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Carbon Storage in Relation to Plant Species of Lowland Dipterocarp Vegetation of Gunung Ledang, Malaysia

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Abstract
The mitigation of carbon emissions is indispensable in the endeavour to combat climate change. The health of our planet is influenced by our forests because of the vegetation which is essential to mitigating climate change by increasing the carbon sequestration capacity of the forest. Some plants are nature's carbon sinks, absorbing large amounts of CO_2 into their biomass thereby making multi-species forests to store carbon higher than a single-species forest. Native and introduced species were selected to evaluate the carbon storage in relation to plant species of lowland dipterocarp vegetation of Gunung Ledang. The objective was achieved by measuring the photosynthetic rate of the selected plants using a portable photosynthesis system. The biomass was determined using non-destructive methods while the carbon contents were estimated using the ash content method. The results obtained show that introduced species had a higher photosynthesis rate (18.3 µmol CO_2 m^{-2} s^{-1}) while native species had higher carbon stock (20.37 ± 0.52 kg/plant). Consequently, the spread of introduced species should be monitored because they have less contribution to Gunung Ledang carbon storage.

Key words: carbon storage; forest; Gunung Ledang; introduced species; native species

INTRODUCTION

Forest ecosystems are a major component of the biosphere and they significantly influence atmospheric composition and climate, being sources and sinks of trace gases and energy (Krasnova *et al*., 2019). Tropical rainforests are expansive, evergreen forests that predominate in equatorial regions with a perpetually humid climate. Gunung Ledang or Mount Ophir is rich in fauna and flora; and it is categorised into montane ericaceous forest, lowland dipterocarp, lower montane and hill dipterocarp.

Forest ecosystems are intricate systems influenced by a variety of factors, including microclimate, canopy structure, plant activity, biodiversity, atmospheric conditions, and soil

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properties. These factors collectively shape the exchange of carbon between forests and the atmosphere (Krasnova *et al.*, 2019).

Carbon sinks are natural reservoirs that absorb and store carbon dioxide (CO_2) from the atmosphere over extended periods. This process, known as carbon sequestration, has gained significant attention since the Kyoto Protocol, which promotes carbon offsetting. Various strategies can enhance carbon sequestration in forests (Yousaf *et al.*, 2017).

The Kyoto Protocol, an international treaty extending the 1992 United Nations Framework Convention on Climate Change (UNFCCC), commits signatory nations to reduce greenhouse gas emissions. This commitment is based on the overwhelming scientific consensus that human activities, primarily the burning of fossil fuels, are the primary driver of global warming. Adopted in Kyoto, Japan, in 1997 and entered into force in 2005, the Protocol currently has 192 parties (Kyoto Protocol, 2014).

Terrestrial vegetation, particularly forests, plays a crucial role in the global carbon cycle in mitigating rising atmospheric CO_2 levels. Forests account for a substantial portion of global gross primary production, absorbing approximately 30% of fossil fuel CO_2 emissions. Deforestation and forest degradation, however, can significantly reduce this carbon sink capacity and exacerbate climate change.

To maintain and enhance forest carbon sinks, effective forest management is essential. Key management practices include determining optimal methods to minimize carbon emissions and maximize long-term carbon storage in forests is crucial for climate change mitigation. Evaluating forest biomass carbon stocks and sequestration potential is essential for informed policymaking.

Historically, old-growth forests were often overlooked in climate change mitigation strategies, as they were considered carbon neutral and less efficient carbon sinks than younger forests. However, recent research has challenged this notion, demonstrating that these ancient forests continue to accumulate carbon biomass and enhance soil carbon storage (He *et al.*, 2018; Krasnova *et al.*, 2019; Rajashekar *et al.*, 2018; Sun *et al.*, 2016; Vinh *et al.*, 2019). Factors such as high biomass density, reduced disturbance, and favorable climatic conditions contribute to this ongoing carbon accumulation.

While the difference between current and potential carbon stocks can provide insights into carbon sink potential, limitations in data availability and sampling bias hinder accurate assessments (Sun *et al.*, 2016). High-biomass forests, often overlooked in previous studies, may have significant carbon storage potential, but uncertainty remains due to data scarcity.

Gunung Ledang, a significant forest ecosystem in Malaysia, lacks comprehensive carbon storage assessments. Understanding the carbon sequestration capacity of its lowland dipterocarp vegetation is crucial for effective forest management and climate change mitigation. This study aims to evaluate the carbon storage potential of Gunung Ledang's lowland dipterocarp forests, considering plant species composition and other relevant factors.

Materials and methods

Study Site
Gunung Ledang (Figure 1) (02˚22ˈ27ˮ North 102˚36ˈ28ˮ East) was the study site. The 64th highest mountain in Malaysia has an elevation of about 1,276 m. It has about 8,611 hectares of land (Tourism Malaysia 2014). The average temperature in the mountain is 22 - 33 °C. The forest receives its maximum rainfall in November. Invasive and native plants (*Clidemia hirta, Mikania micrantha, Chromolena odorata, Piper aduncum, P. sarmentosum, P. betel, Tetracera microphylla,* and *T. scadens*) were selected for the study so as to determine their contribution to Gunung Ledang carbon cycle.

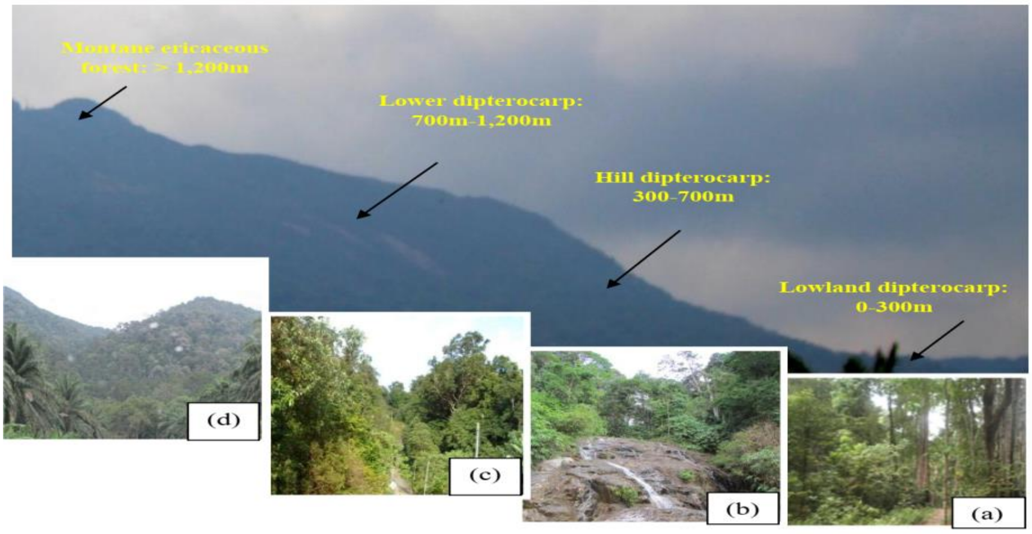

Figure 1: Gunung Ledang Malaysia (02˚22ˈ27ˮ North 102˚36ˈ28ˮ East)

Determination of carbon absorption capacity
Photosynthesis rate was determined using LICOR (LI-6400). LICOR is a system that measures the photosynthesis rate of plants. The rate of CO_2 absorbed is expressed in micromoles of Carbon dioxide per meter square per second. Before measurements of the photosynthetic rate, the CO_2 scrub tube was filled with soda lime and rseattached to the LICOR console. The diedrite desiccant was replaced and reattached to the console. The function of diedrite desiccant is to absorb moisture (humidity). Female 2 spin connectors were connected to an infrared gas analyser (IRGA) while male 25-pin connectors were connected to console. The air outlet was also attached and finally, IRGA head was connected to the console by lining the 2 red dots and pushing the connector, making a click sound (Biosciences, 2002).

A series of checklists were followed during the warm-up of LICOR, after the warm-up of LICOR and during measurements. During warm-up, air supply, temperature, light, pressure, leaf fan, and flow rates were controlled. After warm-up, flow zero, CO_2 zero, and leaf temperature zero, were checked and the absence of air leaks was confirmed.

During measurements, light, flow rate, CO_2, leaf temperature, leaf area, stomatal ratio and humidity were controlled. Photosynthetic active radiation (PAR) was measured using the LI-6400 portable photosynthesis system quantum sensor. Ambient air temperature and humidity were measured using thermocouples attached to the leaf and expressed in ^oC and % respectively. The PAR and CO_2 were maintained at 1500 $\mu mol.m^{-2}.s^{-1}$ and 400 $\mu mol.mol^{-1}$. Healthy leaves of the selected plants were sampled and inserted into LICOR where the assimilation rate was recorded after about 15 minutes (Idris *et al.*, 2019).
Biomass and carbon estimation

Non-destructive analysis was utilised to estimate the biomass of both native and invasive species. Three specimens from each species were selected for biometric measurements, including height and diameter (Arya *et al*., 2017). Subsequently, equations 1 and 2 were employed to calculate the above biomass (AGB) and below biomass (BGB).

$$AGB\ (kg/plant) = 0.0763D^{2.2046} \times H^{0.498} \quad (1)$$

$$BGB\ (kg/plant) = AGB \times 0.26 \quad (2)$$

Where 'D' is breast diameter in cm and 'H' is height in meter (Audu *et al*., 2018).

The carbon content of each plant part was determined based on the ash content (Audu *et al*., 2018). Leaf samples were washed, dried and ground. The ash content was determined by measuring 10 g of each grounded sample and incubated at 500°C for approximately 10 hours. The sample was then removed and allowed to cool down before measuring the weight again (Audu *et al*., 2018). The ash percentage (%) weight and carbon (%) were calculated using equation 3 and 4.

$$\text{Ash content (\%)} = (\text{mass of ash/weight of sample}) \times 100 \quad (3)$$

$$\text{Carbon \%} = 100\ \% - (\text{Ash content} + \text{Molecular weight of oxygen in glucose}) \quad (4)$$

The AGB carbon (kg/plant), BGB carbon (kg/plant), total biomass carbon (kg/plant), and carbon stock (kg/plant) were calculated using equation 5-8.

$$\text{AGB carbon (kg/plant)} = \text{AGB} \times \text{Carbon \%} \quad (5)$$

$$\text{BGB carbon (kg/plant)} = \text{BGB} \times \text{Carbon content \%)} \quad (6)$$

$$\text{Total biomass carbon (kg/plant)} = \text{AGB carbon} + \text{BGB carbon} \quad (7)$$

$$\text{Carbon stock (kg/plant)} = \text{Biomass} \times \text{Carbon \%} \quad (8)$$

Statistical analysis

Data were evaluated in triplicates and statistical differences were analysed using ANOVA at a 95 % confidence level.

RESULTS

The origin of the selected plants is represented in Table 1. Four of the selected plants were introduced species while the remaining 4 were native species. The introduced species are more abundant in the forest than native species. The contribution of the plants to Gunung Ledang carbon absorption capacity is shown in Figure 2.

M. micrantha (18.3 µmol CO_2 m^{-2} s^{-1}) had the highest carbon absorption capacity while the lowest was recorded for *T. microphylla* (8.7 µmol CO_2 m^{-2} s^{-1}). From the results obtained, introduced species had higher absorption capacity than native species.

Table 1: Origin of the selected plants

Plant species	Family	Growth form	Origin	Malaysia local name
Clidemia hirta	Melastomataceae	Shrub	Introduced	Senduduk bulu, Senduduk babi, Senduduk rimba
Chromolena odorata	Asteraceae	Shrub	Introduced	Fausse ramie, maleanum, Pokok german
Mikania micrantha	Asteraceae	Climber, Vine & Liana, Shrub	Introduced	Chroma ulam tikas
Piper aduncum	Piperaceae		Introduced	Sirih liar
P. sarmentosum	Piperaceae	Shrub	Native	Kaduk
P. betel	Piperaceae	Climber, Vine & Liana	Native	Sirih, Sirih cina, Sireh kampong
Tetracera microphylla	Dilleniaceae	Shrub	Native	Hempelas
T. scadens	Dilleniaceae	Shrub	Native	Mempelas

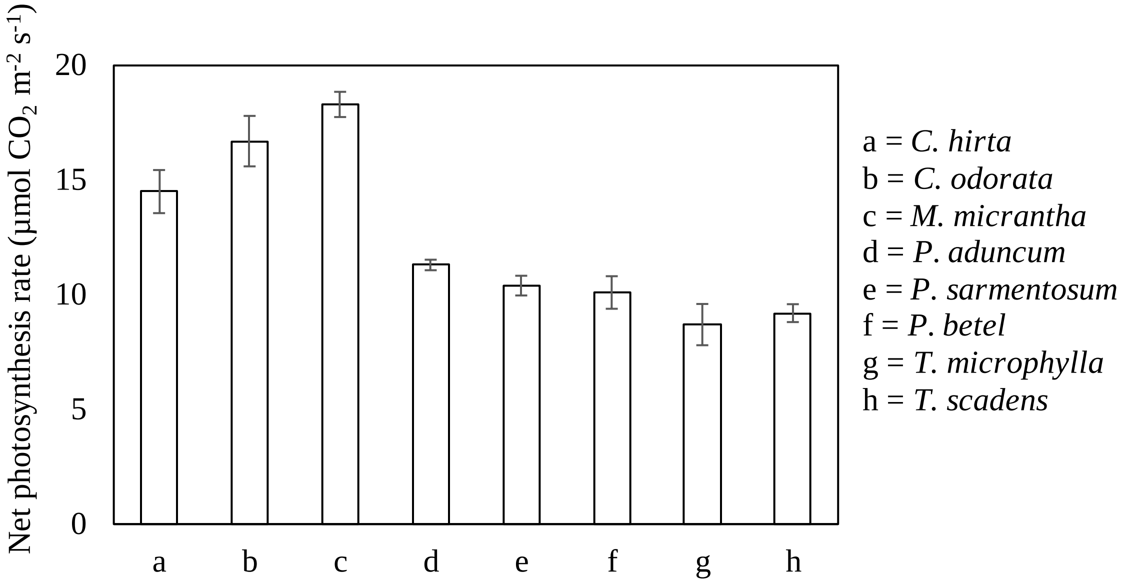

Figure 2: Carbon absorption capacity of the plants

The amount of carbon stored in the selected plants is represented in Table 2. *T. scadens* (20.37 ± 0.52 kg/plant) stored the highest carbon content which is statistically different ($P < 0.05$) from the lowest carbon content stored by *P. sarmentosum* (0.12 ± 0.08 kg/plant). The carbon stored in native species is significantly higher than the carbon stored by the introduced species ($P < 0.05$).

Table 2: Carbon stock of the selected plant

Plant species	AGB (kg/plant)	BGB (kg/plant)	Carbon stock (kg/plant)
Clidemia hirta	1.16 ± 0.12 ^{b}	0.30 ± 0.13 ^{a}	1.46 ± 0.31 ^{b}
Chromolena odorata	1.23 ± 0.13 ^{b}	0.31 ±0.03 ^{a}	1.54 ± 0.06 ^{b}
Mikania micrantha	0.96 ± 0.21 ^{b}	0.25 ±0.12 ^{a}	1.22 ± 0.03 ^{a}
Piper aduncum	4.07 ± 0.34 ^{c}	1.05 ± 0.23 ^{b}	5.13 ± 0.13 ^{b}
P. sarmentosum	0.10 ± 0.01 ^{a}	0.02 ± 0.10 ^{a}	0.12 ± 0.08 ^{a}
P. betel	4.21 ± 0.11 ^{c}	1.09 ± 0.21 ^{b}	5.31 ±0.12 ^{c}
Tetracera microphylla	12.36 ± 0.21 ^{d}	3.21 ±0.04 ^{c}	15.58 ± 0.32 ^{c}
T. scadens	16.16 ± 0.23 ^{e}	4.20 ± 0.31 ^{d}	20.37 ±0.52 ^{d}

Discussion

Assessment of carbon storage in Gunung Ledang forest of Malaysia is vital for ensuring the sustainable management of the ecosystem. The carbon stock of the introduced species obtained in this present study is lower than that of native species, which is consistent with the findings of (Meena *et al.*, 2019), who reported that native species accumulate more carbon than introduced species. In another study, it was reported that fast-growing plants accumulate more carbon than slow-growing species (Chen *et al.*, 2015). Shrubs had high biomass carbon sequestration (Balasubramanian *et al.*, 2017), with low sequestration if the forest is highly disturbed and higher sequestration if the disturbance is low (Anudip *et al.*, 2017). The significantly different carbon stock stored in the selected plants is mainly due to photosynthetic and biological processes (Justine *et al.*, 2017).

The mitigation of carbon emissions is a prerequisite in the endeavor to combat climate change. Forests have strong carbon sequestration capacity. For example, numerous number of studies have reported the carbon stock of several forests (Agidew & Mezgebe, 2019; Atsbha *et al.*, 2019; Gao *et al.*, 2014; Liu and Zhao 2018; Subedi *et al.*, 2016; Yue *et al.*, 2018;). Certain factors like altitude, latitude, temperature, precipitation, forest age, tree density and herbivores can affect Carbon exchange in forest ecosystems (Fei *et al.*, 2017; Liu and Zhao 2018; Ma *et al.*, 2018; Sørensen *et al.*, 2018; Vinh *et al.*, 2019; Xu *et al.*, 2018).

The health of our planet is influenced by our forests because of the vegetation which is essential to mitigating climate change by increasing the carbon sequestration capacity of the forest. There are certain plants with a high ability to fix atmospheric CO_2 into their biomass (Maiti *et al.*,2015), which may be the reason why forests containing many plant species can store carbon higher than a single plantation forest (Liu *et al.*, 2018). Trees introduced to cocoa-based agroforests increase carbon storage and aid in mitigating climate change (Patrick *et al.*, 2018). Moreover, coniferous forests had higher live biomass carbon sequestration while broadleaf forests had higher soil carbon sequestration potential (Gao *et al.*, 2014). Analysis shows that plant reproductive organs contain 45 % of carbon, the stem contains 47.9 %, the leaves contain 46.7 %, and roots contain 45.6 % of carbon. Due to this analysis, it was found that woody plants have higher carbon content than herbaceous plants (Ma *et al.*, 2018).

Reforestation and natural forest protection projects aid in long-term carbon storage (Yue *et al.*, 2018; Kirby & Potvin 2007). The higher the number of trees, the better the carbon storage (Arya *et al.*, 2017). Each tree species plays its specific role in carbon sequestration and therefore choosing plants with higher carbon sequestration capacity can maximize mitigation potentiality (Siraj and Teshome 2017).

CONCLUSION

Carbon storage varies among different plant species. Native species accumulate more carbon than introduced species, but introduced species had higher photosynthesis rate than native species. The findings of the study lead to questions for further research on how an increase in photosynthesis can affect the carbon storage of plant species. Lastly, to maintain the forest's substantial potential, the spread of introduced species should be monitored because they have less contribution to Gunung Ledang carbon storage.

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