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Assessing Carbon Pools in Dipterocarp Forests of Peninsular Malaysia

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Abstract

Modification and loss of forests due to natural and anthropogenic disturbances contribute an estimated 20% of annual greenhouse gas (GHG) emissions worldwide. Accounting GHG emissions associated with forestry, specifically, and land use generally is crucial in recent days because forests play major roles in balancing terrestrial carbon and contribute to the mitigation of global warming and climate change. Consequent to the awareness of climate change, reducing emission from deforestation and forest degradation, and conservation (REDD+) programmed was introduced at the international level to promote forest conservation and enhance forest governances. Intergovernmental Panel on Climate Change (IPCC) came out with protocols on how to account the carbon stored and released from the forests. Principally there are five primary carbon pools in a forest, which are above-ground biomass, below-ground biomass, deadwood, litter, and soils that accumulate and in some conditions release carbon. However, about 98% of carbon stored in a forest comprises trees components (aboveground and belowground living biomass, deadwood and litters) and the remaining is stored in soils. Many factors interact to affect the flux dynamics of these carbon pools, including the type of forest ecosystem, the age of the forest, and if harvested, the length of stand rotation cycles and the forestry practices used. Logging these forests, in a sense, represents an opportunity cost, as the time necessary for a harvested forest to regain its carbon sink capacity can take many decades, and if left undisturbed, would have gone on to expand its carbon pool or at least remain in constant over time. In this study, the lowland dipterocarp forest, where logging often takes place, is profiled in terms of biomass carbon. Pahang, which has the largest forest cover and biggest timber production in Peninsular Malaysia, was selected as the study area. The dipterocarp forests comprise both protection and production functions were categorized into strata based on year elapsed after logging (i.e. logged 1-10, 11-20, 21-30, and > 30 years). Measurements have been conducted on the ground and all the carbon pools in these strata were assessed. The study found significant differences between each stratum in terms of carbon and the results are presented in this paper. The effects of harvesting practices on carbon pools are also discussed.

1. Introduction

Carbon emission as a result from deforestation and forest degradation is one of the most critical elements that need to be assessed in REDD+ participating countries. Statistically, about 1 to 2 billion Mg of carbon per year which is equivalent to 15 - 25% of annual global greenhouse gases (GHG) emissions arises from tropical deforestation and forest degradation [1,2]. The modification and loss of forests due to natural processes and anthropogenic activities are significantly increase GHG emissions where could lead to the global climate change. Therefore, monitor the GHG emissions from forest activities, the carbon stock and changes in the forests need to be assessed periodically. The country is then required to report its emission and verified by an international independent body. These processes will be compiled in a system

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named monitoring, reporting and verification (MRV), which is compulsory before implementing REDD+.

Malaysia is now committed to the REDD+ under the United Nations Framework Convention on Climate Change (UNFCCC) through Intergovernmental Panel on Climate Change (IPCC). The main aim of the program is to stabilize the GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Forest Research Institute Malaysia (FRIM) in collaboration with Pahang State Forestry Department is currently engaged in a research project funded by International Timber Trade Organization (ITTO) to address issues related to GHG emission from tropical deforestation and forest degradation. The project is assigned under the thematic program of reducing emission from deforestation and forest degradation, and ecosystem services (REDDES), led by ITTO. Pahang, which is the largest state in Peninsular Malaysia, was selected as a pilot study area. Currently Pahang has about 2.2 million ha of forest, out of which 1.56 ha is under Forest Reserve. Since Pahang is one of the states that is significantly contributing the timber supplies in this region, about 55% of the reserves is meant for production purpose. Therefore, carbon removal due the logging activities are typical in this state and need to be assessed. The majority of the production areas are in the lowland (elevation <300 m a.s.l) and hill dipterocarp (elevation 300 – 750 m a.s.l) forests. Information on the carbon stored in the remaining forests is also important to be obtained, which acts as baseline for the monitoring activities.

However, methods for assessing carbon pools are not consistent and vary among projects being implemented. Previous studies concentered only on the aboveground living component of carbon stock in a forest as it dominates the carbon pools. Recently attentions not only go to the aboveground component but also to the other pools, which are below ground, dead wood, litter falls, and to some extend soil organic carbon. Although they comprise a small portion of the carbon pools, their amount is important in a forest ecosystem. Measurement of these pools is required as recommended by the IPCC to ensure a holistic and representative assessment following the circumstances of forests in the country.

Given the current gap in knowledge and understanding of carbon at national level, the research presented in this paper aims at providing methodology for assessing carbon pools in the dipterocarp forests in Pahang. This paper focuses on the technical measurement aspects that have been involved in assessing carbon pools in the dipterocarp forests at different conditions of the forests. The assessment was carried out at different levels of forest disturbances, such as logging intensity and the differences that occur naturally within the forests. The idea was to provide baseline information on carbon stock in each pool in the dipterocarp forests of Peninsular Malaysia under the sustainable forest management system (SFM) that is currently practiced in Malaysia. It is also one of the needs in MRV for a successful implementation of REDD+. Benefits from this study not only help country to reduce carbon emissions but it potentially gain credits from carbon stocks from the current REDD+ initiative. It is also ensures that activities under the REDD+ will be able to provide benefits from the SFM that has been practiced since decades.

2. Materials and Methods

Field carbon pools measurements have been conducted in the following forest strata of dipterocarp forests, namely;

i. Protection forest: the forest that is reserved in natural condition without logging activities. It is meant for environmental protection, which includes Virgin Jungle Reserve (VJR), water catchment area, erosion control areas and wildlife reserves.
ii. Logged 1 – 10 years: production forest that has been logged within less than 10 years, based on year 2010.
iii. Logged 11 – 20 years: production forest that has been logged within 11 - 20 years, based on year 2010.
iv. Logged 21 – 30 years: production forest that has been logged within 21 - 30 years, based on year 2010.
v. Logged > 30 years: production forest that has been logged more than 30 years, based on year

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2010. Normally, this forest will enter the second rotation based on 30-year cutting cycle on the current management practices, depending on annual coupe of harvesting.

vi. Stateland: the forest that falls outside the Forest Reserve. It resides on land areas that belong to the State Land Authority and not the Forestry Department. It also includes forested areas that belong to individual, but in small coverage.

The stratification was based on year elapsed after logging and year 2010 was used as the baseline. Information on logging history in compratment basis was used to stratify the forests. Carbon pools within each strata were measured at the field and some samples (i.e. litter and soil) were brought back to the laboratory for further analyses. The carbon pools that were considered in this study is summarized in Table 1.

Table 1: Summary of the measured carbon pools.

Terrestrial carbon	Pools	
Aboveground	Living trees	
	Deadwood	Standing deadwood
		Lying deadwood
	Litter	Dead leaves
		Dead twigs
Belowground	Root biomass of living trees	
	Soil carbon	

2.1. The Sampling Design

Sampling can take place within one area per sampling point or sampling can take place at within multiple areas associated with each other per sampling point. This is often referred to as clustered sampling. The clustering multiple subplots together at one sampling unit allow field crews to sample a larger area per sampling point. Clustering of subplots at each sampling unit is recommended for natural forest areas and especially areas that have been selectively logged.

The sampling design in this study was a modified sampling design according to the standard operating procedure (SOP) that has been developed by Winrock International [3], which follows the IPCC standards [4]. A cluster comprises four (4) subplots and the design is shown in Figure 1. The subplot was designed in circular with smaller nests inside. The biggest nest measures 20 m in radius, followed by the smaller nests measuring 12 and 4 m, as depicted in Figure 1. The sizes of trees were measured according to the nest sizes, which is summarized in Table 2. Depending on the nest size, it indicates that not all stands were measured in a single subplot. In additional to these nests, there is another small nest measuring 2 m in radius, which is used to count saplings (i.e. trees measuring < 10 cm in diameter at breast height (dbh) and > 1.3 m in height). A cross-transect measuring 25 m in radius were laid on the subplot, which made up a total of 100-m transect was used to measure lying deadwood. At the end of transect, a quarter-meter square plot (0.5 × 0.5 m) was laid for sapling, litter and soil sampling as shown in Figure 2. A cluster (a total of four) will produce 1 m2 plot of these pools. The sampling system is design in a way to make the data collection processes easier, faster but reliable and representative for a particular forest stratum. Detailed measurements of all the carbon pools are described below.

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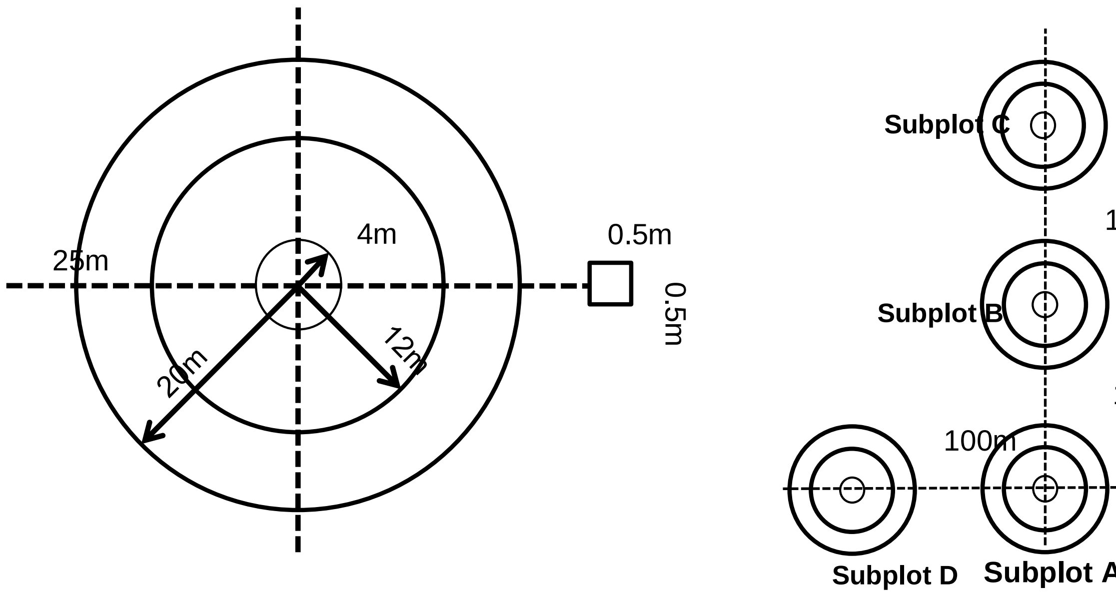

Figure 1: Layout of the sampling plot and sampling design a cluster.

Table 2: Summary living trees measurement in a subplot

Nest radius (m)	Size	Tree size, dbh (cm)
4	Small	≥ 10 cm
12	Medium	≥ 20 cm
20	Large	≥ 40 cm

Figure 2: Sampling plot for sapling, litter and soil.

2.2. Field Measurement Procedures

2.2.1. Living Trees

The dbh (i.e. stem diameter at 1.3 m above the ground) of each tree was measured in each nest following the size limit as described earlier. Trees include all living stands with dbh >10 cm (small trees), dbh >20 cm (medium trees) and dbh >40 cm (large trees). Species of each individual was also recorded.

2.2.2. Sapling

Woody stems with dbh <10 cm, known as saplings were count only for the number within the smallest nest of 2 m in radius. Size or height of these saplings was not recorded.

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2.2.3. Deadwood

Deadwood or woody debris is defined as any dead woody material (twigs, branches or stems of trees). There are two groups of woody debris which are (i) standing deadwood and (ii) lying deadwood. The standing deadwood was collected within a plot for parameters such as diameter at dbh (cm), diameter at base (cm), diameter at top (cm) and height (m). In contrast, the lying deadwood is collected for fallen trees and lied along the entire 100 m transect line through center in north-south, east-west directions. Parameters such as actual piece diameter (cm), decomposition status (solid, intermediate, rotten) and diameter of hollow (if any, cm) were recorded for the lying deadwood.

2.2.4. Understory and Litter

Understory vegetation is defined as all standing vegetation matter that does not reach breast height (1.3 m). This includes shrubs, tree seedlings, herbs and non-vascular plants. Litter on the floor is defined as the surface detritus and recognizable organic matter that lies on top of the mineral soil, excluding fragments of wood. Both understory and litter samples are collected in square clip plot measuring of 0.5 × 0.5 m, where the clip plot is placed at 25 m beyond plot center, normally at the end of the transect line. Materials within this plot were collected weighted and recorded. Some samples were brought back to the laboratory for drying process.

2.2.5. Soil

Three measurements were obtained to determine total soil organic carbon: organic soil depth (to obtained soil volume per area), bulk density (to obtain soil mass per area) and % organic carbon (OC) to convert mass per area to C per area. A core sample is collected at 30 cm depth and a 100 g sample of soil profiles is collected for soil volume and OC.

2.3. Carbon Stock Calculations

2.3.1. Aboveground biomass (AGB)

Comprises all the living aboveground vegetation, including stems, branches, twigs and leaves. It is the most important pool of carbon of all types of forests. In this study, allometric equations from Kato [5] (Eq. 1) and Chave [6] (Eq. 2) were used to calculate AGB. Both equations have been calibrated based on trees sampled in lowland and hill forest in west Peninsular Malaysia. Wood densities were obtained from the Global wood density database [6]. Both equations were used to compare the estimated AGB and thus to suggest the most appropriate allometric equation for the forests in Peninsular Malaysia. A default factor of 0.47 was used to convert the biomass into carbon.

$$1/H = 1/(2.0*D) + 1/61$$
$$Ms=0.0313*(D2H)0.9733$$
$$Mb=0.136*Ms1.070$$
$$1/Mll=1/(0.124Ms0.794)+1/125 \quad (1)$$

$$Wt=\rho*\exp(-1.499+2.148*\ln(D)+0.207*(\ln(D))2-0.0281*(\ln(D))2) \quad (2)$$

D is the stem diameter at breast height; Ms, Mb, and Ml denote the dry mass of stem, branches and leaves respectively; Wt is the aboveground biomass of standing trees; ρ is the wood density.

2.3.2. Belowground biomass (BGB)

Comprises the living coarse and fine roots of trees. The BGB are an important part of total forest biomass after AGB, representing 25% of the total biomass. Equations from Mokany [7] were used to estimate the BGB in this study.

$$BGB=0.235*AGB \text{ if } AGBC > 62.5 \text{ Mg C ha-1} \quad (3)$$
$$BGB=0.205*AGB \text{ if } AGBC \leq 62.5 \text{ Mg C ha-1} \quad (4)$$

2.3.3. Deadwood

Coarse woody debris (CDW) involves large pieces of standing and lying dead wood. Depending on the forest type, stage of succession, land use history and management practices, CDW can be a significant contributor to the total AGB. Calculation of carbon for this category is based on the following equation:

Carbon stock = (Volume × wood density) * 0.47 (5)

2.3.4. Understory and Litter

The oven-dry mass per area of this category was obtained from the samples that have been collected in the field. The carbon stock calculation was based on the following equations:

Carbon = Dry mass × 0.4 (IPCC default for understory vegetation and litter)

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2.3.5. Soils

Samples were oven-dry at a constant temperature of 115°C for about 24 hours and the dry mass was used to obtain the bulk density. Samples were then analyzed at the soil laboratory for OC by using combustion method, after pretreatment to remove carbonate. Soil OC (%) was then multiplied by soil bulk density and soil depth to obtain total soil carbon stock per unit area.

3. Result and Discussion

Results indicated that the biggest portion of biomass carbon is in the living trees, which comprised about 79% of the total carbon pools in the forest. It was followed by belowground living biomass carbon, which consisted of about 19%. Deadwood and litter share the same percentage, which is about 1%. Understory vegetation and soil organic carbon contributes less than 1%. The analysis found the organic carbon stored in the soil consisted only about 1% of the total mass, for all soil types that were collected in the field. It means that for every 1 kg of dry soil, 10 g is carbon. It was estimated that soil organic carbon in the study area ranged from 32 to 49 kg ha-1 with an average of 42 kg ha-1. Figure 3 shows the proportion of carbon stored in a carbon pool of the forest in the study area.

Figure 4 shows a comparison of carbon pools that were calculated based on Kato's and Chave's allometric equations. Results demonstrated there are high variations of carbon stocks between both equations for each forest strata. The study found that Chave's equation estimated more reasonable result because the application of wood density parameter produced more accurate prediction.

The study also found that there were significant differences of carbon stock among forest strata. Based on the Figure 4, the protection forest has the highest carbon stock as compared to the other forest strata. The carbon stock in this area was influenced by large trees composition and coarse woody debris in the forest floor in protection forest. The lowest carbon stock occurred in logged <10 years stratum. It was not surprise that this forest has the lowest carbon stock because most of the large trees have been removed, recently, during logging. The remaining forest strata indicated almost similar carbon stock as the forests grow over time and increased the tree size of the trees and thus biomass.

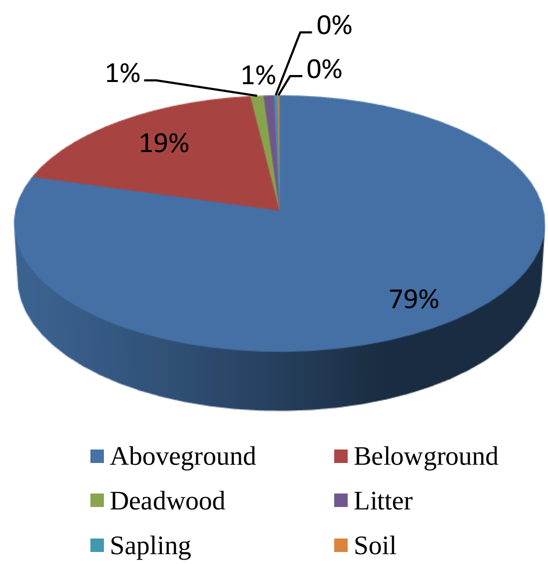

Figure 3: Proportion of carbon pools in the forest.

By using the results obtained from Chave's equation, carbon stock for the entire dipterocarp forests in Pahang was then estimated. It was estimated that in year 2010, Pahang has about 1.94 million ha of inland dipterocarp forests, which is dominated by production areas. The total carbon stock was estimated at about 0.5 billion Mg with average of 238.16 Mg ha-1 throughout all strata. Table 3 shows the breakdowns and summarizes the estimates.

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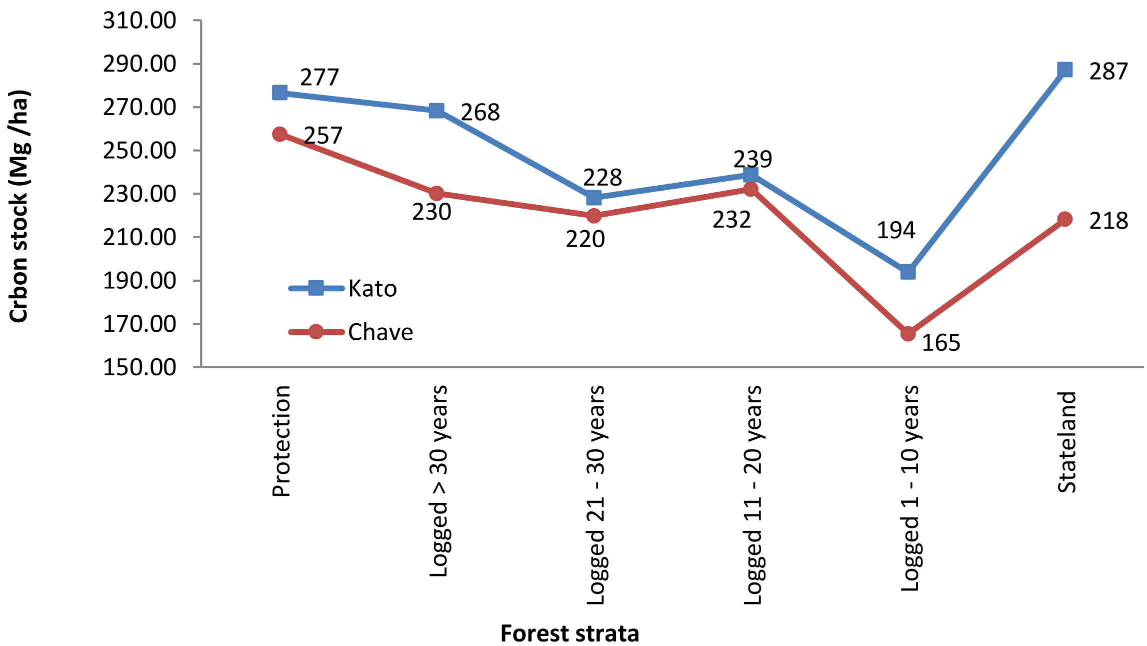

Figure 4: Comparison of estimated carbon stock in the forest strata.

Table 3: Estimated carbon stock for all strata of forest in Pahang over the year 2010.

Strata	Extent (ha)	Carbon stock (Mg ha^{-1})	Total C stock (Mg)
Protection	727,333.82	257.50	187,287,004.03
Logged > 30 years	528,402.76	230.17	121,623,520.07
Logged 21 - 30 years	311,917.06	219.83	68,568,726.20
Logged 11 - 20 years	265,834.27	232.14	61,711,565.64
Logged 1 - 10 years	7,566.03	165.34	1,250,997.50
Stateland	99,461.06	218.23	21,704,890.43
Total	1,940,515.00		462,146,703.87

4. Conclusions

The study demonstrated the sampling design adapted for assessing carbon pools is appropriate to represent dipterocarp forests in Peninsular Malaysia. It is also suite to the current logging practice in which the design has been able to estimate the carbon pools representatively. While national data on carbon assessment have commonly not been available in the past, these researches have generated new information for the country in-line with the REDD+ requirements. The introduced approach is also practical where the forest practitioners can apply the sampling design for more accurate estimates.

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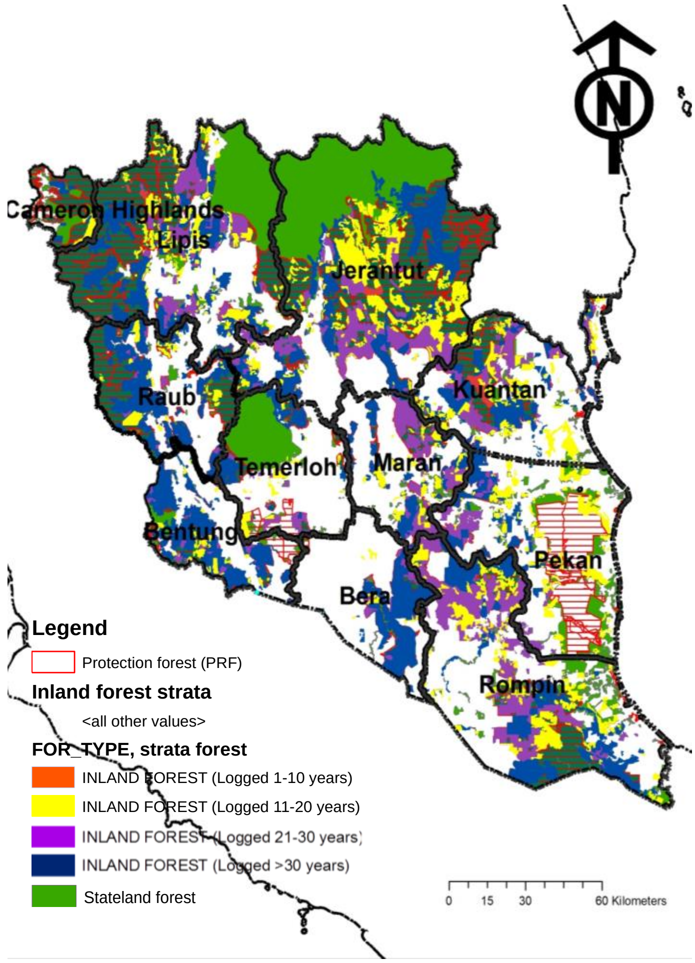

Figure 5: Spatial distribution of carbon stock in the dipterocarp forests of Pahang

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