A Thorough Quantification of Tropical Forest Carbon Stocks in Malaysia

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ABSTRACT

Estimates of carbon stocks in tropical rainforests are critical for informing the development of carbon credit programs. This study sought to determine the level of specificity necessary for accurate carbon quantification in tropical dipterocarp forest in northern Peninsular Malaysia. Past studies have used LiDAR data and regional estimates in order to estimate the carbon stock, but no study has performed in-depth field surveys in an upper hill dipterocarp forest. I quantify the carbon pools in aboveground biomass (ABG), belowground biomass (BGB), soil, and coarse woody debris (CWD). I found a total forest carbon stock of 208.8 Mg(C)/ha (149 Mg(C)/ha AGB, 27 Mg(C)/ha BGB, 22 Mg(C)/ha soil, 10.8 Mg(c)/ha CWD). This value is greater than Southeast Asian regional estimates and greater than carbon estimates in Malaysian lowland dipterocarp forests. I conclude that site-specific in-depth field surveys are necessary for locally accurate carbon quantification.

KEYWORDS

Reducing Emissions from Deforestation and Degradation, upper hill dipterocarp forest, Peninsular Malaysia, logging, aboveground biomass

INTRODUCTION

Environmental degradation from forest conversion and land-use change is an issue of international concern, releasing 17% of the world's greenhouse gas emissions (IPCC 2007). Greenhouse gas emissions from tropical deforestation and degradation in industrializing countries contribute a large portion of these emissions. Southeast Asian forests contain 26% of the world's tropical forest carbon, and unfortunately Southeast Asia had the highest level of deforestation in all the humid tropics of the world in the 1990s (Saatchi et al 2011, Achard et al 2002). This trend has continued in the past decade with a 1% yearly decline in forest cover (Miettinen et al 2011). Given the unique biodiversity of Southeast Asia and the large amounts of carbon stored in tropical rainforests, preserving forest ecosystems of Southeast Asia is of particular concern. Proposed solutions to tropical forest degradation involve the creation of carbon credit programs.

Carbon credit programs are being proposed to industrializing countries as an alternative to forest degradation. Because limiting forest-based greenhouse gas emissions is critical to curbing global warming, the United Nations Framework Convention on Climate Change (UNFCCC 2011) promotes carbon-offset programs. Such programs allow greenhouse gas emitting industries or countries to offset their emissions by the purchase of carbon credits from a greenhouse gas emissions reducing project (UNFCCC 2011). Reducing Emissions from Deforestation and Degradation (REDD) is a carbon offset mechanism developed in 2005 that provides financial incentives to countries preserving tracts of rainforest, thereby reducing emissions through avoided deforestation (UN-REDD 2011). If a country proves a reduction in greenhouse gas emissions through avoided deforestation, they can sell the avoided carbon emissions as carbon credits on an international market. However, proving emissions reductions is a major scientific challenge and a setback to REDD implementation (Kohl et al 2009, Gibbs et al 2007).

The biggest scientific challenge to REDD is quantifying forest carbon stocks, a piece of information critical to proving emissions reductions (Saatchi et al 2011, Gibbs et al 2007). Although there are many studies attempting to quantify forest carbon stocks, estimates of emissions caused by tropical deforestation vary greatly (Ramankutty et al

2007). While it is most accurate to quantify the carbon stock in all pools, studies differ in the carbon pools (e.g. aboveground biomass, soil, woody debris) they include in their analysis (Nunes et al 2010). There is also differing methodology in the quantification of carbon pools, e.g. treating all trees as a uniform source of carbon, regardless of species (Elias and Potvin 2003). Competing methodologies unfortunately compromise accuracy in emissions estimates (Houghton et al 2001). Dealing with such scientific challenges now will prevent future roadblocks to REDD implementation.

The main objective of my study was to fully quantify the forest carbon stock present in an upper hill Malaysian dipterocarp forest. I accounted for all carbon pools and assessed the importance of thorough, site-specific field surveys for accuracy in carbon quantification. How much carbon is present in a primary dipterocarp forest? How do carbon stock values produced from site-specific forest inventories differ from regional estimates? What implications could these differences have for REDD schemes? My hypothesis is that regional estimates of forest carbon underestimate carbon stocks.

METHODS

Study site

The study site lies within a primary hill dipterocarp forest located in the Temengor Forest Reserve in Perak, Peninsular Malaysia. The forest receives about 2500 mm rainfall annually and is dominated by the tree species *Dipterocarpus costulatus* and *Shorea platyclados* (Mandeep et al 2011). The study site is located in Compartment 44, Block 5 of the 9765 ha Perak Integrated Timber Complex (PITC) logging concession, south of the border of Thailand (5° 24' N, 101° 33'E). I collected my data from a 200 ha experimental area of unlogged forest during the dry season from March 2010-August 2010. Logging operations began in June 2010 and prevented the collection of wood core and soil data from all of the twenty-four sites.

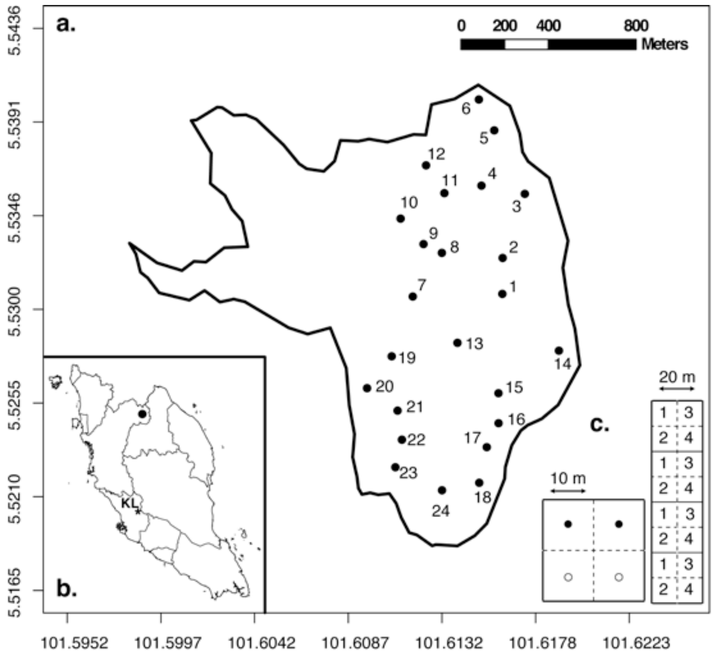

Fig 1. Plot design. Data was collected in 24 plots (a) placed throughout a 200 ha experimental plot in northern Peninsular Malaysia (b) (Mustafa et al 2011).

Sampling design

The sampling design consists of 24 20m x 80 m plots of primary rainforest. For sampling purposes, we placed pegs along the 0m, 5m, 10m, 15m and 20m transect lines every 5 m within a plot. The plots were established in 2009 by the Forest Research Institute of Malaysia.

Data Collection

Aboveground biomass and elemental carbon content

To determine the volume of aboveground biomass, I tagged and recorded the diameter at breast height (DBH, breast height=1.3 m) of all trees with a DBH> 30 cm in a 100 ha area. In a subset of 24 3.84 ha plots, I tagged and recorded the DBH of all of the trees (both<30 cm and >30 cm). To determine elemental carbon (C) content, I took wood cores of all trees with a DBH greater than 10 cm in every other 10m x 20m cross-section along the length of 18 of the plots (*see Figure 2*). I took two cores from each tree using a 12' increment borer and recorded the tree DBH. Australian researcher Rohan Simkin determined values of wood density for a subset of trees in the 24 plots through a water displacement method. I took the wood density of all trees not measured to be the average wood density of the sampled trees.

I derived aboveground biomass using allometric biomass regression equations from Chave et al 2005 for moist forest stands:

$$(AGB)est= \rho \text{ x } \exp(-1.499 + 2.148\ln(D) + .207(\ln(D))^2 - .0281(\ln(D))^3)$$

where ρ= wood density and D=DBH.

I oven dried the wood cores and ground them into a fine powder with a drill press. To determine elemental C content, I processed the wood cores of thirty-three different species in a NC 2100 carbon nitrogen analyzer. I used a two-way analysis of variance (ANOVA) to determine interspecific variation in C content (see Elias and Potvin 2003).

X		X		X		X	

Fig 2: Wood Core Sampling Design. Each box represents a 10m x 20m area, resulting in plot dimensions of 20m x 80m. We took cores in 10m x 20m cross sections along the plot (X=plot sampled). Cores were taken from all trees with a DBH>10 cm.

Belowground biomass

I assumed the belowground biomass to be 18% of the aboveground biomass, as determined by Niyama et al (2010) in Peninsular Malaysia. This percentage was applied accordingly.

Soil Carbon

I took soil cores in eight plots using a soil auger at points specified in the Center for Tropical Forest Science (CTFS) *Soil Carbon Sampling Protocol 2010* at depths of 0-10 cm, 10-20 cm, 20-50 cm, .5-1 m, 1-1.5 m, 1.5-2 m, and 2-3 m. To account for site variability, multiple soil samples were taken depending on depth, ie. 1 sample for 2-3m and 9 samples for 0-10 cm (see *Soil Carbon Sampling Protocol 2010)*. I oven-dried the samples, sieved them to <2 mm, and ground them to a fine powder. I processed them for total carbon (mg(C)/m) using a NC 2100 elemental analyzer. Soil bulk density values were adopted from values measured in a lowland dipterocarp forest in Malaysia (Saner et al 2012).

Woody necromass (fallen and standing CWD)

I calculated CWD volume in all 24 plots using a line-intercept sampling method (e.g. Keller et al 2004) along the 5m and 15m transects. I recorded diameter and hardness using a penetrometer for fallen and standing woody debris intersecting the transects. Standing woody debris was defined as a standing dead tree whose trunk is not touching the ground. We determined the volume of dead wood and the wood density by designing regression equations according to CTFS protocols *Woody Debris CWD Dynamics 2010* and *Woody Debris Long Transects 2009*. I assumed CWD carbon was 50% of CWD biomass (Woldendorp et al 2004).

Total Carbon Content

I applied the values of species-specific C content to the database of all trees in the 100 ha. For the tree species I did not have a C value for, I applied the mean C content of the samples. Aboveground biomass was multiplied by percentage C for each species and summed to calculate the total carbon content for aboveground biomass. I divided this total by the area of all the sites to calculate total C in aboveground biomass per hectare.

For soil pools, I extrapolated my calculated value of mg(C)/m to mg(C)/ha for each plot. I calculated total soil C per hectare to be an average of the soil carbon from each of the eight plots.

For coarse woody debris, I multiplied my calculated value of mg(C)/m^3 of CWD by the volume of CWD to determine the total carbon in coarse woody debris across all twenty-four plots. I then divided this number by the total area of the plots to calculate mg(C)/ha.

To calculate the total carbon content per hectare of rainforest, I took the sum of the carbon in the individual pools.

RESULTS

Aboveground biomass C stock

The average carbon in aboveground biomass was 149 Mg(C)/ha. There was not a significant difference in the carbon content of a tree's bark verses pith. There was not a significant difference in carbon content among individuals of the same species, but there was a significant difference in carbon content between different tree species (standard deviation ±1.04, p<.001). Percentage carbon ranged from 43.489% to 48.537%, with a mean percentage carbon of 46.292%.

Table 1. %C by tree species. Database of species-specific carbon content by dry weight.

Tree Species	%C	Tree Species	%C
Aglaia tomentosa	46.544	*Lithocarpus sundaicus*	47.611
Artocarpus komando	43.489	*Macropanax maingayi*	44.687
Artocarpus nitidus	45.185	*Mallotus dispar*	44.670
Atuna racemosa	46.267	*Mallotus subpeltatus*	47.501
Baccaurea brevipes	46.595	*Nephelium costatum*	46.402
Casearia clarkei	46.130	*Payena lucida*	46.173
Chisocheton ceramicus	47.084	*Pentaspadon velutinus*	47.110
Dacryodes rostrata	46.776	*Pometia pinnata*	47.205
Dialium platysepalum	47.543	*Popowia fusca*	43.493

Elateriospermum tapos	46.905	*Pseuduvaria macrophylla*	46.384
Syzygium filiforme	45.878	*Pterospermum javanicum*	45.330
Gordonia maingayi	46.424	*Ptychopyxis caput-medusae*	46.057
Hibiscus macrophyllus	46.140	*Quercus argentata*	46.793
Hydnocarpus woodii	45.906	*Saraca cauliflora*	46.503
Leptonychia caudata	47.083	*Scorodocarpus borneensis*	48.537
Lithocarpus sundaicus	47.611	*Semecarpus curtisii*	45.907
Macropanax maingayi	44.687	*Shorea leprosula*	46.560
Mallotus dispar	44.670	*Xerospermum noronhianum*	44.456
Mallotus subpeltatus	47.501		

Belowground biomass C stock

The C in belowground biomass was determined to be 18% of the C in aboveground biomass by Niyama et al (2010) in Malaysia. Applying this relation, I estimated that the belowground biomass C stock was 27 Mg(C)/ha.

Soil C stock

I used a soil bulk density value of 1.1 g/cm^3, borrowed from Saner et al 2012’s study in a Malaysian Borneo lowland dipterocarp forest. There was a significant difference in soil carbon content at varying soil depths. The most carbon was found from 0-10 cm and the least from 2.5-3 m. Carbon content decreased linearly with soil depth (Figure 3). The average soil organic carbon content was 27 Mg(C)/ha.

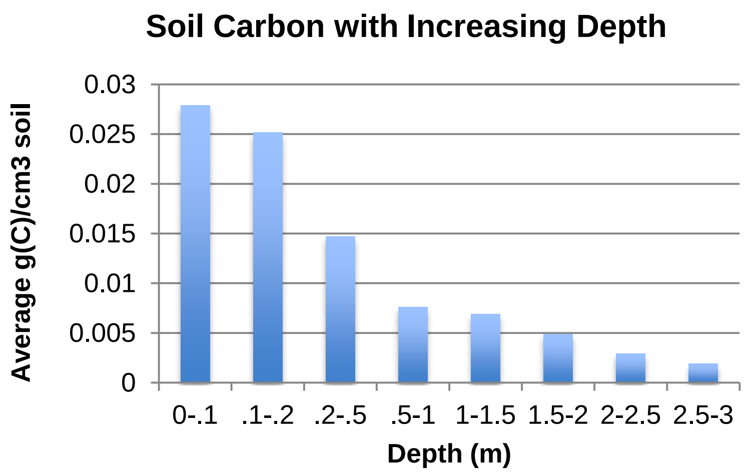

Figure 3. Average soil organic carbon content at various soil depths. Soil carbon content decreased with increasing depth. Soil samples were extracted from 0 to 3 m deep in eight plots. Soil carbon values ranged from .002 to .027 g(C)/cm^3(soil).

Coarse Woody Debris C stock

The average C content of CWD was 10.8 Mg(C)/ha. There are no other studies in Malaysia on the C content of CWD.

Total C stock

The average C stock was 208.8 Mg(C)/ha. The most carbon was in the aboveground biomass pool, followed by belowground biomass, soil, and then coarse woody debris (see Figure 4).

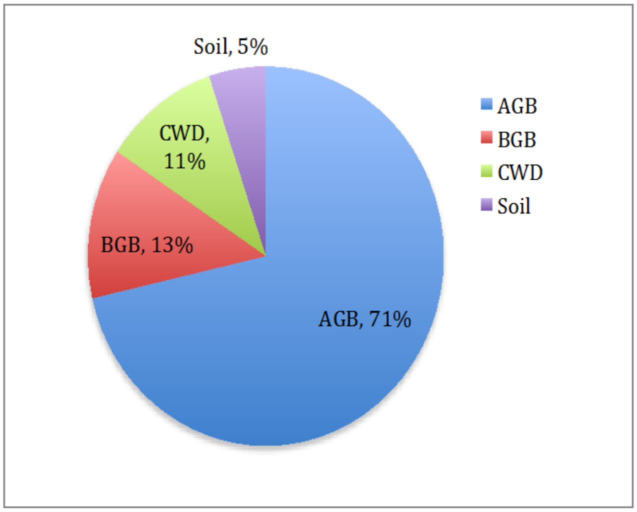

Figure 4. Breakdown of total forest C by pool. The most carbon was found in aboveground biomass (71%), followed by belowground biomass (13%), coarse woody debris (11%), then soil (5%).

DISCUSSION

Through my study, I sought to quantify the carbon present in an upper hill dipterocarp forest of Malaysia. Past studies have used LiDAR data and regional estimates in order to estimate the carbon stock, but rarely in-depth field surveys (Saatchi et al 2011, however see Saner et al 2012). Prior estimations have also differed in which carbon pools they include in quantification, whereas I've chosen to include aboveground biomass, soil, and coarse woody debris.

Carbon stock estimation and sources of error

Aboveground biomass density and carbon content

I estimated the density of aboveground biomass to be 321 Mg/ha. This value is similar to estimates from dipterocarp forests in Sabah, Malaysia of 323 Mg/ha (Pinard and Putz 1996). A study in a lowland dipterocarp forest in Pasoh, Malaysia produced much greater value of 536 Mg/ha (Niyama et al 2010). However, Niyama et al (2010) developed their own size-mass allometric equation for their study site, leaving them with an estimation much larger than values reported for seasonal rainforests in Southeast Asia or South America. I chose to use previously accepted regression equations so that my estimation would be comparable with the literature (Chave et al 2005). A value of 406 Mg/ha was reported in a Philippines dipterocarp forest, different than mine partially due to their use of an alternative allometric equation, which when applied to my dataset produces an estimate 30 Mg(C)/ha greater (Lasco et al 2006). However, the most plausible explanation for differences in our biomass estimates is the variation in location.

My estimation of carbon stocks in aboveground biomass is consistent with estimates for other dipterocarp forests. The 149 Mg(C)/ha at my study site is larger than lowland dipterocarp forest estimates in Pasoh Malaysia (91.9 Mg(C)/ha), smaller than estimates in the Phillipines (406 Mg(C)/ha), similar to Indonesian forests (161 Mg(C)/ha), and in the range of Thaliand rainforest estimates (72-182 Mg(C)/ha) (Saner et al 2012, Lasco et al 2006, Murdiyarso and Wasrin 1995, Boonpragob 1998). The larger estimation produced from the Philippines dipterocarp forest can be attributed to a higher biomass density (406 Mg/ha verses 321 Mg/ha) (Lasco et al 2006). The lower value reported from Pasoh is most likely due to their use of conservative allometric regression equations, but also suggests a difference between lowland and upper hill dipterocarp forest carbon stocks (Saner et al 2012).

Average carbon content and interspecific variation

The average carbon content I estimated at my study site (46%) is significantly different from the common assumption of 50%. Pinard and Putz (1996) also found a percentage of carbon in biomass significantly different from 50% (49.2%) in Sabah, Malaysia. Our studies suggest that the assumption of 50% carbon in biomass does not hold in Malaysian dipterocarp forests. More accurate studies can be achieved by using this lesser value. In accordance with Elias and Potvin (2003), my study showed significant interspecific variation in carbon content. However, the random effect standard deviation from mean carbon content was ± 1.04. Given the variation in species carbon content, some individuals may have a C content closer to 50%. Therefore, I have included a database of species-specific C values, which should be consulted for the most accurate estimation of tree species C.

Soil organic carbon stocks and variation in depth

My estimation of 22 Mg(C)/ha in soil is much less than other studies in the area, representing only 5% of total forest carbon. My study sampled to deeper depths than all other studies in the area, yet produced a smaller carbon pool. The soil in the top 20 cm was 72% of the soil in the 3 m profile. This leads me to conclude that either assuming a uniform bulk density at all depths introduced large errors in my calculations, or including soil samples down to 3 m did not have much of an effect on the soil carbon pool. Therefore sampling down to smaller depths is sufficient for carbon quantification (ie. 0-30 cm Lasco et al 2006, 1 m Saner et al 2012). Potential error in my estimation of soil carbon comes mainly from a borrowed value of soil bulk density. The value is not site-specific, causing soil carbon to be the most inaccurate component of my study.

Coarse woody debris (CWD) carbon stock

The 10.8 Mg(C)/ha in CWD is smaller than estimations in other rainforests. CWD contributed 5% of the total C stocks in my study, which is less than the 10-20% assumed for all rainforests (Gibbs et al 2007). The only other study of forest C in Malaysian dipterocarp forests did not include CWD; therefore, this estimation of C in CWD is important for Malaysian carbon quantification (Saner et al 2012). However, additional studies encompassing the variety of forest types within Malaysia could improve regional CWD(C) estimation.

Total forest carbon and methods of quantification

Table 2. Southeast Asian Forest Carbon Estimation. A comparison of forest carbon stock estimations in Peninsular Malaysia, Philippines, Indonesia, and Southeast Asia in general. My study produces an estimation significantly different from other studies in the area.

Location	Total forest C stock (Mg(C)/ha	Authors/Year
Peninsular Malaysia (upper hill dipterocarp forest)	208.8	*(this study)*
Philippines	258	*Lasco et al (2006)*
Southeast Asia (average)	172	*Saatchi et al (2011)*
Peninsular Malaysia (lowland dipterocarp forest)	167.9	*Saner et al (2012)*
Indonesia	161	*Murdiyarso and Wasrin (1995)*

There are a limited number of studies on C in Malaysian dipterocarp forests. The only other study explicitly in Malaysia also uses in-depth field surveys to quantify forest C (Saner et al 2012) (see Table 2). The main difference between our studies is the location of upper hill forest verses lowland forest. Considering the variation in our estimations, I conclude that site-specific measurements are necessary for accurate C quantification. To assume an average C content in Malaysia from our two studies would be to underestimate the forests in northern Peninsular Malaysia, which is where most of the primary forest in the country resides.

There is no study using solely satellite data to estimate Malaysian forest C. The one other study quantifying C in Malaysian forests uses a combination of satellite data, tree surveys, and LiDar to produce an estimation of average forest C throughout Southeast Asia (Saatchi et al 2011). The average C content produced from Saatchi et al (2011) is less than my estimation by 30 Mg(C)/ha. Regional estimates are not likely to be locally accurate because of the variation in landscapes and forest types. Furthermore, the use of satellite data within their study could explain their smaller estimation of forest C, since satellite data only quantifies the C in aboveground biomass. Although in-depth field surveys produced a greater and more accurate value of C for the forest in my study, this method can be more time-consuming. Satellite data has the advantage of reduced time and cost for data collection, albeit more technically demanding (Gibbs et al 2007). When possible, in-depth field surveys are the most accurate quantification method for a forest. However, the choice of method will depend on previous data collection, workforce availability, and time constraints.

My estimation falls in the upper range of estimates for the Southeast Asian region, greater than all estimates except for a dipterocarp forest in the Phillipines (see Table 2). Variations in estimation could be attributed to difference in location, as well as which C pools were included in the study. Lasco et al (2006) found 258 Mg(C)/ha in a Phillipines dipterocarp forest, including trees, litter, soil, and understory vegetation in their quantification. While I do not include understory vegetation, they do not include coarse woody debris, possibly explaining the difference in our estimates beyond variation in location. Saner et al (2012) included more carbon pools than my study (specifically understory vegetation, fine root biomass, and standing litter), but the relative contribution of these pools to total C were all <1%, which does not explain the variation in our carbon values as much as the difference in forest types does.

Limitations and recommendations for future research

As I did not include the carbon in understory vegetation, fine root biomass, and leaf litter pools, this study can still be considered a conservative estimate of Malaysian forest carbon. However, the contribution of these pools to the total C pool in a similar site in Malaysia were 5%, <1%, and <1%, respectively (Saner et al 2012). Therefore, the contribution of these pools to total carbon is minor and may not have greatly altered my estimation. My estimation of soil carbon could be improved by calculating soil bulk density at the site, instead of borrowing a value from lowland Malaysian forests. While time restrictions prevented me from collecting this data, site-specific bulk density values would strengthen estimation accuracy. Future studies should also employ destructive sampling before using biomass allometric regression equations to improve accuracy (Chave et al 2005).

Additionally, I did not have species-specific C content for all species in the forest due to time constraints. Future studies could create an even larger database of C content by species in Malaysia. I also did not sample the wood density of all the trees in the 100 ha experimental plot, as this would have been extremely time consuming. A more accurate estimation of aboveground biomass could either attempt to sample the wood density of all species, or to take family-level wood density averages. Finally, I have not included a confidence interval around my final C estimation due to error propagation difficulties. This calculation would give me a better idea of the precision of my estimate and is recommended for future studies on forest carbon.

Broader Implications

My study has provided a database of carbon content values for dominant Malaysian tree species, which can be used in both field surveys and regional estimates to further quantification accuracy. The most important conclusion from my study is that site-specific in-depth field surveys are necessary for accurate carbon quantification. Regional estimates from Saatchi et al (2011) fail to account for local variability, which could have adverse consequences for the economic viability of carbon credit schemes by miscalculating carbon stocks. Failure to recognize the difference between lowland and hill dipterocarp forests can also greatly affect the accuracy in carbon quantification (Saner et al 2012).

If REDD is to be effective in reducing emissions, carbon quantification needs to be site-specific. My study has shown that accounting for interspecific variation in carbon content and utilizing in-depth field surveys is necessary for REDD to be scientifically sound. While these methods may be more costly and time consuming, they are necessary for a true fight against global warming.

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