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Changes of carbon storage of forests under MRRP operations in Taungoo district, Myanmar

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Abstract

This study emphasized on the estimation of the species composition and carbon storage of forests under assistant natural regeneration (ANR) operation under MRRP, and forests which are not. The study also developed the carbon storage model of forests. Based on the results, A total of 31 species and 14 species were found in forests with ANR and forests with no ANR, respectively. Species diversity was assessed with the Shannon and Simpson diversity indices. The Shannon index and evenness tended to increase from forests with no ANR to those with ANR. The Shannon index at forests with ANR was 2.95±0.26 and those with no ANR was 2.29±0.32. Similarly, the carbon storage of forests was significantly higher in forests with ANR in comparison with forests with no ANR. The carbon storage of forests with ANR showed 108±8.95 ton per ha and those in forests with no ANR was 58.76±4.33 ton per ha. The model development also highlighted the effectiveness of ANR under MRRP.

Keywords: Assistant natural regeneration; Carbon storage; Regeneration; Species diversity; model.

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1. Introduction

Nowadays global warming caused by environmental pollution is one of the major problems that needs to be controlled as a worldwide problem. During the period of 1983 □ 2012, North Hemisphere has been facing the warmest of the previous 1,400 years (IPCC 2014). The global average temperature increased by 0.65ºC to 1.06ºC between 1880 and 2012 as a result of increasing anthropogenic greenhouse gas emissions (IPCC 2014). Noticeable changes in weather and climate have been found in recent decades.

Carbon dioxide emissions are a major cause of global warming. There are many sectors that emit CO2. Among them, deforestation and forest degradation have been occurred as a main source of carbon emissions. Global forest areas decreased from 4,128 M ha to 3,999 M ha between 1990 and 2015 (Keenan et al. 2015). Generally, CO2 emissions caused by forest degradation and deforestation account for 0.9 Pg C yr-1 (IPCC 2013). Tropical forests alone cover about half of global forest areas, and their decimation significantly contributes to the overall decrease in global forests. Between 1990 and 2015, tropical forests decreased in area from 2,022 M ha to 1,819 M ha (Keenan et al. 2015). On the other hand, forests act as a sink for carbon; it is estimated that they store over 500 Pg of carbon globally (FAO 2016).

The world forests cover about one third of the global land area, and it could be considered as a sink or source of carbon (Köhl et al. 2015). Globally, forests stored 650 Pg of carbon (Khaine and Woo 2015). On the other hand, it omitted a large amount of carbon from deforestation and forest degradation (Phillips et al. 2016). The rate of forest decline was estimated as 13 million ha $year^{-1}$ (Thompson et al. 2014).

Like other tropical countries, Myanmar has faced the impacts of climate changes. Forest degradation has been found throughout the country. The deforestation rate was the third highest rate in the world during a period of 2010 □ 2015 (FAO 2016). Because of a wide coverage of forests in Myanmar, the impact from forest degradation and deforestation or the benefits from conservation of forests would be larger than other countries that have a lower forest coverage. Therefore, a well-planned management of forests is essential for the sustainability of forests and regulation of climate change. Understanding the main mechanisms that effects carbon storage of forests is crucially important to assess and manage for the increase of the carbon storage potential of forests (Cai et al. 2016).

Deforestation was due to a number of political, social and economic factors of the nations. Large scale reforestation and rehabilitation is, thus, urgently needed in order to increase forest cover, and to be compliance with the international agreements related to climate change mitigation and adaptation. Therefore, Myanmar Restoration and Rehabilitation Program (MRRP) (2017-18 to 2026-27) has been implementing in order to regain the ecosystem rich in biodiversity through reforestation and rehabilitation of forests; mitigate the impacts of climate change; support the socio-economic development of the nation and support the sustainable forest management. Reforestation is implementing in 68 Forest Districts of 15 States and Regions dividing into six zones. This study emphasized on the estimation of the species composition and carbon storage of forests under ANR operation, and forests which are not. The study also developed the carbon storage model of forests.

2. Materials and Methods

2.1 Sampling procedure and experiments

The study sites were selected in Taungoo District, Bago Region of Myanmar. The sample plots were situated between the latitude of 19° 15′N to 19° 23′N and longitude of 95° 51′E to 95° 58′E. The climate of these regions was a tropical savanna climate. Through the period of 1982 to 2014, the average annual precipitation of the study site is 2,035 mm. Sampling plots were laid down at each study site using the stratified sampling. A preliminary survery was performed in each site before establishing the sample plots. Then the forests were stratified depending on the apparent density of forests and the occurrence of minor disturbance (Khaine et al. 2017). In each stratum, the sample plots were laid out randomly so that the sample plots covered and represented the individual sites.

The size of each sample plot was 1,017.36 m^2 (18 m in radius of the circle) with a distance of 100 m. The plots were set up by L shape extending from the centre to south and west positions. In each plot, the diameter and height of all trees greater than 5 cm in diameter at breast height (dbh) were measured. Fifteen sample plots were carried out for the survey covering the forests under MRRP (ANR) and the forests which MRRP activities were not conducting. The survey for natural regeneration was carried in 2 m circle plots with a distance of 10 m.

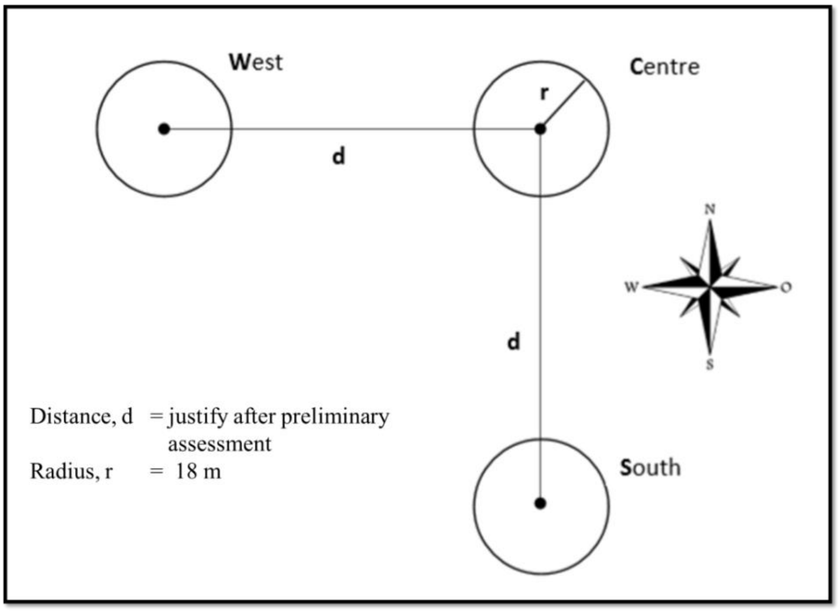
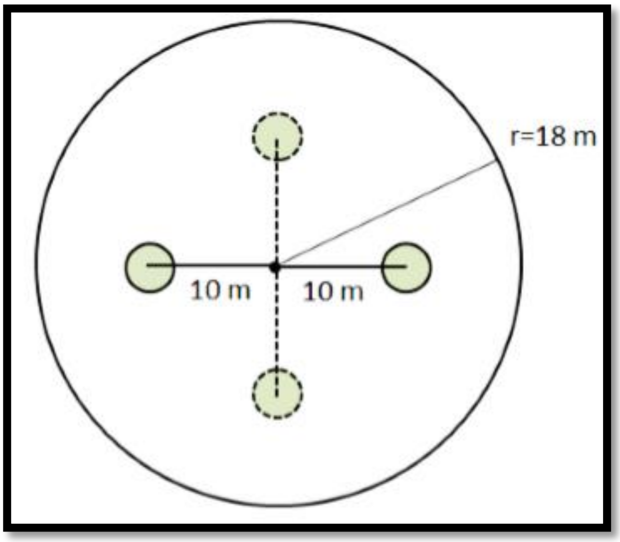


Figure 1. Plot design



2.2 Data analysis

In case of species diversity, two commonly accepted diversity indices, namely, Shannon index (Shannon and Weaver 1949) and Simpson index (Simpson 1949) were calculated. The diversity index could be defined as a mathematical measure of species diversity of a forest. The Shannon diversity index give a favor for rare species, while the Simpson diversity index give a more outweigh to the common species (Heip et al. 1998; Oo 2009; Hakkenberg et al. 2016). Both indices are the products of the richness of species and the abundance of individual species in a forest. Duncan's multiple range tests was used to express the differences among indices.

The formula for Shannon's diversity index is as follows:

$$H' = \sum_{i=1}^{s} (Pi)(\ln Pi),$$

where, H' = Shannon's diversity index

s = the number of species in the sample

Pi = the proportion of the total sample belonging to the i^{th} species

ln = the natural logarithm

The formula for the Shannon evenness index is as follows:

$$E\,(\%) = 100\,(H'/\ln H_{max})$$

where, E = the Shannon evenness index in percentage

H' = Shannon's diversity index

H_{max} = the number of total species

The formula for Simpson's diversity index is as follows:

$$D = \sum_{i=1}^{s} \{n_i\,(n_i - 1)/N\,(N - 1)\}$$

where, $(1 - D)$ = Simpson's index of diversity

n_i = the number of individuals of species i

s = the number of species in the sample

N = the total number of individuals in the sample.

The above-ground carbon storage was calculated using formulas recommended by Brown (1997) and FAO (2015).:

The carbon storage of forests at the study site was calculated using the following formula:

$$Y= \exp \{-2.134 + 2.530 \times \ln(D)\}$$

where, Y = above-ground biomass of forest

D = diameter of tree

The carbon conversion factor, 0.47, (IPCC 2006) was used for calculating the carbon storage of forests.

The three growth parameters, namely, diameter, height, and basal area of trees were used as tentative independent variables for the development of carbon storage model. The most influencing parameters on the development of models were selected in order to reduce the redundancy or error propagation when developing a model. Selection of the most influencing parameters was perfomed using both a step-wise selection and a correlation/regression analysis in SPSS statistical software (Version 24, International Business Machines Corporation (IBM), United States, 2016). The most influential parameters were selected based on the following criteria: AIC, Pearson coefficient, the coefficient of determination, adjusted coefficient of determination, the calculated probability value for Pearson correlation, and the calculated probability value for coefficient of determination.

After selecting the most influencing parameters (to be used as independent variables in the model), the type of model form was facilitated. All types of basic linear model forms, known as linear, logarithmic, quadratic, and cubic, were considered for the establishment of a carbon storage model. In addition, multilinear model and the type of model developed by Brown et al. (1989) and Martinez-Yrizar et al. (1992) were considered. Table 33 showed the tentative models analyzed during the development of the best fit models.

Although there were three growth variables for the establishment of carbon storage models, 'height' was excluded based on the process described above used to screen independent variables. Therefore, only two independent variables (diameter and basal area) were used to develop the carbon storage models. In the basic model form, diameter and basal area were tested separately. The settlement of all functions were perfomed in SPSS statistical software (Version 24, International Business Machines Corporation (IBM), United States, 2016).

3. Results and Discussions

3.1 Species richness and diversity

A total of 31 species and 14 species were found in forests with ANR and forests with no ANR, respectively. Species diversity was assessed with the Shannon and Simpson diversity indice. The Shannon index and evenness tended to increase from forests with no

ANR to those with ANR. The Shannon index at forests with ANR was 2.95±0.26 and those with no ANR was 2.29±0.32. The dominant species in forests with ANR were Kha Paung (*Strychnos nux-blanda*), Kyo (*Schleichera oleosa* (Lour.) Oken), Kyun (*Tectona grandis* Linn.f), Phet Than (*Haplophragma adenophyllum* (Wall. Ex G.Don) Dop) and Zi phyu (*Emblica officinalis* Gaertn.) species. Whereas, the dominant species in forests without ANR were Binga (*Mitragyna rotundifolia* (Roxb.) Kuntze), Kyo (*Schleichera oleosa* (Lour.) Oken), Chin Yoke (*Garuga pinnata* Roxb.), and Thin Win (*Millettia pendula* Benth).

3.2 Natural Regeneration

The status of natural regeneration was determined depending on the transition of seedlings, saplings, and matures in each forest. The number of plants generally reduced in the transition from the seedling to sapling stages and from the sapling to the mature stages at all study sites. Forests with ANR had better natural regenerations than that of no ANR. Kyun (*Tectona grandis* Linn.f), Pyinkado (*Xylia dolabriformis* Benth.), Khu than (*Hymenodictyon excelsum* (Roxb.) Wall.), and Thayin Gyi (*Croton oblongifolius* Roxb.) were dominant species in natural regeneration in forests with ANR. Binga (*Mitragyna rotundifolia* (Roxb.) Kuntze) is the most dominant species and Kyun (*Tectona grandis* Linn.f) was not occurred in forests with no ANR. The composition of commercial species in forest with no ANR is significantly lower than that of the forests with ANR.

3.3 Carbon storage

The carbon storage of forests was significantly higher in forests with ANR in comparison with forests with no ANR. The carbon storage of forests with ANR showed 108±8.95 ton per ha and those in forests with no ANR was 58.76±4.33 ton per ha. The forests with no ANR area were degraded forests so that it would be one of the factors of reducing the carbon storage potential of forests. The carbon storage of forests with ANR is still lower than that in the natural good forests in mixed deciduous forests developed by Khaine 2018. Compared to other countries, the carbon storage is lower than the Panama forests (Rui-Jaen and Potvin 2010) and the Colombia forests (Phillips et al. 2016).

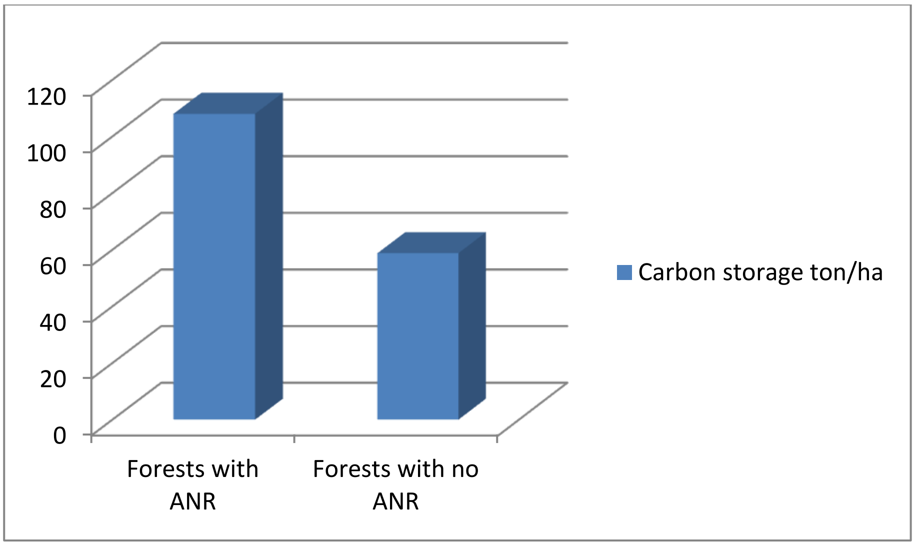


Figure 2. Carbon storage of different forests

3.4 Development of carbon storage model

Before developing a model, a case-wise diagnostic test (outside of three standard deviations) was applied to identify the presence of outliers. That process is necessary because outliers can affect regression models, and large outliers may even cause the model to fail. In this study, residuals from the original data set were within the range of three standard deviations.

Table 1. Tentative basic regression forms for a comparison of models to develop the best fit model

Model	Reference
Basic forms (independent – D)	
$y = \beta_0 + \beta_1 x$	Basic linear
$y = \beta_0 + \beta_1 In(x)$	Basic logarithmic
$y = \beta_0 + \beta_1 x + \beta_2 x^2$	Basic quadratic
$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3$	Basic cubic
$y = \beta_0\ e^{\beta 1x}$	Basic exponential
Basic forms (independent – BA)	
$y = \beta_0 + \beta_1 x$	Basic linear
$y = \beta_0 + \beta_1 In(x)$	Basic logarithmic
$y = \beta_0 + \beta_1 x + \beta_2 x^2$	Basic quadratic
$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3$	Basic cubic
$y = \beta_0\ e^{\beta 1x}$	Basic exponential

Multilinear form (independent – D, BA)	
$y = \beta_0 + \beta_1 D + \beta_2 BA$	Multilinear
Other model forms	
$y = e^{\beta 0 + \beta 1 \ln(D)}$	Brown et al. (1989)
$y = 10^{\beta 0 + \log(BA)}$	Martinez-Yrizar et al. (1992)

D, BA, x, and y are tree diameter (cm), the basal area (m^2), independent variables, and tree carbon storage (kg), respectively. β_0, β_1, β_2 and β_3 are the estimated parameters.

Screening tentative parameters is an important early step in model development. The error and complexity of a model can be reduced and controlled by trimming parameters that fail to significantly impact the target variables. In this study, all three growth parameters (i.e. diameter, basal area, and height) were included in the development of above-ground carbon storage models.

Results from a correlation analysis showed that all three parameters had strong correlations with carbon storage without showing big differences among three parameters ($0.955 < r < 0.999$). Similarly, both the coefficients of determination and adjusted coefficients of determination for all three parameters were high. This meant the effects of all three parameters were very strong and significant. The basal area showed a higher Person correlation coefficient, coefficient of determination and adjusted coefficient of determination than other two parameters (diameter and height). Still, the values for diameter and height were similar. In the livelihood analysis, diameter and basal area had a much greater influence than tree height on the models at each study site. Based on our analysis, diameter and basal area were the most suitable and effective parameters to consider for the development of above-ground carbon storage models.

Table 2. Analytical values of model parameters showing the effects of parameters on model development.

Description	AIC	r	R^2	Adj. R^2	Per. Sig.	Reg. Sig.
Diameter	< -0.0001	0.945	0.901	0.839	0.020	0.052
Basal area	< -0.0001	0.997	0.990	0.993	0.002	0.015
Height	36.212	0.956	0.918	0.867	0.020	0.050

AIC = Akaike information criterion; r = Pearson correlation coefficient; R^2 = coefficient of determination, Adj. R^2 = adjusted coefficient of determination, Per. Sig. = calculated probability value for Pearson correlation; Reg. Sig. = calculated probability value for coefficient of determination.

The results shown that diameter and basal area are the most influential parameters. Therefore, they were used as independent variables for the establishment of the carbon storage models.

The basic quadratic model was found to be the best fit model for estimating carbon storage of forests. It gave the minimum value for AIC, sum square residual (SSR), FI, and CF. The AIC value of Eq. 1 was -39.64; FI was 0.05; and CF was 1.00002. The coefficients and parameters of the individual models for five dominant species are shown in Table 3.

Table 4. The coefficients of variables in the establishment of the best fit carbon storage model.

Model	Eq	Coefficient β_0	Coefficient β_1	Coefficient β_2	Coefficient β_3
$y = \beta_0 + \beta_1 BA + \beta_2 BA^2$	1	-3.056	2809.85	22550.860	
$y = \beta_0 + \beta_1 BA + \beta_2 BA^2 + \beta_3 BA^3$	2	-3.052	2809.84	22550.856	0.000
$y = \beta_0 + \beta_1 D + \beta_2 D^2 + \beta_3 D^3$	3	-9.690	2.13	0.000	0.009

The bias of the best fit models showed less than -0.00013%, and as such was considered insignificant.

For validation, the comparison between the predicted and observed values showed that the best-fit models of each species were robust enough to use for the calculation of carbon storage. The root of mean square error (RMSE) was 0.12, and the bias ranged from -2.5%. Neither the RMSE nor the bias showed significant errors (which would have indicated poor fitness of the models).

4. Conclusion

The carbon storage of forests with ANR was significantly higher than those with no ANR. Carbon storage could be significantly affected by the diversity and structure of forests. The development of model is very important to use for all respective sites. For the development of carbon storage model, screening key parameters before developing the models was necessary for identifying the parameters with the greatest influence. This screening process is very important for the development of models because it can reduce error propagation and data redundancy. The reliability and performance of the best-fit model was strong in each case. There was no interaction between the standardized predicted values and the standardized residuals. They scattered independently within a narrow range of deviation, and with very low error and bias. Like before, we found that some situations warranted the use of alternative models, while others did not. Factors such as AIC, FI, and CF should be considered together with the R2 value when developing above-ground carbon storage models. All the results pointed out that the

MRRP operation such as ANR will significantly affect the positive trend of carbon storage of forests.

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