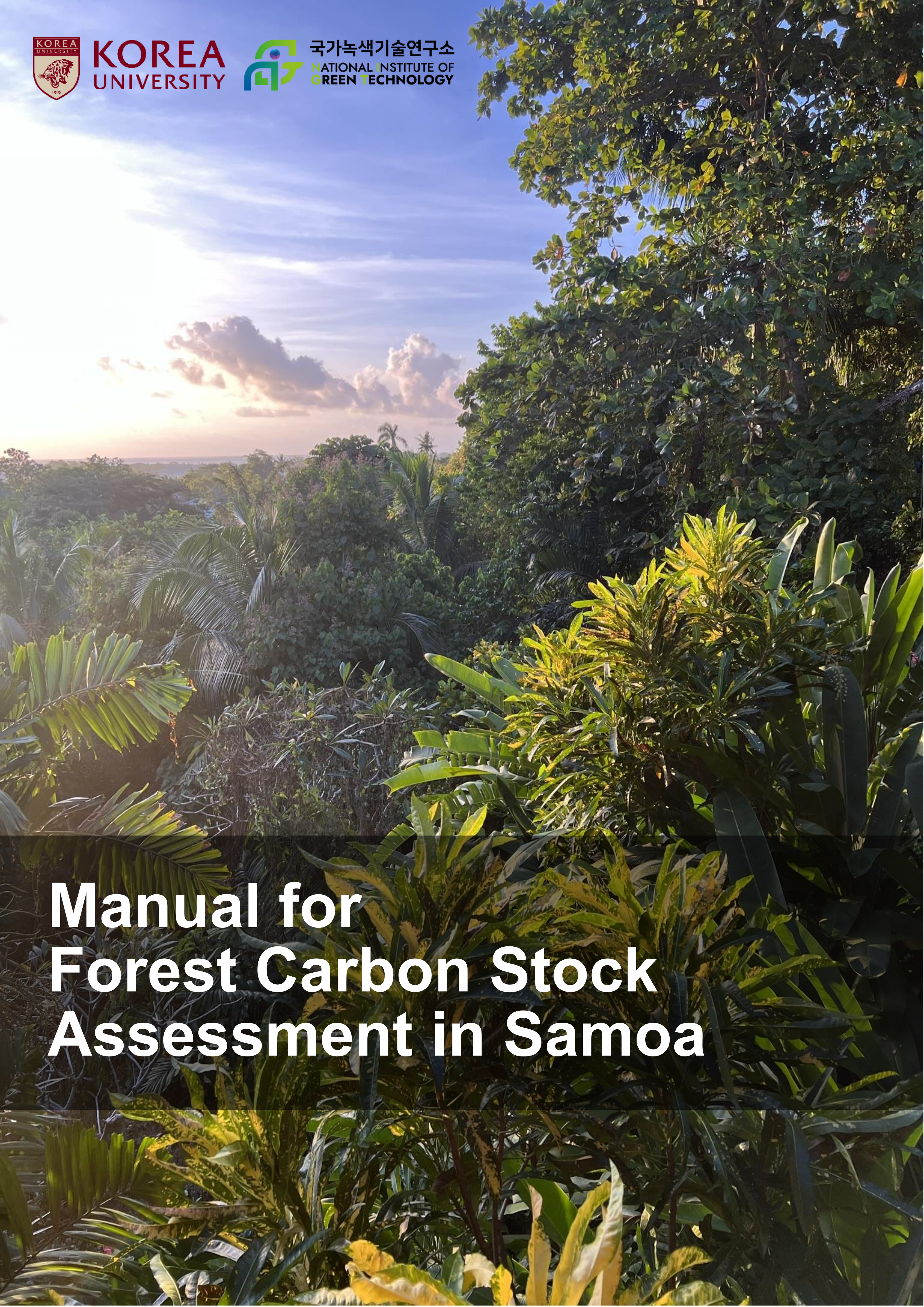

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Manual for Forest Carbon Stock Assessment in Samoa

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Korea University

Contents

1. Introduction

Forests are one of the most significant terrestrial carbon pools, absorbing carbon dioxide from the atmosphere. Trees store carbon within their biomass, including stems, branches, leaves, and roots. Additionally, a substantial portion of carbon is stored in the forest floor's organic matter, such as soils, litter, and deadwood. As global concerns over climate change intensify, the need to accurately estimate carbon stock in forests has become paramount. Accurate assessment of forest carbon stock serves as a fundamental baseline for evaluating the current carbon sequestration capacity of forests and their potential for future carbon storage. Such assessments provide valuable insights into the contribution of forests to the global carbon balance, guiding policymakers, forest managers, and conservationists in making informed decisions to safeguard these invaluable ecosystems. Furthermore, forest carbon stock assessment plays an important role in meeting international commitments, including those under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, where many nations have pledged to reduce emissions and enhance carbon sequestration.

This manual serves as a guide to demystify the forest carbon assessment process, providing accessible and comprehensive methodologies for field survey and estimation carbon stock in tree biomass, soils, litter, and deadwood in forests. By empowering researchers and practitioners with the knowledge and skills to conduct precise assessments, this manual aim to contribute significantly to global efforts in combating climate change and fostering sustainable forest management practices worldwide.

2. Field survey and estimation of forest carbon stock

1) Sampling and plot design

The fieldwork commences with the selection of an inventory area followed by the establishment of a plot within the chosen area to conduct the field survey. It is essential to ensure that the inventory area represents diverse area to encompass various types of forests and soils. The survey plots should be chosen for forest survey within the inventory area. The survey plot comprises four subplots, each set in three directions of 0° (subplot 2), 120° (subplot 3), and 240° (subplot 4) centered on the subplot 1 (Fig. 1). The size of each subplot is established at 0.04 ha, which can be achieved using either a circle plot with a radius of 11.3 m or a square plot with dimensions of 20 m × 20 m. To ensure robust data collection, the number of survey plots within the inventory area should incorporate at least three replicates. Additionally, considering the magnitude of expected carbon stock variation, it is advisable to establish more survey plots if the expected variation is significant. Moreover, to account for the variation in soil properties that might arise within the inventory area, it is essential to ensure that each plot is at least 50 m apart from one another.

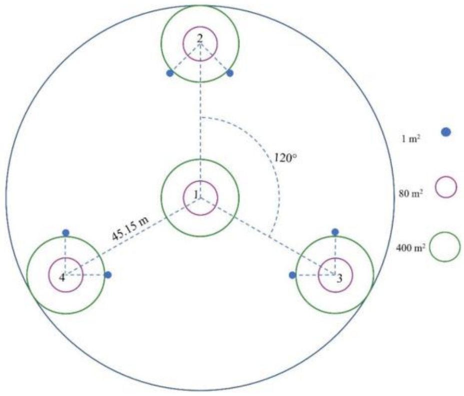

Fig. 1. Survey plot for field survey. The figure was derived from Soriano-Luna et al. (2018).

2) Tree biomass

Measure the diameter at breast height (DBH) and height of all trees with a DBH greater than 10 cm in the plots and mark the measured trees with a red marker. Identify all trees with the assistance of experts. If expert help is unavailable, collect leaves and branches and send them to experts to identify the species. The measured DBH and height are utilized in the biomass allometric equations to calculate the above-ground biomass. The biomass allometric equation reported by previous studies or IPCC could be used for the calculation. However, it is crucial to exercise caution and select the appropriate equation that is suitable for the specific regions and tree species under consideration. For example, Chave (2014) developed the allometric equation for the above-ground biomass in tropical forests (Eq. 1).

$$\text{Above-ground biomass} = 0.0673 \times (\rho D^2 H)^{0.976} \tag{1}$$

where ρ is basic wood density, D is DBH, and H is tree height. The standard method for measuring wood density is to calculate the ratio of dry weight to the volume of wood. If direct measurement of wood density is not feasible, the wood density values reported in previous studies can be employed for the calculation of biomass. Below-ground biomass can be estimated by multiplying the above-ground biomass with the root-to-shoot ratio (R/S ratio). Carbon stock in tree biomass can be determined using Eq. 2.

$$\begin{gathered}\text{Carbon stock in tree biomass} = \{\text{TAGB} + (\text{TAGB} \times \text{R/S ratio})\}\ (\text{Mg/0.04 ha}) \\ \times \text{Carbon conversion factor (\%)}\end{gathered} \tag{2}$$

where TAGB is the total above-ground biomass. R/S ratio and carbon conversion factor can be utilized for existing values by previous studies, forest resources assessment (FRA), or IPCC. For instance, in FRA 2020, the values for R/S ratio and carbon conversion factor in Samoa are reported as 0.20 and

47%, respectively.

3) Soils

For the estimation of carbon stock in soils, select 2–4 points within the subplot and collect soil samples up to a depth of 30 cm using a soil core sampler with a depth of 10 cm and a volume of 406.944 cm^3 (Fig. 2). When sampling soil, be careful not to mix the fallen leaves and herbaceous plants with soil samples.

Fig. 2. Collecting soil samples using soil core sampler

After collecting the samples from the field, air-dry them and then filter the dried samples through 2-mm sieves (US standard No. 10) to exclude any roots and gravel. Subsequently, oven-dry the filtered samples at 105 °C for 24 h and weight them to obtain the dry weight of samples. The bulk density can be calculated using Eq. 3.

$$\text{Bulk density} = \text{Dry weight of soil sample (g)} / \text{Volume of soil core sampler } (406.944\ \text{cm}^3) \qquad (3)$$

Afterward, the carbon concentration in the soil samples should be measured using an elemental analyzer. Carbon stock in soils can be estimated using Eq. 4.

$$\text{Carbon stock in soils} = \text{Bulk density} \times \text{Soil depth (cm)} \times \text{Carbon concentration (\%)} \qquad (4)$$

4) Litter

Select 2–4 points within the subplot and collect all fallen leaves and twig using a 0.3 m × 0.3 m square frame (Fig. 3). When collecting samples, be careful not to mix the soils with litter samples.

Fig. 3. Sampling litter using a 0.3 m × 0.3 m square frame.

After bringing the litter samples to the laboratory, dry them in an oven at 85 °C for 24 h and measure the dry weight. The carbon concentration in litter samples should be measured after grinding the samples. Then, carbon stock in litter can be estimated by Eq. 5.

$$\text{Carbon stock in litter} = \text{Dry weight of litter sample (g/0.09 m}^2\text{)} \times \text{Carbon concentration (\%)} \quad (5)$$

5) Deadwood

Deadwood indicates the standing or fallen trees with a dimeter greater than 10 cm and a length greater than 1 m within the subplot. Deadwood can be categorized into two types: snag (standing deadwood) and log (fallen deadwood) (Fig. 4).

Fig. 4. Standing (left) and fallen (right) deadwood. The images were obtained from World Wide Fund for Nature.

Figure out the decay degrees of deadwood, which can be classified into four classes (Table 1).

Table 1. Decay degree and criteria for deadwood

Code	Decay degree	Criteria
I	Freshly fallen	Bark, branches, and twigs still present.
II	Partially decomposed	Most bark still present and twigs are absent.
III	Moderately decomposed	Most bark and all branches are absent.
IV	Stage of fungal colonization	Deadwood can be easily broken, even with a light touch.

To determine the volume of deadwood, measure the diameters at the base, middle and top, as well as the length of each deadwood. The volume of deadwood can be calculated using Newton's formula (Eq. 6).

$$V = L \times \left(\frac{S + 4S_{1/2} + s}{6}\right) \tag{6}$$

where V is the volume of each deadwood, L is the length of deadwood, S is the basal sectional area, $S_{1/2}$ is the mid-sectional area, and s is the top sectional area.

Collect some deadwood samples which can represent the decay degree in the plots. After bringing the samples to the laboratory, dry them in an oven at 85 °C and measure the dry weight. Then, measure the volume of samples, basic wood density (dry weight/volume of sample), and carbon concentration. Carbon stock in deadwood can be estimated by Eq. 7.

$$\text{Carbon stock in deadwood} = \text{Total volume of deadwood within the plot } (m^3/0.04\ \text{ha}) \times \text{Basic wood density} \times \text{Carbon concentration } (\%) \tag{7}$$

2. Estimation of changes in forest carbon stock

1) Background

To estimate changes in forest carbon stock, two approaches are commonly used: 1) “gain-loss” (or “process-based”) approach, which estimates the net balance of additions and removals of carbon regarding a carbon stock, and 2) “stock-difference” (or “stock-based) approach, which estimates the difference in carbon stocks at two points in time. The “gain-loss” approach relies on estimating rates of growth and losses of carbon pools and requires apportioning the annual transfer of biomass into litter, deadwood, and soil carbon pools. However, to estimate the losses of carbon pools is difficult due to extraction, fire, decay, and other causes in the project area. In contrast, the “stock-difference” approach allows for easier accounting of changes in all relevant carbon pools to obtain the per-hectare change, despite varying measurement frequencies for different pools.

The Intergovernmental Panel on Climate Change (IPCC) recognizes the “gain-loss” approach as the default when limited data are available. However, for greater accuracy, the “stock-difference” approach is suggested due to its relative simplicity in calculation, making it an accessible and efficient option for researchers and practitioners. As a result, this manual focuses on utilizing the “stock-difference” approach to achieve more precise forest carbon stock assessment.

2) Equation

Changes in forest carbon stock can be estimated as follows (Eq. 8):

$$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \tag{8}$$

where ΔC is the annual change in carbon stocks in the pool (Mg C yr^{-1}), C_{t_2} is the carbon stock in the pool at time t_2 (Mg C), and C_{t_1} is the carbon stock in the pool at time t_1 (Mg C).

3) Procedure for estimating change in carbon stock

(1) Forest area and tree biomass carbon stock

This manual examines the changes in area by forest type for the years 1999, 2013, and 2023 using the Samoa NFI, Global Forest Resources Assessment (FAO, 2020), and field survey data as a resource (Table 2). By calculating the area (in hectares) for each forest type at these time points, tree biomass carbon stocks were estimated (Table 3). This is achieved by applying the most recently estimated biomass carbon stock for each forest type. Notably, more frequent assessments of forest type areas and carbon stock lead to greater accuracy in reporting changes in carbon stocks.

Table 2. Area and biomass carbon stocks (2023) by forest type in 1999, 2013, and 2023

Forest type	**Area (ha)**			**Biomass carbon stock in 2023 ($Mg\ C\ ha^{-1}$)**
	1999	**2013**	**2023**	
Open forest	55,322	53,288	66,068	67.7
Plantation forest	4,881	4,881	5,137	74.4
Secondary forest	36,203	35,932	36,957	81.9
Total	96,406	94,101	108,162	

Table 3. Tree biomass carbon stocks by forest type in 1999, 2013, and 2023

Forest type	**Biomass carbon stock (Mg C)**		
	1999	**2013**	**2023**
Open forest	3,745,299	3,607,598	4,472,804
Plantation forest	363,146	363,146	382,193
Secondary forest	2,965,026	2,942,831	3,026,778
Total	7,073,472	6,913,575	7,881,775

(2) Estimation of annual change in carbon stock

The annual change in tree biomass carbon stocks is calculated by dividing net change in these carbon stocks between two time points by the number of years elapsed between these points (Table 4).

Table 4. Net and annual change in tree biomass carbon stocks (1999–2013 and 2013–2023) by forest type

Forest type	**Change in carbon stock**			
	Net change	**Annual change**	**Net change**	**Annual change**
	1999-2013		**2013-2023**	
Open forest	-137,702	-9,835	865,206	86,520
Plantation forest	0	0	19,046	1,904
Secondary forest	-22,195	-1,585	83,948	8,394
Total	-159,897	-11,420	968,200	96,818

Tree biomass carbon stocks for the period of 1999–2023 were estimated based on the annual change in carbon stock (Table 5).

Table 5. Tree biomass carbon stocks by forest type for the period of 1999–2023

Forest type	1999	2000	2001	2002	2003
Open forest	3,745,299	3,735,464	3,725,629	3,715,794	3,705,959
Plantation forest	363,146	363,146	363,146	363,146	363,146
Secondary forest	2,965,026	2,963,441	2,961,856	2,960,271	2,958,686
Total	7,073,471	7,062,051	7,050,631	7,039,211	7,027,791
Forest type	**2004**	**2005**	**2006**	**2007**	**2008**
Open forest	3,696,124	3,686,289	3,676,454	3,666,619	3,656,784
Plantation forest	363,146	363,146	363,146	363,146	363,146
Secondary forest	2,957,101	2,955,516	2,953,931	2,952,346	2,950,761
Total	7,016,371	7,004,951	6,993,531	6,982,111	6,970,691
Forest type	**2009**	**2010**	**2011**	**2012**	**2013**
Open forest	3,646,949	3,637,114	3,627,279	3,617,444	3,607,598
Plantation forest	363,146	363,146	363,146	363,146	363,146
Secondary forest	2,949,176	2,947,591	2,946,006	2,944,421	2,942,831
Total	6,959,271	6,947,851	6,936,431	6,925,011	6,913,575
Forest type	**2014**	**2015**	**2016**	**2017**	**2018**
Open forest	3,694,118	3,780,638	3,867,158	3,953,678	4,040,198
Plantation forest	365,050	366,954	368,858	370,762	372,666
Secondary forest	2,951,225	2,959,619	2,968,013	2,976,407	2,984,801
Total	7,010,393	7,107,211	7,204,029	7,300,847	7,397,665
Forest type	**2019**	**2020**	**2021**	**2022**	**2023**

Open forest	4,126,718	4,213,238	4,299,758	4,386,278	4,472,804
Plantation forest	374,570	376,474	378,378	380,282	382,193
Secondary forest	2,993,195	3,001,589	3,009,983	3,018,377	3,026,778
Total	7,494,483	7,591,301	7,688,119	7,784,937	7,881,775

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