided to define both the full NFI frame, and the subset of that frame that would be the focus of 2018 field work, through a single effort. The full NFI frame serves to guide future years' inventories, but only those segments of the full NFI frame which had not been measured in the past ten years were included in the 2018-specific NFI frame.

2.6 Calculation of Sample Size

For the initial 2018 fieldwork based on a stratified landscape, the sample size was chosen with consideration to the following factors:

1. The desired confidence level under which the true population mean should fall within the sample margin of error (a 95% confidence interval was selected)
2. The desired margin of error (a 10% error was selected)
3. The relative size of each stratum in hectares (from the final stratification)
4. The variability of each stratum (from pilot data that was available)

Equation 1 was used to develop estimates of plot allocation for three forested strata.

Equation 1 | Calculation of Sample Size

$$n_{total} = \frac{1}{\frac{1}{N} + (\frac{A}{(t\,x\,wCV)^2})}$$

Where

a) Weighted coefficient of variation; $wCV = \sum \frac{area_h\,x\,CV_h}{area_{population}}$

   Where

   i. $area_h = area\ (ha)\ of\ each\ stratum$
   ii. $area_{population} = the\ area\ of\ the\ population$
   iii. The coefficient of variation of each stratum (CV_h) is $\frac{s}{\bar{x}} * 100 = CV_h$

   Where

   $\bar{x} = \frac{\sum x}{n}$, the sample mean

   $s = \sqrt{(\frac{\sum(x-\bar{x})^2}{n}}$, the sample standard deviation

b) Allowable error, A, set to 10%
c) T value (based on the confidence interval, from the T distribution)
d) Population size (how many sample units could fit into the forest of Malawi), N

Additional fieldwork following the initial effort in 2018 did not use stratification, and the sample size was driven entirely by available resources.

2.7 Plot Allocation Method

Plots were allocated by stratum (n_h) based on the area in each stratum (f_h) the coefficient of variation in each stratum (CV_h).

Equation 2 | Plot Allocation

$$n_h = n_{total}(\frac{f_h \, x \, CV_h}{wCV})$$

The number of plots for each stratum was calculated accordingly.

Initial plots required per stratum were allocated using random geographic placement. Additional sampling in 2018 following this initial target was conducted using random plot placement without respect to stratification. For the additional sampling stage, a technique of visually pre-screening plots using Google Earth was adopted. This was done to avoid unnecessary foot travel by field teams that could be in situations where they previously had travelled long distances to non-forest areas. Sixty-five plots were generated randomly from within the sample frame and visually inspected for forest cover. Plots clearly exhibiting non-forest land cover were excluded. A list of valid plots was compiled until twenty-two plots were identified. This twenty-two plot subset was used to direct the second phase of 2018 field work. The second subset of plots had a larger nest size for trees with DBH greater than 30 cm, having a radius of 30 m.

2.8 Plot Allocation Results

Based on the design and confidence level selected, the target number of measurements for each stratum was calculated. The design of this NFI allowed for the incorporation of prior inventories into the design. So that sampling was representative, the ratio of the areas sampled in each forest stratum in prior inventories to total forest area in each stratum in Malawi was used to determine the number of plots from prior inventories that could be used. The stratification maps compared to the sampling frames of past inventories show that the least-forested landscapes, characterized by patchy or discontinuous forest parcels, were underrepresented in relation to more dense forested landscapes (Table 2).

Table 2 | Distribution of Plots between Three Landscape Strata in Areas Inventoried before 2018

Stratum	Area (km^2) Previously Sampled	Area (km^2) Not Previously Sampled	Proportion Sampled Previously
(1) 30 to < 70% forested	294	1,485	0.20
(2) 70 to < 95% forested	3,091	5,288	0.59
(3) ≥ 95% forested	5,446	10,179	0.54

Based on a half width of the 95% confidence interval equal to 10% of the mean, it was estimated that 167 measurements would be required within the sampling frame, eighty-nine of which could be accounted for with measurements provided by pre-2018 inventories (Table 3). This left seventy-eight plots to be collected in 2018. An additional 20% buffer was added on top of the seventy-eight, resulting in a target of ninety-four plots ultimately being set.

Table 3 | Results of Sample Size Estimation; Figures in Green are the Sample Size Necessary for Using a Half-Width of the 95% Confidence Interval (CI) Equal to 10% of the Mean

Group/Stratum	Total N Samples Required			
	0.9/0.1	0.9/0.05	0.95/0.1	0.95/0.05
Total Plots Required	118	467	**167**	663
Plots Taken from Prior Inventories	63	250	**89**	354
New 2018 Plots	55	217	**78**	309
(1) 30 to < 70% forested	4.7	18.7	**6.7**	26.6
(2) 70 to < 95% forested	16.1	64.0	**22.9**	90.8
(3) ≥ 95% forested	34.0	134.6	**48.1**	191.1

Following the data collection of these ninety-four plots, it was determined that enough financial and human resource remained to allow for additional sampling. For the second phase of the NFI 2018 sampling, resource availability allowed for between twenty and twenty-five additional plots to be measured.

Initial analysis of the ninety-four plots showed that canopy cover and biomass had little relationship with stratum. Therefore, a decision was made by the WG to generate additional plots in a non-stratified random sample manner that included the entire 2018 portion of the NFI sampling frame, even the small area of "<30% forested" stratum that was specifically excluded in Phase I.

Twenty-two additional plots were generated for the NFI 2018 second phase based on the Google Earth pre-screening of sixty-five plots. The addition of these Phase II plots to the target raised the total number of targeted plots to 116. Plots, either stratified or unstratified, were distributed randomly within the 2018 NFI sample frame (Figure 5).

Table 4 | Sampling Design by Strata, NFI 2018 Phases I & II; Number of Plots in Parentheses Indicate the Number of Pre-Screened Plots, Not Plots Actually Visited in the Field

Landscape Strata	Stratum Area (km^2)	2018 Phase I Plots	2018 Phase II Plots	Sample Density (Plots km^2)
≥ 95% forested	10,179	58	-	58 / 10,179 = 0.0057
70 to < 95% forested	5,288	28	-	28 / 5,288 = 0.0053
30 to < 70% forested	1,485	8	-	8 / 1,485 = 0.0054
< 30% forested	190	-	-	-
Non-stratified (Equals total of all other strata)	17,142	-	22 (65)	65 / 17,142 = 0.0038
TOTAL	17,142	94	22 (65)	(94+65) / 17,142 = 0.0093

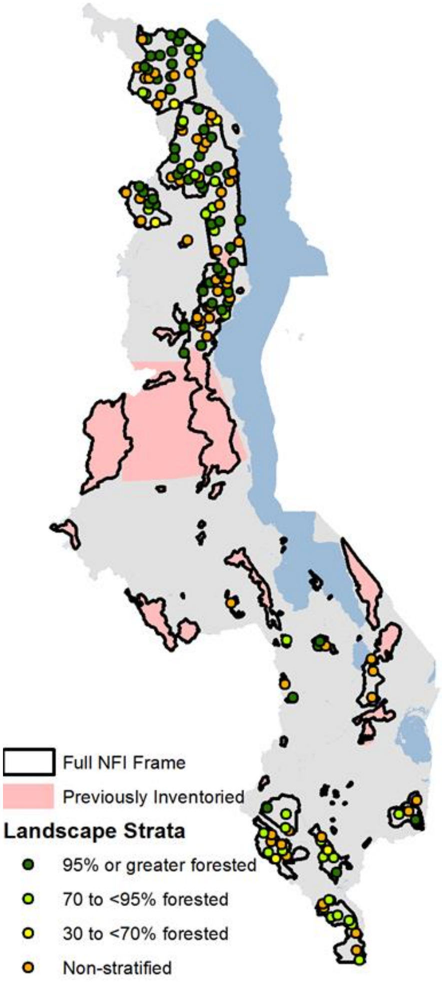

Figure 5 | Distribution of Sample Plots Generated for NFI 2018

2.9 Plot Design and Approach to Fieldwork

The plot design of the 2018 NFI followed the same approach as the GIZ-SADC, USAID-PERFORM, and the WAG inventories with the use of 3-subplot t-cluster plots with a 20m largest radius. Initially, field teams took and recorded all measurements in the field regardless of tree cover or perceptions about land use. This resulted in a large portion of recorded subplots not meeting the National Forest Definition of 10% canopy cover. In Phase II, visual pre-screening of plots was undertaken using Google Earth to rule out plots with little to no apparent canopy cover. For all phases of the 2018 NFI, field teams were instructed not to relocate plots or subplots in the event of low tree cover or non-forest land use. Instead, field teams always took plot measurements where safety allowed. In summary, the plot design and approach was as follows:

- 3-subplot cluster plots, 20m largest radius
- Initially, took all measurements in field regardless of tree cover, no pre-screening
- Later, allowed to pre-screen, but still measured whatever found in field
- No allowance for 'moving' the plot in field except in cases of safety

2.10 Consistency between NFI 2018 Phases

Several design elements were modified between Phase I and Phase II of the 2018 NFI (Table 5). The abandonment of stratification was driven by the very weak relationship stratum showed on canopy cover, forest prevalence, and biomass, following Phase I. The pre-screening of plots in Google Earth was done to limit wasted effort and resources on visiting non-forested plots. This decision was supported by a choice made by the WG to use a sample-based approach to activity data estimation. However, all plots were post-stratified through a visual assessment of Google Earth imagery. In addition, a 30-m plot was used in Phase II as an attempt to reduce the variance of plot measurements, but initial feedback from field crews was that it was unreasonably onerous relative to the 20 m.

Table 5 | Differences between Phase I and Phase II Design Elements

Element	Phase I	Phase II
Sample Frame	NFI 2018 frame, excluding 1% of the frame located in "<30% forested"	Entire NFI 2018 frame
Plots Visited in the Field	94	22
Pre-Screening of Plots Using Google Earth	No	Yes – 65 plots
Radius of Largest Subplot Nest	20m	30m
Presumed Activity Data Monitoring Approach for Greenhouse Gas (GHG) Estimation	Map-based, area of change among strata	Sample-based, frequency of forest vs. non-forest units within sampling frame
Post-Stratification of Plots Using Google Earth	Yes – all plots	Yes – all plots

3.0 DATA ANALYSIS

Data from the NFI 2018 field collection were analyzed based on a simple stratification into forest and non-forest, based on the 10% canopy cover national forest definition.

3.1 Statistical Measures

The estimation of biomass carbon stocks was based on sampling the forest stratum, to achieve a representative dataset of the population as efficiently as possible. Data collected through sampling was then used to infer information about the population through a set of descriptive statistics. The basic standard statistical equations used are:

Equation 3 | Arithmetic Mean

1. The arithmetic mean (**mean**) is the average value of the sampled trees.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{i=n} x_i$$

Where:

$\bar{x}$	is the mean
x	is the sampled value
n	is number of samples

Equation 4 | Standard Deviation

2. The standard deviation provides a measurement of variation from the average value.

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{i=n}(x_i - \bar{x})^2}$$

Where:

S	is the sample standard deviation
x	is the sampled value
n	is the number of samples
$\bar{x}$	is the arithmetic mean

Equation 5 | Standard Error

3. The standard error provides the standard deviation of the mean.

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Where:

SE	is the standard error
$\bar{x}$	is the arithmetic mean
s	is the sample standard deviation
n	is the number of samples

Equation 6 | Confidence Interval

4. The confidence interval gives the estimated range of values likely to include an unknown population parameter at the chosen confidence level.

$$CI = t * SE_{\bar{x}}$$

Where:

CI is the confidence interval at a specific confidence level, often 95% or 90%

t is the t-value, function of the confidence level and the number of samples

SE is the standard error

$\bar{x}$ is the mean

While the sample size selection (i.e. number of plots) was done to allow an assessment of stock uncertainties with a 95% confidence interval, the analysis of the NFI data finally used a 90% confidence interval to accommodate for the high variability of the data collected.

Equation 7 | Uncertainty

5. Uncertainty was estimated as a percentage, using the half width of the confidence interval as a percent of the mean.

$$Uncertainty = \frac{CI}{\bar{x}}$$

Where:

CI is the half width of the confidence interval at a specific confidence level.

$\bar{x}$ is the mean

Note: The resulting range is then generally expressed as the mean plus or minus half the confidence interval (x ± CI).

6. Lastly, differences between forest strata (i.e. by canopy coverage) during the 2018 NFI campaign were assessed with a one-way ANOVA with α=0.05 to determine Significant Difference between biomass stocks.

3.2 Plot Analysis

3.2.1 Calculation of Sampled Plot Area

Plots and nested plots were assumed to be circular, with the basic area calculated as the area of a circle:

Equation 8 | Area of a Circle

$$A = \pi * R^2$$

Where:

A is the area of nest

R is the radius of the nest

However, all data on carbon stocks of pools are expressed on the horizontal projection of a unit area of land. Where plots are on sloped ground, an adjustment was necessary during data analysis so that the plot area reflected the true horizontal projection (ellipse). As ellipses have two radii; it is assumed the first radius of the ellipse is parallel with the horizon while the other is parallel to the slope in the field. Therefore, a calculation is conducted to estimate the horizontal projection of the radii lying along the slope:

Equation 9 | Horizontal Projection of the Radii

$$R_{slope-horizontal} = R_{field} * \cos\theta$$

Where:

$R_{slope\text{-}horizontal}$	is the projected horizontal length of the radii lying parallel to the slope in the nest (m)
R_{field}	is the radius of nest measured in the field (m)
cos θ	is the cosine of the slope, in degrees

The area of this horizontal ellipse is then calculated using these two radii:

Equation 10 | Area of Horizontal Eclipse

$$NA = \pi * R_{field} * R_{slope-horizontal}$$

Where:

NA	is the horizontally projected area of a circular nested plot (m^2)
R_{field}	is the radius of the nest, measured in the field (m)
$R_{slope\text{-}horizontal}$	is the projected horizontal length of the radii lying parallel to the slope in the nest (m)

3.2.2 Calculation of Scaling Factors

A scaling factor was used to extrapolate the field measurements taken at the plot to a ‘per hectare’ basis. A unique scaling factor should be developed for each nest. This scaling factor is converting the area units from square meters to one hectare:

Equation 11 | Scaling Factor from Square Meters to One Hectare

$$SF = \frac{10,000}{NA}$$

Where:

SF	is the scaling factor to convert to per hectare basis (dimensionless)
10,000	is the number of meters squared in one hectare
NA	is the horizontally projected area of nested plot (m^2)

3.3 Calculation of Live Tree Carbon Stocks

To estimate the stocks of live tree carbon in the area of interest, the biomass of all sampled trees is first estimated and then a plot-level estimate is calculated. A mean carbon stock is then calculated by taking the average of all plot estimates.

3.3.1 Allometric Equations

The aboveground biomass of live trees was estimated using the allometric equation from Kachamba et al[3], which relates tree biomass with tree diameter at breast height (DBH):

Equation 12 | Aboveground Biomass Allometric Equation

$$AGB_t = 0.21691 * DBH^{2.318391}$$

Where:

AGB_t	is the aboveground biomass of tree *t*; kg dry mass (d.m.)
DBH	is the tree diameter at breast height (cm)

3.3.2 Biomass Carbon Pools

The biomass estimate is converted to tons of carbon and the scaling factor is applied to estimate carbon stocks on a per hectare basis. The biomass of all trees sampled in each plot is then summed to estimate a total carbon stock in each sampled plot. Unlike aboveground biomass, allometric equations for belowground biomass (BGB) based on metrics such as DBH do not generally exist. However, belowground biomass for forests is highly correlated with estimates of aboveground biomass, and the equation by Mokany et al[4] allows to estimate belowground biomass based on aboveground biomass:

[3] Kachamba, D.J., T. Eid, T. Gobakken. 2016. Above- and Belowground Biomass Models for Trees in the Miombo Woodlands of Malawi. Forests 7, 38.
[4] Mokany, K., R.J. Raison, A.S. Prokushkin. 2006. Critical analysis of root: shoot ratios in terrestrial biomes. Global Change Biology 11:1-3.

Equation 13 | Belowground Biomass based on Aboveground Allometric Equation

$$BGB_t = 0.489 * (AGB_t)^{0.89}$$

Where:

BGB_t Belowground biomass of the tree *t*; kg dry mass (d.m.)

AGB_t Aboveground biomass of the tree *t*; kg dry mass (d.m.)

Note: The total tree biomass is equivalent to the sum of aboveground and belowground biomass.

The total biomass was converted to tons of C multiplying by 0.47 t C t-1 dry matter to convert to mass of carbon, which can then be multiplied by (44/12) to convert to mass of CO_2, following IPCC 2006[5].

Once the total tree biomass is calculated, the mean and confidence interval for the forest carbon pool is estimated in the cluster plots. For that, the average of all subplots in a cluster was calculated and used as a plot-level estimate. This method accounts for inter-cluster (between clusters) variance but not the intra-cluster (within clusters) variance.

Total plot biomass was converted to average biomass per hectare using the scaling factor (see Section 3.2.2).

3.3.3 Deadwood Carbon Pools

The deadwood pool includes both standing and down deadwood. As in previous forest inventories conducted in Malawi, the estimates of deadwood in the 2018 campaign used the field measurements of each down piece of wood from which the volume was computed, and kilograms of dry biomass were estimated using the wood density value of 0.66 g/cm3 used in previous site-based forest inventories[6]. Deadwood was recorded in 65% of the plots of the 2018 NFI (Table 6), yielding a deadwood biomass pool with high uncertainty (61% uncertainty at the 90% confidence level). All deadwood recorded was lying deadwood.

Table 6 | Down Deadwood in NFI 2018

Number of Plots with Down Deadwood	Total Number of Down Deadwood Pieces	Total Number of Trees	Total Biomass (Tons C ha^{-1}) ± 90CI
61	1,776	3,274	0.064 ± 0.039

[5] IPCC 2006 Guidelines, Vol. 4, Chapter 4, Table 4.3. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf
[6] Malimbwi, R.E. & Luoga, E.J. 1994. Estimation of biomass and volume in miombo woodland at Kitulangalo Forest Reserve, Tanzania. Journal of Tropical Forest Science. 7.

3.4 Aggregation of Data from All Forest Inventories for the National Forest Inventory

This analysis incorporates the data collected during the five forest inventories conducted in Malawi since 2011: one USAID-PERFORM campaign in 2016, one JICA in 2011-2012, one SADC-GIZ in 2013, a WAG campaign in 2016, and the NFI 2018. These forest inventories combined, offer a comprehensive picture of Malawi's forest stocks.

The process of aggregating data from all site-based forest inventories required data transformation to ensure inventory results were comparable and could be averaged to obtain one estimate for the entire forest stratum. The first transformation was to exclude all non-forest plots from the site-based forest inventories done before the PERFORM-supported 2018 NFI, which only covered forest strata (except for SADC-GIZ in 2013). This was done through visual interpretation on Google Earth of all NFI plots. To exclude non-forest stratum in SADC-GIZ plots, those with a biomass stock below the average lower bound of the forest plots in the NFI 2018 (13 Mg biomass-C per ha) were discarded, resulting in a SADC-GIZ sample size of 75 plots instead of 80.

Furthermore, to meet Malawi's forest definition (i.e. canopy coverage has to be greater than 10% in forests), all forest inventory plots with a biomass stock below that corresponding to forests with 10% canopy coverage were excluded. The biomass stock of a forest with 10% canopy coverage was determined using data from the 2018 NFI.

Individual forest inventory data were analyzed following the statistical measures described above to obtain forest inventory average total biomass per hectare, and the results were used to calculate a weighted average of the total biomass stocks of Malawi's forest land.

Equation 14 | Weighted Average of All Forest Inventories

$$W\_Ave. = \left(\sum A_n * X_n\right) / A_t$$

Where:

W_Ave. is the weighted average of all forest inventories

A_n is the forest area covered in each forest inventory (hectares)

x_n is the average (mean) of each forest inventory (tons total biomass per hectare)

A_t is the total area covered by the forest inventories (hectares)

The WG calculated the error of the weighted average by doing a propagation of the standard deviation from the mean of each forest inventory that was then used to compute the weighted average confidence interval as described above. The propagation of the standard deviation was calculated as:

Equation 15 | Total Standard Deviation of the Weighted Average of All Inventories

$$s\_total=\sqrt{s\_1^2+s\_2^2+\cdots+s\_n^2}$$

Where:

S_total	is the total standard deviation
sn	is the standard deviation of each forest inventory

Uncertainty of the weighted average was then calculated as the half width of the confidence interval over the mean, as described above.

4.0 NATIONAL FOREST INVENTORY DATA ANALYSIS RESULTS

NFI 2018 results are presented as both specific to measurements taken in 2018 and derived from the pooled analysis of the previous inventories. Results related to canopy cover and biomass relationship, species distribution, and carbon stocks are presented for 2018. For the pooled inventories, only biomass stocks were estimated.

4.1 National Forest Inventory 2018

4.1.1 Biomass Distribution of Forests in Malawi

The 2018 NFI data was explored by comparing biomass stock in the Northern Region in the country with the stocks of the Southern Region. This revealed that Northern forests were richer in biomass than those in the South (Table 7), and their stocks present less variability (uncertainty). Similarly, a comparison between 2018 forest plots in protected areas with plots in customary lands shows that forest protection improves overall forest stocks, while also decreasing uncertainty of the forest stock estimate (Table 8).

Table 7 | Total Biomass (Tons per Hectare AGB + BGB) of Northern and Southern Region Forests Sampled During NFI 2018

	Northern Region Forest Areas	Southern Region Forest Areas
Number of plots	54	27
Average stock (tDM ha^{-1} AGB + BGB)	103.48	107.85
± half 90% confidence interval	11.02	17.16
Uncertainty	10.7%	15.9%

Table 8 | Total Biomass (Tons per Hectare AGB + BGB) of Protected Areas and Forests on Customary Lands Sampled During the NFI 2018

	Protected Area Forests	Forests on Customary Land
Number of plots	49	32
Average stock (tDM ha^{-1} AGB + BGB)	110.70	96.12
± half 90% confidence interval	11.85	14.68
Uncertainty	10.7%	15.3%

4.1.2 Canopy Cover and Biomass Relationship

The forest in the 2018 NFI was stratified according to canopy density (100%, 75%, 50%, and 25%) by assessing Google Earth imagery. Each stratum has significantly different biomass stock (p-value < 0.001; Figure 6), which decreases steadily with canopy coverage. While the relationship (i.e. the linear regression) is significant (p-value < 0.001), canopy coverage only explains 30% of the biomass variability.

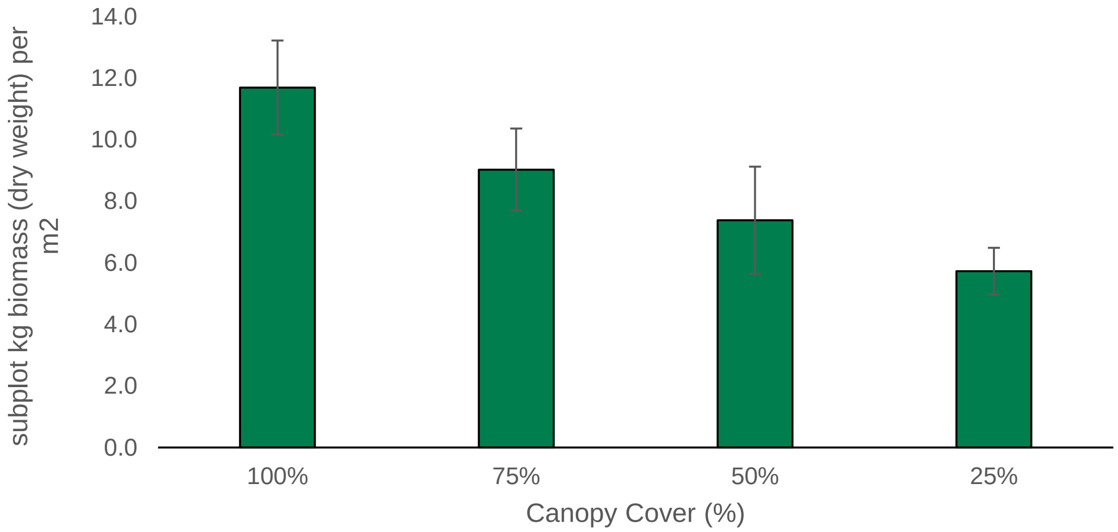

Figure 6 | Average Subplot Aboveground Biomass Stock in kg of Dry Weight per m^2; Error bars represent 90% Confidence Intervals

The uncertainty of these stocks and analyses of data variability presented in Table 9 indicate that variability and therefore uncertainty of the estimate was highest in the plots with 50% canopy closure, despite having similar number of samples as those with 100% and 75% canopy closure. Biomass variability in the 25% canopy covered forest is similar to that of subplots with 100% and 75% canopy closure, despite having over 2.5 times the number of samples than the other strata.

Table 9 | NFI 2018 Aboveground Biomass at the Subplot Level

	Canopy Coverage			
	100%	75%	50%	25%
Number of samples	33	43	39	92
Average stock (kg AGB per m^{-2})	11.7	9.0	7.4	5.7
Variance	27.63	27.73	42.56	19.39
Standard deviation	5.34	5.33	6.61	4.43
Standard error	0.93	0.81	1.06	0.46
Half 90% confidence interval	1.53	1.34	1.74	0.76
Uncertainty	13.1%	14.8%	23.6%	13.3%

Belowground biomass was added to the biomass stock by applying the Mokany et al. equation, which resulted in the final stock and uncertainty per canopy coverage described in Table 10.

Table 10 | NFI 2018 Total (AGB + BGB) Biomass at the Subplot Level

	Canopy Coverage			
	100%	75%	50%	25%
Number of samples	33	43	39	92
Average stock (kg DM m^{-2} AGB+BGB)	17.6	13.6	11.0	8.7
Variance	60.17	58.80	86.92	43.49
Standard deviation	7.88	7.76	9.44	6.63
Standard error	1.37	1.18	1.51	0.69
Half 90% confidence interval	2.23	1.83	2.02	1.10
Uncertainty	12.7%	13.5%	18.3%	12.7%

4.1.3 Biomass of Sampled Forests

Given the high variability of the 2018 plot-level biomass estimates, the relationship between canopy coverage and biomass was used to determine the non-forest threshold in the data, i.e. the biomass stock of forest with canopy coverage below 10%. The relationship between canopy coverage and total biomass produced the following equation:

Equation 16 | Canopy Cover and Total Biomass Equation

$$\text{Biomass (kg/m}^2\text{ AGB+BGB)} = 11.728*(\%\text{canopy})+5.377$$

Following the 10% canopy of the forest definition in this equation and the uncertainty range of the total biomass estimate, it was established that the lower-bound carbon stock estimate of Malawi's forests was 3.84 kg biomass m^{-2}. This resulted in the final eighty-one forest plots that were used to generate the total biomass estimate for the 2018 NFI. From these eighty-one plots the WG derived an average 104.9 ± 10.2 tons of biomass (AGB+BGB) per hectare, equivalent to **49.3 ± 4.8 t C ha^{-1}, with an uncertainty of 9.7%** (based on the uncertainty target of less than 10% of the mean).

Deadwood is a rather small portion of the carbon pool in the 2018 NFI (**0.064 ± 0.039 t C ha^{-1}**) with high uncertainty (61%). This result is consistent with previous forest inventories done in Malawi.

4.1.4 Tree Distribution in Forests of Malawi

A further analysis of the 2018 NFI (Table 11) reveals that 82.6% of trees are small trees (i.e. trees with DBH of 5-15 cm, sampled in the 6-m nest). Medium (15-30 cm DBH, sampled in the 12-m nest) and large (DBH over 30 cm in the 20-m nest) trees represent 14.2% and 3.2% of the total forest inventoried in 2018, respectively. The tree size and average biomass stock (kg biomass per ha) increased with nest size, yet differences were greater between small and medium trees than between medium and large trees.

Table 11 | NFI 2018 Comparison of Trees per Sampled Nest Size

Tree Size Class (cm DBH)	Stems ha^{-1}	% of tree stems ha^{-1}	Average tree DBH (cm)	Average tree biomass (kgDM per stem AGB + BGB)	% of tree biomass tDM ha^{-1} AGB + BGB (%)	Average biomass stock density (tDM ha^{-1} AGB +BGB)
5-15	533.1	82.6%	8.5	52	26.2%	27.1
15-30	91.3	14.2%	20.5	387	34.0%	35.1
30+	20.7	3.2%	39.6	1,977	39.8%	41.2

The inventory identified 217 species of trees in the 2018 NFI, however the sample was dominated by a much smaller subset of species. Of the 217 species, 114 were recorded with five or fewer specimens. Over 50% of the total biomass estimated from the sample was attributed to just fourteen species (Figure 7). Just five species: *Julbernardia globiflora*, *Uapaca kirkiana*, *Colophospermum mopane*, *Brachystegia bussei*, *Brachystegia spiciformis* make up almost 25% of the total tree biomass.

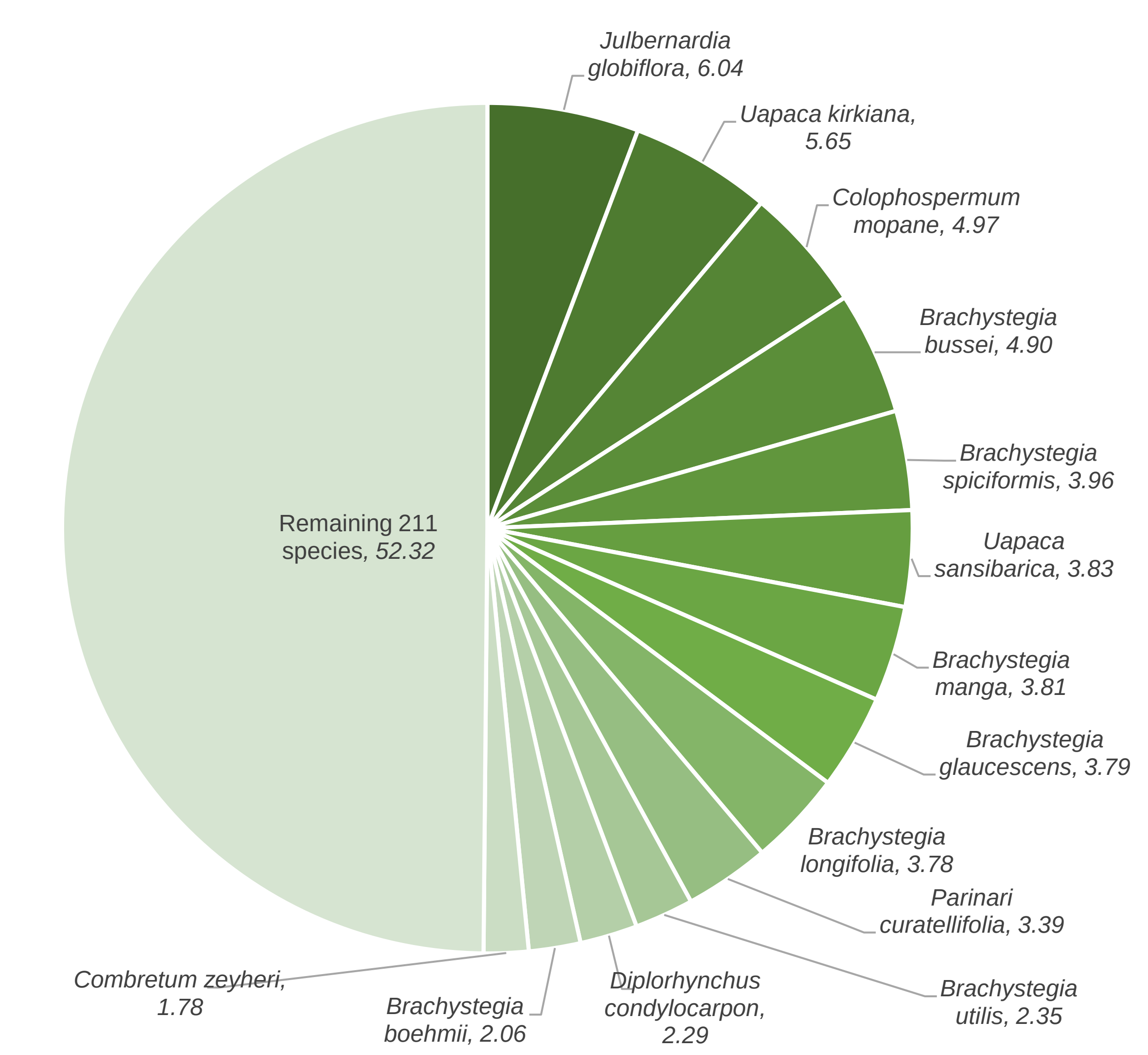

Figure 7 | Biomass Densities (tDM ha^{-1}) AGB + BGB for 14 Species Contributing to Over 50% of Biomass in NFI 2018 Sample

Results show that there is wide variation among species as it relates to stand structure (Figure 8). Some species, like *Brachystegia glaucescens* and *Colophospermum mopane* are dominated by biomass contained in trees in the >30cm DBH size class, while others like *Diplorhynchus condylocarpon* show a higher representation of small 5-15cm DBH trees.

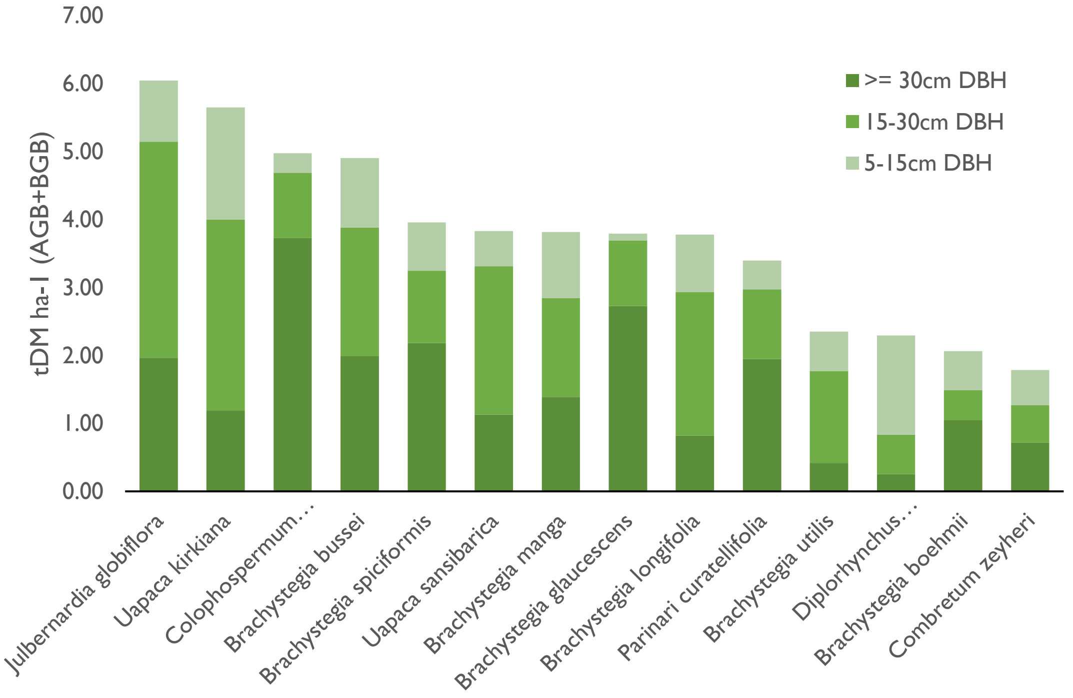

Figure 8 | Total Biomass Density and Distribution among Three Measured DBH Classes for Species Accounting for 50% of Total NFI 2018 Biomass (tDM ha^{-1} AGB + BGB)

4.2 Aggregation of All Forest Inventories

The national weighted average total biomass stock of Malawi is **97.7 ± 8.3 t biomass ha^{-1} (AGB+BGB)**, equivalent to 45.9 ± 3.9 t C ha^{-1}, with an uncertainty of **8.5%**.

These forest stock results are within range of those reported by other countries in the region. Zambia's 2016 Forest Reference Level indicates that its forest carbon stocks are 41.2 t C ha^{-1}, with an uncertainty of 7% over the estimate. Similarly, Tanzania reports forest carbon stocks that range from 33.6 to 12.3 t C ha^{-1}, with an uncertainty that varies from 1 to 7.5%. Mozambique reported in 2018 an uncertainty on their forest carbon stock estimate of 6%.

Table 12 shows the forest area covered and the corresponding average total biomass stock of the forest inventories done in Malawi.

Table 12 | Summary of Malawi's Forest Inventories; Error of Average Indicates 90% Confidence Interval

Forest Inventory	Forest Area Covered (ha)	NFI Average Total Biomass (tons ha^{-1})	Uncertainty (%)	Number of Plots
NFI 2018	1,518,781	104.9 ± 10.2	9.7%	81
USAID- PERFORM	48,019	88.2 ± 6.9	7.8%	69
WAG	39,415	72.7 ± 9.1	12.5%	30
JICA	279,342	106.6 ± 8.1	7.5%	160
SADC-GIZ	471,390	72.2 ± 6.8	9.4%	58

The WAG forest inventory had the highest uncertainty, reflecting the high biomass variability of that Forest Reserve and the low number of sampled plots, while JICA's campaign had the lowest uncertainty due to its high number of samples, followed by the PERFORM 2016 inventory.

5.0 WORKS CITED

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6.0 ANNEX

6.1 Stakeholder Consultations

6.1.1 March 2018

PERFORM held a workshop consultation with the REDD+ Science Technical Working Group, which is composed of experts from academia and government institution representatives. This was a two-day meeting focused on conducting an accuracy assessment of the draft forest cover map products developed in 2017 by the NFMS Working Group. The meeting also aimed to provide a training on the objective of the accuracy assessment (AA) and standard operating procedures to conduct AA, as well as hands-on experience on conducting AA and interpreting the results.

The training covered materials on Forest Stratification for Malawi's Reference Level Development, where the facilitators emphasized that the overall goal for covering materials on Stratification and Sampling design was to achieve quality process and output for NFI. Some of the topics under stratification and sampling design include what is sampling, why sampling is necessary, sampling for carbon stocks in forests, best estimate ± uncertainty, selecting a sampling approach, advantages and disadvantages of each approach, what stratification is, why stratify for carbon inventory, types of stratification for forest carbon inventory, and strata proposed and reasons why to use in Malawi.

The meeting was conducted from March 26th-28th at Ufulu Gardens in Lilongwe. The meeting participants are listed in the table below:

Number	Name	Organization	Phone	Email
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4	Rutiya Katiyi Kayange	Department of Forestry	0999133200	ruttiakatiyi@yahoo.com
5	Maganizo Namoto	Department of Forestry	0888343156	mwnamoto@yahoo.org
6	Bennet Mataya	Mzuzu University	0999555414	Bennet.mataya@gmail.com
7	Daud Kachamba	LUANAR	0993605154	dkachamba@yahoo.co.uk
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9	Clifford Mkanthama	PERFORM	0999215722	Clifford.Mkathama@mw-perform.org
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11	Henry Utila	PERFORM	0999324906	heutila@gmail.com/ henry.utila@mw-perform.org
12	Ramzy Kanaan	PERFORM	0996316207	Ramzy.Kanaan@tetratech.com
13	Ben Caldwell	PERFORM		Ben.Caldwell@mw-perform.org

6.1.2 June 2018

On June 5-7th, 2018 in Salima, Members of the Malawi Department of Forestry Working Group on REDD+ conferred with representatives from the USAID/Malawi-funded PERFORM project to resolve outstanding issues related to REDD+, NFI, and forest carbon inventory design. This document provides a summary of key outcomes. The first section, Agreements provides a list of discrete items that have been agreed among representatives of DoF and PERFORM. The second section, Discussion, proves context to how and why these particular decisions were made.

AGREEMENTS

1) The National Forest Inventory is a permanent function of the DoF that will continue to be the authoritative source of information on natural forests in Malawi. It is not a 'one-time' activity, but a perpetual process.
2) The NFI should be designed with two linked but distinct objectives:
   a. Develop Malawi-specific emission factors for the purposes of monitoring progress towards emission reduction under national REDD+
   b. Assess national forest cover following the national forest definition using visual sampling of imagery
3) All design elements of the NFI should logically flow from the national forest definition codified in 2018, even if some maps and stratification methods employed aggregate these official land types into larger or generalized units for practical purposes.
4) An area encompassing all existing and proposed Protected Areas, plus several DoF-identified 'priority customary lands,' will tentatively be termed as the 'Core Forested Landscapes'
5) Emission factors for REDD+ will only be developed for Core Landscapes. Malawi will choose to geographically restrict its eligibility for avoided deforestation crediting under REDD+ to Core areas. (Afforestation/Reforestation, avoided degradation, and improve forest management will be available in all geographies)
6) The NFI will be 'wall-to-wall' and sampling plots will be established for all lands in the country. However, only Core landscapes will have carbon biomass inventory.
7) For non-core areas, NFI will entail visual interpretation of high-resolution imagery, and will not produce an estimate of carbon or emission factors.
8) Core landscapes will be stratified for the purpose of facilitating a carbon inventory sampling design based on grouping DoF's Landsat-derived vegetation index (fractional cover) map into aggregate landscape units, tentatively termed:
   a. Contiguous treecover landscape
   b. Mosaic treecover landscape
   c. Fragmented treecover landscape
   d. Minimal treecover landscape

9) These landscape classes will consider the forest definition, but will themselves be considered neither 'forest' nor 'non-forest.' Rather, they will be defined and mapped based on the expected proportion of land meets the national forest definition.
10) A sampling design for a forest carbon inventory will include a substantially larger number of plots than can be sampled in 2018 (300-500 plots total). Additional plots beyond those sampled in 2018 will be considered to constitute the 'full NFI design.'
11) The 2018 NFI will not re-sample areas already covered by existing SADC/GIZ, JICA, or USAID/Malawi-funded PERFORM supported inventories, but the 'full sampling design' referenced in item 10) will include a subset of those previously-sampled plots to set aside for future resampling.
12) A 'national forest map' should be developed with the objective to support broad national scale policy and can be at a coarse/generalized representation of forest cover. It will be communicated that this national map cannot be assigned carbon values, as it will not be directly compatible with stratification used for carbon inventory.
13) A national forest map will be stratified based on the same elements as in item 6) (Core landscapes) based on DoF fractional cover maps

Carbon Inventory Design

1) The SOP used in the PERFORM-supported 2016 inventories will be the template for the 2018 carbon inventory with some minor modifications
2) All plots will be sampled on the ground regardless of what they are located in (safety aside). Any plot where it becomes apparent on the ground is located in non-forest or edge between forest/non-forest will be recorded with no deviation from normal SOPs.
3) DoF will add some additional questions to the field data sheet regarding 'general impressions' of the field crew regarding land use, such as presence of agriculture, settlement, human impact, or fire.
4) SOP will include 'best guess' estimation of canopy cover in addition to densimeter measurements.

Expressed capacity building desires of DoF

1) DoF desires to transition to QGIS. Any agreed upon GIS routines that comprise the NFI should be translated and codified in QGIS scripts, instructions, or SOPs.
2) DoF will enforce QGIS-only rule on any future capacity building sessions by any entities.
3) DoF has concerns about hosting inventory data on a web-based platform not located in Malawi. A data storage solution must be completely free of any risk of losing access due to policy changes from a 3rd party.

DISCUSSION

These decisions have been driven by a few main observations of the group regarding roadblocks that have until now prevented moving forward. The major ones are harmonizing a set of uncoordinated past carbon inventories, agreeing on an acceptable land cover mapping effort, and debates about to what degree the focus should be on all lands, or only protected areas.

<u>Move towards a permanent NFI program from past pilots</u> Three carbon inventories conducted in the past 7 years in Malawi have varying geographies, sampling strategies, and field methods. This makes comparison challenging. Moving forward, Malawi would benefit greatly from a unified 'Malawi NFI' that is a permanent program encompassing sampling design, SOPs, land stratification, etc. Such a program can encompass a single sampling design with various 'subsets' reserved for particular purposes. In PA's (core landscapes) up to 500 plot coordinates can be developed. PERFORM would thus be supporting measurement of the first group of these plots. Additional

funders or GoM wishing to support ongoing carbon inventory work can be presented with a ready-made design already approved by the DoF. There is a great desire for 'wall-to-wall' forest maps of the country by high level policy makers. It is not likely that a highly spatially detailed map is useful at this level. The NFI can support this requirement by encompassing a visual-based sampling of land cover for all lands to aid in producing a generalized forest map and national forest statistics appropriate for national-scale communication.

Accept that high-detailed, accurate, land cover mapping from automated spectral analysis is not feasible. NFI methods should be designed with this assumption at the forefront Malawi's natural forest types are highly varied in their density, canopy cover, and tendency to self-organize in discrete groves and stands. Additionally, the predominantly small-scale actors that drive forest cover disturbance in Malawi produce a complex mottled or mosaic-like forest and agricultural system in many regions. These natural and human factors create a particularly challenging environment for remote sensing methods based on Landsat-type imagery that were developed for temperate or tropical moist forests. Landsat derived maps (such as fractional cover) are successful in Malawi at showing general vegetation trends over a landscape scale, but are insufficient for producing detailed 'forest non-forest maps.'

The proposed approach for the NFI is to develop maps of generalized landscape types based on these Landsat-derived products, and to stratify carbon inventory samples with these classes. The advantage is that by generalizing into landscapes, the resulting strata map is more resilient to small-scale errors in underlying remote sensing techniques. The drawback is that such an approach is an acknowledgment that these strata will include a mix of 'forest' and 'non-forest' following the strict national definitions.

Avoided deforestation under REDD+ will in all practicality be focused in PA's and a few select customary areas ('core forested landscapes') The vast majority of contiguous natural forests Malawi are in in PA's and a few selected customary areas. Furthermore, it is in government-controlled lands where there is greatest potential to actually develop and implement policies that could reduce forest loss. The generally low forest prevalence, and the difficulty of government to influence customary lands, results in little potential for emissions reductions from avoided deforestation in those lands. Other REDD+ activities such as degradation and enhancements are not currently estimated in a spatially-explicit manner, meaning this restriction to 'core landscapes' does not apply to these activities. For REDD+, there is very little incentive to invest in carbon inventory in lands outside of this core landscape.

Land use is a critical part of the forest definition and must be addressed in all aspects of the NFI
The forest definition of 2018 excludes predominantly agricultural lands, even if they meet the 10% forest canopy threshold. Non-forest land with extensive Tree cover are widespread in Malawi and contribute strongly to the divergence in various estimates of forest cover. Moving forward, all satellite and ground-based approaches that purport to identify the presence or absence of forests must attempt, as much as feasible given the limitations of the instrument, to differentiate land use as well as land cover. This is much more readily done by site visits and visual interpretation of high-resolution imagery than by automated remote sensing of medium-resolution images.

6.2 Malawi Land Use and Land Cover Classification Schema

CODE	LEVEL 1	LEVEL2	LEVEL 3	LEVEL 4
1	Forest Land			
1M		Managed Forest		
1Mp			Tree Plantation	
1Mpp				Eucalyptus spp.
1Mpp				Pine (Pinus spp.)
1Mpr				Rubber (Hevea spp.)
1Mpo				Other plantation spp.
1U		Unmanaged Forest		
1Ud			Dense Forest	
1Ude				Montane Evergreen
1Udm				Miombo
1Uda				Acacia
1Udc				Mopane
1Udl				Lowland Evergreen
1Udo				Other Woodland Complex
1Um			Moderate Forest	
1Ume				Montane Evergreen
1Umm				Miombo
1Uma				Acacia
1Umc				Mopane
1Uml				Lowland Evergreen
1Umo				Other Woodland Complex
1Us			Sparse Forest	
1Use				Montane Evergreen
1Usm				Miombo
1Usa				Acacia
1Usc				Mopane
1Usl				Lowland Evergreen
1Uso				Other Woodland Complex