TREE CARBON ASSESSMENT AFTER SELECTIVE LOGGING IN TERENGGANU, MALAYSIA

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ABSTRACT

Forests play a prominent role in carbon storage and regulating global climate by sequestering carbon dioxide in the atmosphere. This situation has resulted prevalent interest among stakeholders for identifying actions that maintain or enhance carbon storage in forests. Assessment on tree carbon at local scale is useful in providing information for forest management and mitigation of climate change. A study was carried out in three districts in Terengganu, Malaysia to assess tree carbon with respect to four different forest categories based on years after logging (i.e., 1-10 years, 11-20 years, 21-30 years and 30+ years). A total of 12 study plots of 50 × 50 m were randomly set up. Tree with diameter-at-breast-height (DBH) > 10 cm were collected at the first subplot of 10 × 10 m, while trees with DBH > 15 cm were collected at the whole plot. The DBH and height were used to calculate total tree biomass, and the carbon conversion coefficient of 0.47 was then used to calculate the tree carbon. Based on the results, large amount of tree carbon stored at forest categories of 30+ years after logging. The present of large trees contribute higher carbon in this forest category. In term of species group, in forest category of 30+ years after logging, higher tree carbon was contributed by dipterocarp Meranti and dipterocarp non-Meranti. Thus, this study may provide insights for forest management in Malaysia that maintaining big trees and certain species groups as prescribed in the current Selective Management System (SMS) are important to serve as carbon sequester in efforts of combating climate change.

Key words: Tree carbon; forest management; selective logging; climate change; Terengganu.

INTRODUCTION

Functions of forests are significantly prominent as carbon storage and global climate regulation due to dual ability to act a sink and a source of carbon dioxide in the atmosphere. Moreover, forests also can be considered as a major terrestrial carbon reserve where trees constitute about 80% of forest biomass (Kindermann et al., 2008; Kuruppuarachchi et al., 2015). Logging and degrading trees within these forests will facilitate substantial amount of carbon dioxide releases back to the atmosphere, and eventually contributing to global warming (Le Quéré et al., 2018). The increasing trends of carbon dioxide concentration in the atmosphere and its implications towards climate have created global attention on the role of forest ecosystem (Munishi & Shear, 2004). Basically, degradation can be defined as a human-induced decreased in the capacity of an ecosystem to provide services (Thompson et al., 2013). Through previous record, 69% of total carbon losses from tropical forests has resulted from forest degradation (Baccini et al., 2012). This situation has created widespread interest among land managers and stakeholders for identifying actions that maintain or enhance carbon storage within forests (Ontl et al., 2020).

While, forestry sector is one of important economic sectors in several countries including in Malaysia although there is increasing recognition of the protective roles of the forests (Samsudin et al., 2010). Most of these countries are practicing selective logging to ensure sustainable timbers and species composition. According to Annual Report 2018 of Forestry Department Peninsular Malaysia (FPDM) showed that Terengganu was recorded third largest timber production in Peninsular Malaysia (FDPM, 2019). This shows that Terengganu is dependable on timber as one of economy contributors to the state. However, selective logging, if poorly implemented, may cause substantial damage to residual stands and possibly affects all components of biodiversity, from genes to landscape (Medjibe et al., 2011). Continuous expansion of logging and production areas over time will also affect carbon dynamic of forests. (Blanc et al., 2009). Hence, assessment of carbon stocks within production forests in Terengganu sounds beneficial for providing recent information, forest management references and mitigation measures in Malaysia.

The amount of collateral damage from logging activities to remaining trees, the frequency of intervention and the rate of regrowth affect the landscape level carbon density and biodiversity (Fauzi et al., 2017). Speaking on species diversity and composition, different plants carry different ability to sequester carbon between species (Ma et al., 2015). For example, some major or special species may bring service to environment by presenting as largest carbon storage over other species within particular forest areas. Damages to residual stands of these major or special species may be induced long-lasting reduction of forest biomass and directly affect the long term trend of carbon storage. Despite the significant roles of trees are eminent for environment, lack of studies had been conducted to determine the status of tree carbon as affected from certain years after logging in Malaysia. Therefore, this study was carried out to assess the tree carbon based on years after selective logging in Terengganu. The information from this study is expected to provide baseline information on tree carbon of Terengganu and indirectly promoting sustainable forest management in Malaysia.

MATERIALS AND METHODS

Study area

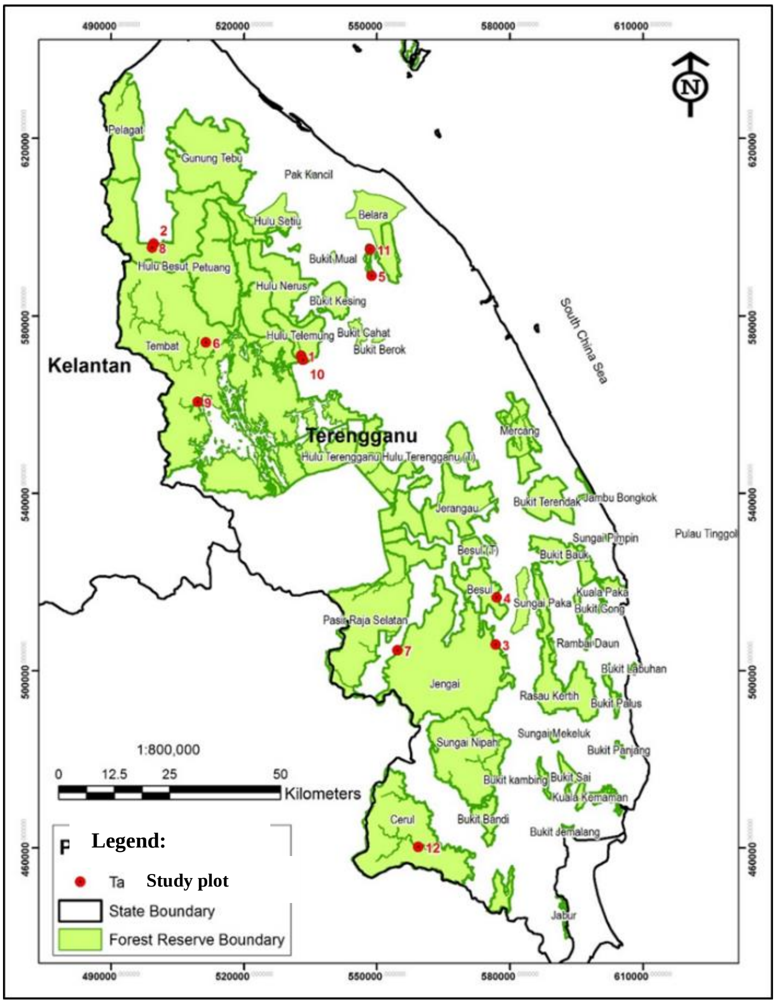
This study was conducted in selected forest reserves in Terengganu, Malaysia (Table 1). In term of geography, this state is located approximately 500 kilometres northeast of Kuala Lumpur and pointing up to the South China Sea. In term of weather pattern, Terengganu is having a tropical rainforest climate. The mean temperature and annual rainfall were recorded at 26.7 ˚C and 2911 mm, respectively (Radi et al., 2015). General information of study plots is shown as in Table 1. These 12 compartments of selected forest reserves distributed in three forest districts which is known as Terengganu Utara, Terengganu Selatan and Terengganu Barat.

Table 1: General information of study plots in Terengganu

No.	Comp. No	Forest reserve	Forest category
1.	25	Hutan Simpan Hulu Telemung	1-10 years after logging
2.	60	Hutan Simpan Hulu Besut	
3.	63	Hutan Simpan Jengai	
4.	14	Hutan Simpan Besul	11-20 years after logging
5.	42	Hutan Simpan Belara	
6.	99	Hutan Simpan Sungai Tembat	
7.	23	Hutan Simpan Jengai	21-30 years after logging
8.	62	Hutan Simpan Hulu Besut	
9.	473	Hutan Simpan Sungai Tembat	
10.	10	Hutan Simpan Hulu Telemung	30+ years after logging
11.	43	Hutan Simpan Belara	
12.	48	Hutan Simpan Cherul	

Each plots were classified into four different forest categories based on years after logging (i.e., 1-10 years, 11-20 years, 21-30 years and 30+ years). These categories were based on logging year of 2018. Each forest districts consist of four study plots accordingly. Distribution of study plots were scattered in Terengganu as show in Figure 1. The red dots with number in the map (Figure 1) represent the point of study plots. The light green colour is represent the boundaries of forest reserve areas throughout Terengganu.

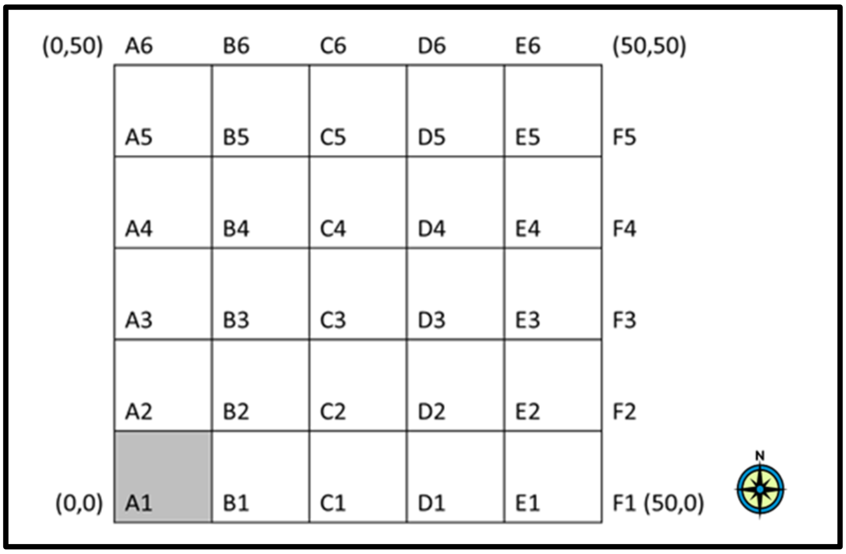
Figure 1: Study areas in Terengganu



Sampling and data collection

A total of 12 study plots measuring at 50 × 50 m were randomly established in selected forest reserves in Terengganu as described in Table 1. The layout of study plot is illustrated as in Figure 2. All study plots were established with pointing out to the north. For the field measurement, by using diameter-at-breast-height (DBH) tape, tree with DBH $\geq$ 10 cm were measured at the first subplot of 10 × 10 m (grey area in Figure 2), while trees with DBH $\geq$ 15 cm were collected at the whole plot. In case of high buttressed stems, the tree DBH was measured at 30 cm above the upper end of plank buttress. Each tree was temporarily tagged. Tree height was determined using laser rangefinder TruPulse 200. Trees were identified to species level during fieldwork and for unknown species, the voucher samples were collected for species identification at Herbarium Kepong, Forest Research Institute Malaysia (FRIM).

Figure 2: Layout of study plot



Tree carbon calculation and data analysis

Tree carbon assessment is derived from tree biomass estimation through certain conversion factors. Basically, total tree biomass is summation of aboveground biomass (AGB) and belowground biomass (BGB). Allometric functions are the best way to estimate AGB and BGB. The values of DBH and height of tree measured during field assessment, the dry mass of stem, branches, leaves (AGB) and root (BGB) of sample tree were estimated. In this study, local allometric functions that are found in literatures were used to estimate the total tree biomass of living trees in the study areas as shown in Table 2. Next, a default carbon conversion coefficient of 0.47 as suggested by Intergovernmental Panel on Climate Change (IPCC) was then used to calculate the tree carbon.

Table 2: Allometric functions used for AGB and BGB estimations

Biomass	Allometric function		Source
AGB	$M_S = 0.0313(DBH^2H)^{0.9733}$	(1)	Kato et al. (1978)
	$M_B = 0136(M_S)^{1.070}$	(2)	
	$\frac{1}{M_L} = \frac{1}{0.124(M_S)^{0.794}} + \frac{1}{125}$	(3)	
	AGB = $M_S + M_B + M_L$	(4)	
BGB	$M_R = 0.023 \times DBH^{2.59}$	(5)	Niiyama et al. (2010)

Notes: AGB and BGB denote aboveground and belowground biomass, respectively (kg/tree), M_S, M_B and M_L represent dry mass of stem, branches and leaves in kg, respectively (Eqs. (1)-(4)), M_R is dry mass of root (belowground) in kg (Eq. (5)), DBH is diameter-at-breast-height in cm, and H is tree height in meter.

Both biomass functions developed by Kato et al. (1978) and Niiyama et al. (2010) can be applied to all tree species in the study areas. Thus, total tree biomass (TTB) calculation can be summarized as in equation (6) below:

$$TTB = AGB + BGB \quad (6)$$

In this study, the dry mass of total tree biomass was presented in ton/ha. Tree carbon was then calculated in accordance to the method from IPCC where 47% of the biomass in the forest is assumed as carbon.

Means of tree carbon for each categories were obtained and analysed into diameter classes and species group. Present study separated the means of tree carbon into seven diameters classes (i.e., 10-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-75 cm, 75-90 cm and 90+ cm). Most of tree species in this study are represented by only a few individuals. Hence, each of trees was grouped into eight specific classes which is called as species group. This species group was established based on prescription in the current Selective Management System (SMS). Table 3 shows the detail description of this species group.

Table 3: Species group descriptions

Species group	Description
Dipt Meranti	Dipterocarp Meranti-type trees. Usually consist of high commercial and marketable timber species.
Dipt non-Meranti	All species from Dipterocarpaceae except from Meranti-type trees. Usually consist of high commercial and marketable timbers species.
LHW	Non-dipterocarp light hardwood. Timbers in this group are relatively light with density below 720 kg/m^3. Not naturally durable in tropical climate buat quite durable in temperate condition. Consist of marketable timber species.
MHW	Non-dipterocarp medium hardwood. Timbers in this group are moderately heavy to heavy and range in density from about 720 to 880 kg/m^3. Consist of marketable timber species.
HHW	Non-dipterocarp heavy hardwood. Timbers in this group are heavy and possess density above 880 kg/m^3. Mostly used as constructional timbers. Consist of marketable timber species.
Partially commercial	Timber species with partially commercial and marketable values.
Non-commercial	Timber species without commercial value.
Pioneer	Light-demanding timber species. Timbers are lower quality with less or without commercial values.

Statistical analysis
Means of tree carbon between forest category 1-10 years, 11-20 years, 21-30 years and 30+ years after logging of Terengganu were analysed using one-way analysis of variance (ANOVA). All statistical analyses were performed using RStudio Version 1.1.463.

RESULTS AND DISCUSSION

The total AGB, BGB, TTB and tree carbon for forest category 1-10 years, 11-20 years, 21-30 years and 30+ years after logging are summarized in Table 4. The values presented in this table are mean values of AGB, BGB, TTB and tree carbon for all forest categories. Result from ANOVA showed that forest category 30+ years after logging recorded significantly higher mean of tree carbon with the value of 204.29-ton C/ha ($p = 0.0119$) followed by forest category 21-30 years, 11-20 years and 1-10 years after logging (Table 4). Further analysis using multiple comparison test (i.e., Tukey test) indicated that the tree carbon in forest category 30+ years is significantly greater than in forest category 1-10 years after logging ($p < 0.05$). While the rest remain no significant differences between each other.

Table 4: Summary of AGB, BGB, TTB and tree carbon for all forest categories

Forest category	Number of study plot	AGB (ton/ha)	BGB (ton/ha)	TTB (ton/ha)	Tree carbon (ton C/ha)
1-10 years	3	168.87	45.95	214.81	100.96 (10.59)^{a}
11-20 years	3	220.20	66.68	286.86	134.82 (43.13)^{a,b,c}
21-30 years	3	293.45	84.10	377.53	177.44 (38.21)^{a,b,c}
30+ years	3	336.30	98.36	434.66	204.29 (8.87)^{c}

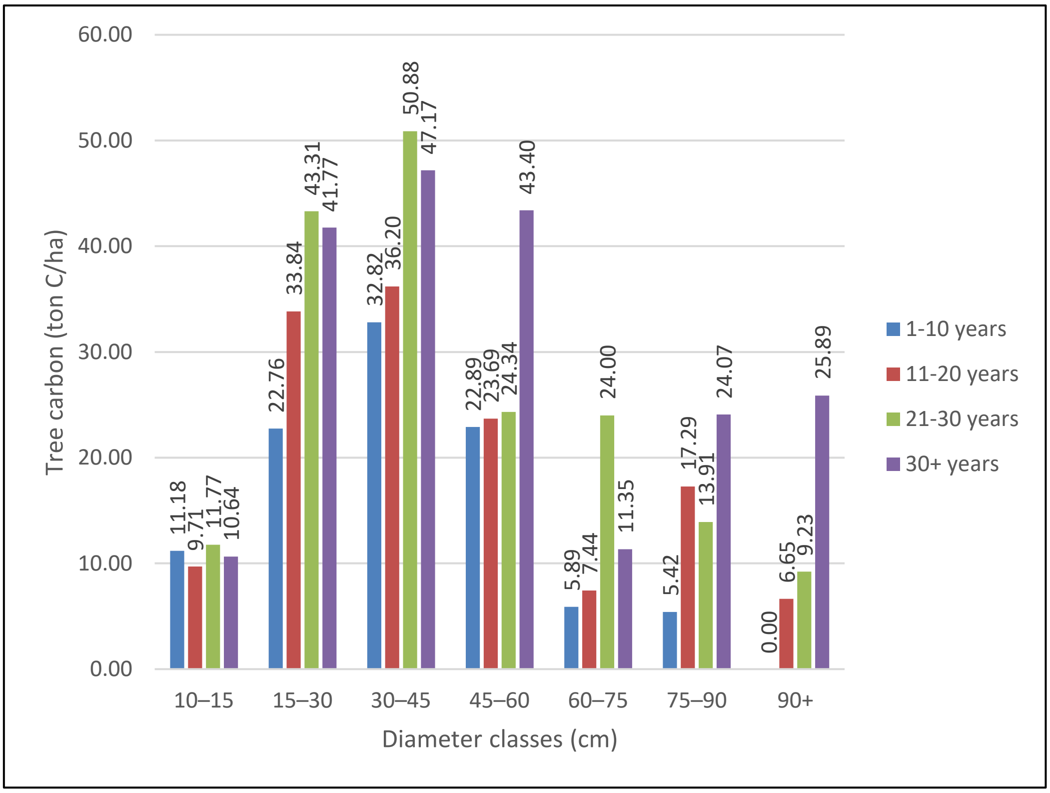
Note: All values are expressed as means and values in bracket are standard deviation. Means with same letter indicate no significant difference at $p < 0.05$.

As comparison with previous study, Zani et al. (2018) presented the total tree carbon for all tree sampled with DBH more than 10 cm in lowland dipterocarp, hill dipterocarp and riparian forests of Pahang National Park, Malaysia were ranged in value of 161.67-289.52 ton C/ha. Pahang National Park is protected area where logging or degrading activities within this area are prohibited by law. While in this present study, the total tree carbon for forest reserve of above 21 years after logging in Terengganu were found comparable to the values recorded for this protected area. Present study also found similar trend as stated by Omar et al. (2015). It was reported that the lowest carbon stock occurred in logged over forest below than 10 years in Pahang, Malaysia. This situation was influenced by the extraction of large trees during logging. Besides that, this present study demonstrated that increment of tree carbon as reflected to the increasing years after logging. This situation was clarified by Blanc et al. (2009) where the increment on this tree carbon predominantly beginning about 10 years after logging where most logged areas began to sequester more aboveground carbon than they released from decomposing dead and harvested trees.

Figure 3 shows the mean of total tree carbon by diameter classes for all forest categories. Small trees (10-15 cm) exhibit relatively similar tree carbon in all forest categories which values range from 9.71-11.77 ton C/ha. The trend of this total tree carbon is changed as the diameter classes increase in all forest categories. Forest category 1-10 years after logging exhibited lower total tree carbon in all diameter classes from tree with DBH 15 cm and above. Total tree carbon found highest in forest category 21-30 years after logging in three diameter classes which are 15-30 cm, 30-45 cm and 60-75 cm (43.31 ton C/ha, 50.88 ton C/ha and 24.00 ton

C/ha, respectively). While, forest category 30+ years after logging also recorded highest total tree carbon in three diameter classes with respect to 45-60 cm, 75-90 cm, 90+ cm as shown in Figure 3.

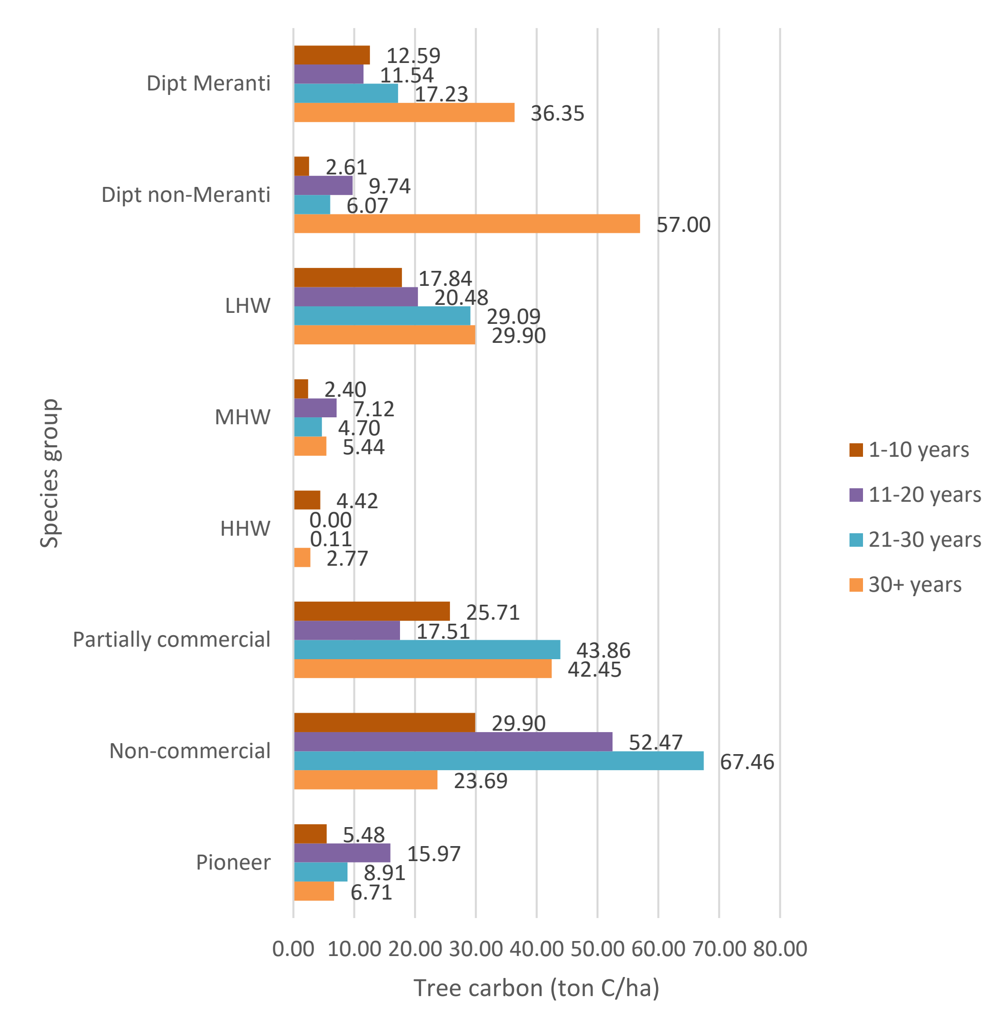
Figure 3: Mean total tree carbon by diameter classes for all forest categories



According to Figure 3, trees with DBH above 15 cm within forest 11 years and above after logging were reported contribute higher tree carbon compared to the forest below than 10 years after logging. A study in Sinnamary, French Guiana explained that this condition affected by tree mortality and carbon emissions which found peak immediately after logging. This forest however needs 5-10 years after disturbance, to recover to stable carbon conditions (Blanc et al., 2009). Besides that, previous study in Eastern Amazon by Sist et al. (2014) stated that large trees also play important role to stock up almost 50% of tree biomass inside forest areas. This trend can be found in forest category 30+ years after logging where large trees present in the study plots (Figure 3). Thus, forests with numerous large tree are useful to act as carbon storage and ultimately assist global carbon cycle.

This present study also extent tree carbon assessment to species group in all forest categories of Terengganu. Based on Figure 4, dipterocarp Meranti and dipterocarp non-Meranti exhibit higher total tree carbon in forest category 30+ years after logging compared to other forest categories. The recorded values for both species groups are 36.35 and 57.00 ton C/ha. Moreover, non-commercial group marked the highest total tree carbon in forest category 21-30 years after logging (67.46 ton C/ha). Besides that, total tree carbon found missing for HHW group of forest category 11-20 years after logging. The presence of pioneer group was discovered through the accumulation of total tree carbon which range from 5.48 to 15.97 ton C/ha in all forest categories.

Figure 4: Mean total tree carbon for species group for all forest categories



Previous study by Pinard and Cropper (2000), through simulated data of Malaysian dipterocarp forests, by removing 20-50% out of tree density inside logging area will possibly replace persistent forest species with pioneer tree species. This situation has led in reduction of potential carbon storage from 15 to 26% within 40-60 years. In this case, the dominant tree species play an important role as the major contributors towards forest carbon stock especially dipterocarp trees. This can be supported by a previous study in Guandong, China which found that the dominant tree species were contributed up to 65.13% out of total carbon stock within subtropical evergreen forest (Hu et al., 2015). Proper planning and management are required to reduce the possibilities of removing high commercial or dominant species within particular forest areas. These efforts may be useful to enhance forest services especially on climate regulations.

CONCLUSION

Tree carbon was assessed for forest categories 1-10 years, 11-20 years, 21-30 years and 30+ years after selective logging in Terengganu, Malaysia. Analysis on total tree carbon between forest categories showed that the means of total tree carbon in forest category 30+ years after logging was significantly higher than other forest categories with value of 204.29 ton C/ha. The higher number of total tree carbon attained by high contribution of large trees with DBH more than 45 cm. In term of species group, total tree carbon recorded highest for dipterocarp Meranti and dipterocarp non-Meranti for forest category 30+ years after logging (36.35 ton C/ha and 57.00 ton C/ha, respectively). Besides that, non-commercial group found peak in total tree carbon at forest category 21-30 years after logging (67.46 ton C/ha). The sustainability of large trees and certain species groups after logging is deemed important in carry out function as carbon storage where the stands finally can provide service towards global climate regulation. Therefore, this study may bring useful insights for sustainable forest planning and management in Malaysia.

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