INTRODUCTION

Tropical deforestation has been an issue within science and society since the 16th century (Grove, 1994; Jepsen, 2006). Forest assessment is important for estimating not only national but also international carbon storage (Kenzo et al., 2009), and includes such activities as reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC allows flexibility for countries to start developing their forest reference levels and forest reference emission levels, and to monitor and report at a sub-national scale as an interim measure in accordance with national circumstances (UNFCCC, 2010). The general method used by the Intergovernmental Panel on Climate Change to estimate forest carbon changes consists of multiplying activity data by an emission factor (GOFC-GOLD, 2012; Picard et al., 2015). Emission factors, i.e. carbon stocks per hectare, are estimated using forest survey data and biomass equations.

Nonetheless, 16 countries in Asia together reported a total of approximately 24 million hectares of bamboo-dominant forest, constituting 4.4 % of the total forest area in the countries surveyed (Lobovikov, Paudel, Piazza, Ren, & Wu, 2007). In Myanmar, bamboo is primarily used by household consumers for general household goods (e.g. mats, panels and utensils), the construction sector (e.g. bamboo poles) and cottage industries (e.g. handicrafts and bamboo shoots) (BIF, 2015). Bamboo on land also defined as forest can be found in Myanmar (FAO, 2006), with 2.7 % of forest area in Myanmar dominated by bamboo (Lobovikov, Paudel, Piazza, Ren, & Wu, 2007). Carbon stock estimation of bamboo is indispensable for accurate forest carbon accounting in Myanmar.
diameter at breast height (DBH) or basal area (Chan, Takeda, Suzuki, & Yamamoto, 2013; Chan, Takeda, Suzuki, & Yamamoto, 2016; Kiyono et al., 2007; Singh & Singh, 1999; Yuen, Fung, & Ziegler, 2017). A field survey is essential for estimating the emission factor in REDD+ activity. However, bamboo stands are dense and multiple culms, so measuring every bamboo DBH during a forest survey is both labor intensive and time consuming. Generally, bamboo does not undergo secondary hypertrophic growth (Wilson & Loomis, 1966), and it is considered that the bamboo culm has a relatively homogeneous size. Therefore, instead of measuring the DBH of all bamboo in one plot, by first measuring several DBHs for each species and then counting only the remaining number of bamboo culms, it is possible to estimate the total amount of biomass by estimating the average weight of biomass and multiplying by the number of each bamboo species. This is considered that labor saving of the field survey can be achieved. The aims of this study were to examine how to measure bamboo DBH for biomass estimation and to conduct a survey of bamboo measurements in Myanmar using this method.

Table 1. General descriptions of bamboo measured in 37 plots in Paung Laung Reserve Forest, Myanmar

<table>
<thead>
<tr>
<th>Local Name</th>
<th>Scientific Name</th>
<th>Number of Measured Plots</th>
<th>Number of Measured Culms</th>
<th>DBH (cm) Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyat Thaung</td>
<td>Bambusa polymorpha</td>
<td>9</td>
<td>3,685</td>
<td>6.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Tin Wa</td>
<td>Cephalostachyum pergricile</td>
<td>11</td>
<td>5,240</td>
<td>5.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Wa Bo</td>
<td>Dendrocalamus brandisii</td>
<td>26</td>
<td>3,595</td>
<td>8.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Wa Net</td>
<td>Bambusa vulgaris</td>
<td>1</td>
<td>123</td>
<td>3.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Wa Nwe</td>
<td>Dinochloa macilelandii</td>
<td>3</td>
<td>330</td>
<td>3.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Wa Gauk</td>
<td>Oxytenanthera albociliata</td>
<td>23</td>
<td>10,281</td>
<td>2.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Htee Yoe War</td>
<td>Thyrosostachys siamensis</td>
<td>1</td>
<td>10</td>
<td>11.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Thana Wa</td>
<td>Thyrosostachys oliveri</td>
<td>3</td>
<td>940</td>
<td>19.6</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Remarks: DBH= diameter at breast height; SD= standard deviation
MATERIALS AND METHODS

Site Description

Forest survey data were obtained from the Paung Laung Reserve Forest (RF) site located in central Myanmar, which extends over 1700 km² (Fig. 1, lat. 19°45’–20°28’ N, long. 96°22’–96°49’ E, and elevation 300–1,700 m a.s.l.). The precipitation at the study site is higher in the eastern parts, i.e. Shan State. The maximum and minimum annual total rainfalls are 2,167 mm and 812 mm, respectively (Mon, Kajisa, Mizoue, & Yoshida, 2009). Forests cover most parts of the RF, and they can be broadly classified as mixed deciduous forests and evergreen forests (Zin, 2005). In 2015, the Upper Paung Laung Dam located on the Paung Laung River, which runs from north to south in the middle of the study area, was established to generate electricity and to provide irrigation for various crops. This area is an important source for both local and commercial timber supplies. Accordingly, the Paung Laung watershed has diverse intrinsic value not only for the local and national economies but also for biological diversity conservation (Mon, Kajisa, Mizoue, & Yoshida, 2009).

From February 2016 to February 2017, 53 temporary plots, each 0.16 ha (40 × 40 m), were set up (Fig. 1). All living trees in each plot with a DBH ≥ 10 cm were individually measured, and the species were identified. Trees with a DBH ≥ 5 cm were measured in two subplots (10 × 10 m) in the northeast and southwest corners of each of the 53 temporary plots. This research used the same procedure of tree inventory defined by Sato & Miyamoto (2016). All bamboo culms with a DBH ≥ 1 cm within the plots were measured. Of the 53 temporary plots, bamboo was measured in 37 plots. Table 1 shows the descriptions of the bamboo measured in the 37 plots. The average number of bamboo culms per plot was 654, with one plot having 2,606 bamboo culms. The range of bamboo coverage was from 4 % to 96 %.

Data Analysis

DBH function allometric equations used to estimate aboveground (Chan, Takeda, Suzuki, & Yamamoto, 2013) and belowground bamboo biomass (Singh & Singh, 1999). Commonly, the total biomass is calculated using the following equation:

\[ W = \frac{\sum_{i=1}^{n} w_i}{A} \]  

(1)

where \( W \) is the weight of total bamboo biomass per hectare, \( w_i \) is the weight of the observed bamboo culm \( i \) that was calculated using an allometric equation, \( n \) is the number of bamboo culms in one plot, and \( A \) is the plot area (hectares). To reduce the number of DBH measurements, we used the following equation:

\[ W_e = \frac{\bar{w} \cdot n}{A} \]  

(2)

where \( W_e \) is the estimated weight of total bamboo biomass per hectare and \( \bar{w} \) is the average weight of sampled bamboo culms for which the DBH was measured. To evaluate how many samples (DBH measurements) were required to estimate the average weight in one plot for each bamboo species, the probability density functions of \( w \) for each plot and each species were estimated using Monte Carlo sampling with the data set of 37 plots as follows. First, samples were randomly selected from the original data pool without replacement. The sampling ratio was changed from 100 % to 1 % at intervals of 1 %. For each sample, the procedures were repeated 10,000 times, and the probability density function of averages was determined (e.g. Inoue, Kitahara, Suga, & Wajima, 2011; Kumagai et al., 2005). Thus for the sample range, the standard deviations of \( w \) were obtained by Monte Carlo sampling. To evaluate the potential precision in estimating biomass caused at a given sampling size, the change in the coefficient of variation (CV), which represents potential estimation precision, with the sampling size was analyzed.
RESULTS AND DISCUSSION

Sampling Ratio

Fig. 2 shows the relationship between the sampling ratio for bamboo culm and the CV, which was computed with the Monte Carlo sampling, for each species. If one plot contains a large number of total bamboo culms, the CV, which was calculated using the population means and standard deviations from the probability functions, tends to be small even when the sampling ratio is small. Here, it is assumed that the target (threshold) value of the CV is 10%. Fig. 3 shows the relationship between the bamboo density (the number of bamboo culms) for each plot and for each species and the minimum sampling ratio when the CV is less than 10%. The relationship between bamboo density and minimum sampling ratio was approximated by the following equation:

\[ MR = 331.1 - N^{-0.599} \]  

(3)
where $MR$ is the minimum sampling ratio and $N$ is the bamboo density for each plot and each species. Multiplying both sides of Eq. (3) by $N/100$, it can be obtained the following equation to estimate the required sampling number:

$$RN = 3.311 - N^{0.401}$$

where $RN$ is the required sampling number, and $N$ is the bamboo density for each plot and each species. Eq. (4) can be used to estimate the sampling numbers (DBH measurements). However, knowing the bamboo density before field surveyors decide how many DBHs to measure is difficult. Therefore, a summary of simplified required sampling numbers is shown in Table 2. As an example of bamboo survey procedure, if there is bamboo in a plot, field surveyors need to measure the DBH of 20 bamboo culms. When there are more than 20 bamboo culms, surveyors count the number of culms up to 50. If there are more than 50 bamboo culms, surveyors measure another 30 bamboo DBHs and count the remaining number up to 500, and so on.

As a method of determining sample number for DBH measurement considering sampling ratio, this research developed a method utilizing an equation representing the relationship between required sampling number to satisfy target value of CV (10\%) and culms density (Eq. 4) (hereafter, Method 1).

**Remarks:** The solid line indicates the obtained power regression equation (Eq. 3).

**Fig. 3.** Relationship between the observed number of bamboo culms in a plot for each species and minimum sampling ratio when the coefficient of variation is less than 10\%.

**Table 2.** Summary of simplified required sampling numbers for bamboo survey procedure

<table>
<thead>
<tr>
<th>Number of bamboo culms (N)</th>
<th>Required sampling number (RN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>N</td>
</tr>
<tr>
<td>21 – 50</td>
<td>20</td>
</tr>
<tr>
<td>51 – 500</td>
<td>50</td>
</tr>
<tr>
<td>501 – 1,000</td>
<td>60</td>
</tr>
<tr>
<td>1,001 – 1,500</td>
<td>70</td>
</tr>
<tr>
<td>1,501 – 2,000</td>
<td>70</td>
</tr>
<tr>
<td>2,001 – 2,500</td>
<td>80</td>
</tr>
<tr>
<td>2,501 – 3,000</td>
<td>90</td>
</tr>
</tbody>
</table>

**Sampling Size**

Fig. 4 depicts the relationship between the sampling size and the CV for each plot and each species. The sampling size was calculated by multiplying the sampling ratio by $N/100$. The CV rapidly decreases when the sampling size is less than 20. However, if the sampling size is between 20 and 30, the reduction rates of most CVs are stable. One method for determining the required number of measurements uses the stability of the CV reduction rate as a threshold (e.g. Inoue, Kitahara, Suga, & Wajima, 2011). Therefore, it is assumed that another target value for the required number of DBH measurement is 30 bamboo culms. As a method determining sample number for DBH measurement considering sampling size, a method selecting 30 bamboo culms for each species in one plot was accepted (hereafter, Method 2).

**Validation**

Fig. 5 shows the validation results for the two target values (Method 1 and 2). The estimated biomass was calculated using the average weight taken from the required sampling number of culms, which were selected randomly. The average absolute error ratios were 6.0\% and 6.9\%, and the coefficients of the linear regression model between observed and estimated biomass without intercept were 1.02 and 1.09, respectively. Method 1 is complicated for field survey instruction and is expected to degrade the accuracy of biomass estimation if there is a local bias of individual culm size in a plot. Method 2 requires surveyors to select 30 bamboo culms for the actual field survey. Furthermore, since the measurements of DBH for Method 2 include only 30 culms per plot and per species, the accuracy of the estimation is inferior to that of Method 1 when the number of culms is very large. Otherwise, it is considered that the survey time for Method 2 will be shorter than that for Method
1. In the future, it will be necessary to compare these results by assessing the time to measure the diameters and the time to count the number of culms, and to discuss the optimum laborsaving survey method that balances the estimation accuracy and survey time that means cost efficiency.

Fig. 4. Relationship between sampling size and the coefficient of variation (CV) for average bamboo biomass

Remarks: Solid lines indicate the results for one plot. As the sampling size was calculated by multiplying the sampling ratio by N/100, some lines are broken when the sampling size is small.
CONCLUSION AND SUGGESTION

This study examined a method for reducing the number of DBH measurements for estimating bamboo biomass in Paung Laung Reserve Forest, Myanmar. However, it is considered that the results differ depending on the region and bamboo species, and the allometric equation has as much influence on the biomass quantity as the emission factor. Further accumulation of data is required for a forest survey of REDD+ activities in developing countries.

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REFERENCES


