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RESEARCH PAPER

A Natural Forest of Commercial Timber Species: Logging or Not Logging

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Abstract

Most tropical forests outside protected areas have been or will be selectively logged because the timber industry is a main income-generating resource for many developing countries. Therefore, understanding the composition of commercial timber species and logging types is key for sustainable forest management in countries like Vietnam as they move toward fulfilling Reducing Emissions from Deforestation and Forest Degradation (REDD+) agreements. Seven 1-ha plots were surveyed in the Central Highland of Vietnam, and 18 commercial tree species from these plots, whose timber is widely used by local people for housing and furniture making and timber is easily sold at local markets for high prices, were analyzed. In total, 151 tree species with a diameter at breast height (DBH) of ≥ 10 cm were recorded. The 18 commercially valuable species assessed in this study accounted for 33.2% of all stems (total of 524 stems ha^{-1} for all species), 47.1% of basal area (total of 34.35 m^2 ha^{-1} for all species), and 50.8% of aboveground biomass/AGB (total of 262.68 Mg ha^{-1} for all species). Practicing diameter-limit harvesting of all commercially valuable species with DBH of ≥ 40 cm, which is widely performed in Vietnam, will reduce the number of stems by 7%, basal area by 31.6%, and AGB by 38.2%. Because such harvesting practices cause severe ecological impacts on the remaining forest, logged forests may require > 40 years to recover the structure status of a pre-logged forest. In addition, the recovery of the 18 commercially valuable species may require a much longer time because they comprised 33.2% of stems. Permission for logging natural forests should be given in Vietnam to sustain lives of local communities, where logging has been prohibited. However, alternative harvesting systems, such as reduced-impact logging systems, should be considered. The systems selected must simultaneously generate economic returns for local people and respect the REDD+ agreements with regard to protecting biodiversity and reducing carbon emissions.

Keywords Logging system · REDD · Sustainable management · Timber species · Tropical forest

Introduction

Because tropical forests greatly vary in the stocking rates of timber and the commercial values of different tree species (Schulze et al. 2008), this greatly affects the economics of logging (Fisher et al. 2014). In addition, tropical forests vary with regard to the number of highly valued timber species they contain. For example, South American forests contain a relatively small number of commercially valuable timber species (Schulze et al. 2008), whereas the dipterocarp-dominated lowland rainforests in Southeast Asia have a large number (Fisher et al. 2011). In the tropics, strict protection of pristine forests is likely to remain a conservation and environment priority (Sodhi et al. 2009; Gibson et al. 2011); however, recognition of the value of forests, both for timber production and non-timber uses, has been increasing (Ghazoul and Sheil 2010). Most tropical forests outside protected areas have been or will be selectively logged because traditionally, the timber industry has been a main income-generating resource, particularly in many developing countries (Putz et al. 2012).

Selection logging, where large-sized trees of commercially valuable species are logged, is a management strategy that might shift the economic balance away from land uses that require clear felling toward those that maintain healthy forests (Bushbacher 1990). Conventional logging, widely practiced in the tropics, depletes timber stocks and causes severe ecological impacts on the remaining forests (Repetto and Gillis 1988). The conventional logging system has been widely used in Southeast Asia; it only targets stems of commercially valuable species with a certain diameter at breast height (DBH) (Bertault and Sist 1997). In this system, little action is taken to reduce forest damage during harvest, thereby causing soil damage and high tree mortality and leaving remaining stands in poor condition (Bertault and Sist 1997; Matricardi et al. 2010). Reduced-impact logging has been globally promoted in response to domestic and international concerns regarding the ecological and economic sustainability of harvesting natural tropical forests (Sist et al. 1998; Dionisio et al. 2017). Reduced-impact logging generally benefits biodiversity and reduces carbon emissions (Miller et al. 2011; Putz et al. 2012) and is increasingly suggested for timber production in the tropical forests of Southeast Asia (Putz et al. 2008). In addition, it incorporates pre- and post-logging guidelines such as conducting preliminary surveys, employing directional felling, planning skid trails, and using climber cutting methods (Sist et al. 1998). Reduced-impact logging can reduce the overall damage to remaining forests by 30–50% (Bertault and Sist 1997), thereby promoting better stand development.

Although foresters have been recommending the implementation of methods for reducing the effects of logging for decades (Heinrich 1995; Haworth 1999), good logging practices remain an exception rather than a rule in most of the tropics. Uncontrolled logging, including over-logging and poor forest management practices, is an important cause of deforestation (FAO 1996; Achard et al. 2002). Disappearance of tropical forests has become a major international concern, and this has led to the development of the potential emission-trading mechanism

Reducing Emissions from Deforestation and Forest Degradation (REDD+), which promotes conservation or more sustainable logging techniques to reduce greenhouse gas emissions (Sasaki et al. 2011). Since the Vietnam government signed the REDD+ agreement, logging timber from natural production forests has dramatically reduced, with logging being prohibited in many regions. This affects the national economy and the income of local people, whose livelihoods often depend on forest resources.

In this study, the composition of commercially valuable species in evergreen broadleaved forests in the Central Highland of Vietnam where logging was largely prohibited by the government was assessed. Furthermore, logging techniques to support logging permission for generating income while using sustainable forest management techniques are discussed.

Study Site and Methods

Study Site

The study was at Kon Ha Nung experimental forest (14°30′N–108°44′E) in the Central Highland of Vietnam. The Central Highland is classified as the largest forest cover region in Vietnam (FIPS 2011). Of 2.6 million ha of natural forests in the Central Highland, 1.6 million ha are evergreen broadleaved forests (Vo et al. 2015).

The annual temperature of the study site was 23.6 °C, with a minimum temperature of 13.6 °C in January and a maximum temperature of 29.6 °C in June (Huong 2011). There are two distinct seasons: the rainy season from April to November and the dry season from December to March. The annual precipitation was 2042 mm, with the lowest and highest monthly precipitations in February (38 mm) and October (315 mm), respectively. The mean monthly air humidity was 82%. Rhodic ferralsols, which developed on neutral–to-alkaline magma parent rocks, are the dominant soil type.

In the Central Highland, the population was 5.3 million people in 2011 (GSOV 2012). Of which, 45 ethnic minorities accounted for 25.3%. Growing industrial crops as coffee, cacao, and pepper, has highly benefited local people. However, livelihood of many ethnic minorities highly depends on forest resources (harvesting non-timber forest products and logging timber) as they could not own industrial crop gardens.

Data Collection and Aboveground Biomass Estimation

For data collection, seven 1-ha (100 m × 100 m) randomly located plots were established. Such plot size is widely used for forest researches in the tropics including Vietnam (Tran et al. 2018). Recorded data included tree species and DBH. Only trees with stem DBH of ≥ 10 cm were measured. For unknown tree species, specimens such as leaves, fruits, roots, and/or bark were collected from the field and taken to the laboratory for identification by specialists. Aboveground biomass (AGB) of each stem was estimated as $\mathrm{AGB} = 0.12843 \cdot \mathrm{DBH}^{2.409076}$ (Bao et al. 2016).

Data Analysis

Two data sets comprising tree species classified as commercially valuable and non-commercially valuable species were considered. Commercially valuable species are trees from which timber has been widely used by local people for housing and furniture making and timber that is easily sold at local markets for high prices (Le 1996; Soa 1999). For the seven surveyed plots, data of the stem density, basal area, and AGB were calculated as means per hectare and were compared using *t*-tests. The data were divided into different DBH classes. Comparisons among the DBH classes were performed using ANOVA and Tukey's post hoc test. All data analyses were conducted using the SAS 9.2 software.

Results

In total, 151 timber species were recorded across the seven 1-ha plots. Of these species, 18 were classified as commercially valuable (Table 1). Five commercially valuable species had largest stems of >90 cm DBH, eight had largest stems of ≤ 90 cm DBH, four had largest stems of ≤ 60 cm DBH, and one had largest stems of ≤ 30 cm DBH. The average stem density (stems ha^{-1}) of commercially valuable species in larger DBH classes exponentially decreased (Fig. 1a) from 74 stems in the 10–20 cm DBH class to 40 stems in 20–30 cm DBH class, 11 stems in 50–60 cm DBH class, and to one stem in the >100 cm DBH class. Commercially valuable species accounted for 33.2% of the stems. The basal area of the commercially valuable species was highest in the 30–60 cm (7.00 m^2 ha^{-1}) DBH classes, followed by the 60–90 cm (3.84 m^2 ha^{-1}) and <30 cm (3.10 m^2 ha^{-1}) DBH classes. The ≥ 90 cm DBH class had the lowest basal area (2.27 m^2 ha^{-1}), and the distribution pattern of basal area to DBH classes was in the form of a nearly normal distribution with a peak at 50–60 cm DBH class (Fig. 1b). The commercially valuable species accounted for 47.1% of the basal area. The pattern of AGB by DBH classes was different from that of the stem density but to basal area (Fig. 1); the pattern formed a nearly normal distribution with a peak at the 50–60 cm DBH class (Fig. 1c). The 30–60 cm DBH class had the highest AGB of 54.19 Mg ha^{-1}, decreasing to 36.3 Mg ha^{-1} in the 60–90 cm DBH class and 25.7 Mg ha^{-1} in the ≥ 90 cm DBH class, whereas the <30 cm DBH class had the lowest AGB of 17.55 Mg ha^{-1} (Table 1 and Fig. 1c). The 18 commercially valuable species accounted for 50.8% of the total AGB. Stem density, basal area, and AGB in different DBH classes were significantly different ($p = 0.05$) between the 18 commercially valuable species and 133 non-commercially valuable species (Table 1).

The <50 cm DBH classes accounted for 92.4% of the stems for all 151 recorded species. In these classes, the 18 commercially valuable species accounted for 28.8% of the stems (Fig. 1a). In the ≥ 50 cm DBH classes, the stems of the commercially valuable species accounted for 4.5% of the total stems, whereas those of non-commercially valuable species accounted for only 3.1% of the total stems. The difference in stem density between commercial and non-commercial valuable species led to a difference in basal areas (Fig. 1b) and AGB

Table 1 Average parameters of 18 commercially valuable species and 133 non-commercially valuable species in different DBH (diameter at breast height) classes in the Central Highland of Vietnam

Commercially valuable species	No. of stems (ha^{-1})					Basal area ($m^2\ ha^{-1}$)					AGB ($Mg\ ha^{-1}$)				
	Mean ± SE	DBH class (cm)				Mean ± SE	DBH class (cm)				Mean ± SE	DBH class (cm)			
		< 30	30–60	60–90	≥ 90		< 30	30–60	60–90	≥ 90		< 30	30– 60	60–90	≥ 90
Paramichelia braianensis	22 ± 2.1	7.5	11.1	2.5	1.0	3.96 ± 0.86	0.26	1.77	1.03	0.91	35.34 ± 9.32	1.50	13.91	9.71	10.21
Pometia lecomtei	18 ± 2.3	14.7	3.0			0.71 ± 0.11	0.40	0.31			4.49 ± 0.76	2.27	2.21		
Castanopsis poilanei	17 ± 2.6	10.7	5.6	0.3		1.22 ± 0.19	0.35	0.76	0.11		8.85 ± 1.47	2.00	5.87	0.98	
Machilus odoratissimus	17 ± 2.3	12.0	5.0	0.5	0.2	1.41 ± 0.21	0.34	0.73	0.19	0.16	10.91 ± 1.87	1.93	5.53	1.73	1.72
Aglaia silvestris	16 ± 1.6	13.1	2.6	0.2		0.79 ± 0.17	0.32	0.39	0.07		5.54 ± 1.34	1.79	3.06	0.69	
Nephelium bacsasense	15 ± 2.6	11.9	2.9	0.1		0.73 ± 0.11	0.34	0.36	0.03		4.90 ± 0.73	1.91	2.73	0.26	
Dialium cochinchinensis	13 ± 2.5	7.0	2.3	2.5	0.9	2.41 ± 0.71	0.17	0.35	1.07	0.82	23.02 ± 7.32	0.95	2.76	10.22	9.09
Ormosia balansae	13 ± 2.4	10.1	2.4			0.57 ± 0.12	0.26	0.31			3.79 ± 0.91	1.41	2.38		
Pasania ducampii	11 ± 1.5	6.8	3.2	0.9	0.1	1.12 ± 0.17	0.18	0.50	0.37	0.07	9.22 ± 1.52	0.98	3.99	3.53	0.73
Dacryodes dungii	10 ± 2.0	4.9	3.2	1.4	0.2	1.55 ± 0.54	0.11	0.57	0.57	0.32	14.44 ± 5.60	0.57	4.57	5.35	3.95
Cinnamomum obtusifolium	6 ± 1.3	4.1	1.5	0.1		0.31 ± 0.07	0.10	0.17	0.04		2.14 ± 0.55	0.54	1.29	0.32	
Artocarpus parva	6 ± 0.8	5.1	0.5			0.17 ± 0.02	0.12	0.05			1.01 ± 0.16	0.66	0.35		
Michelia mediocris	4 ± 1.7	2.0	1.3	0.3		0.35 ± 0.12	0.04	0.22	0.09		2.80 ± 1.02	0.22	1.80	0.78	
Aglaia gigantea	2 ± 0.8	1.0	1.2			0.19 ± 0.08	0.03	0.16			1.35 ± 0.60	0.18	1.17		
Canarium tonkinensis	2 ± 0.5	1.5	0.6	0.2		0.23 ± 0.09	0.06	0.09	0.08		1.78 ± 0.80	0.37	0.69	0.71	
Podocaropus imbricatus	2 ± 0.5	0.4	1.1	0.2		0.26 ± 0.11	0.01	0.16	0.09		2.18 ± 1.02	0.09	1.24	0.85	
Canarium subulatum	2 ± 0.4	0.7	0.5	0.3		0.23 ± 0.08	0.02	0.08	0.12		1.96 ± 0.69	0.15	0.64	1.17	
Ormosia hoaensis	1 ± 0.3	1.0				0.01 ± 0.01	0.01				0.04 ± 0.04	0.04			
18 commercially valuable species	175 ± 22.3*	115*	48*	10	2	16.21 ± 1.88*	3.10*	7.00*	3.84*	2.27*	133.75 ± 13.91	17.55*	54.19*	36.30*	25.70*

Table 1 (continued)

Commercially valuable species	No. of stems (ha^{-1})					Basal area (m^2 ha^{-1})					AGB (Mg ha^{-1})				
	Mean ± SE	DBH class (cm)				Mean ± SE	DBH class (cm)				Mean ± SE	DBH class (cm)			
		< 30	30–60	60–90	≥ 90		< 30	30–60	60–90	≥ 90		< 30	30– 60	60–90	≥ 90
133 non-commercially valuable species	349*	278*	64*	6	1	18.13 ± 1.21*	6.88*	8.66*	2.21*	0.38*	128.93 ± 12.18	38.13*	66.17*	20.37*	4.26*
All species	524	393	112	16	3	34.35	9.98	15.65	6.06	2.65	262.68	55.68	120.36	56.67	29.96

*Significant difference between 18 commercially valuable species and 133 non-commercially valuable species at $p = 0.05$

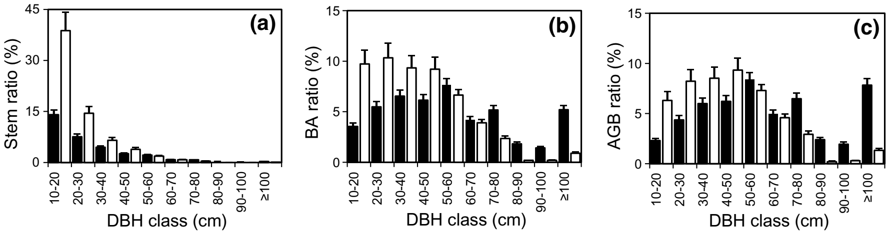


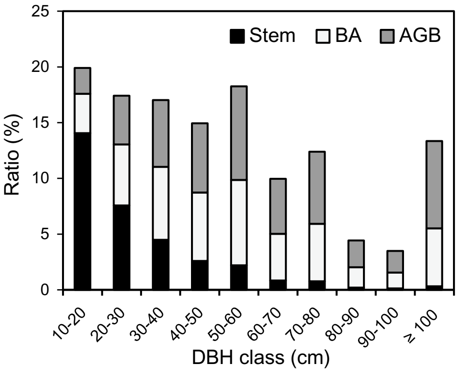
Fig. 1 Stem ratio (**a**), basal area (BA) ratio (**b**), and aboveground biomass (AGB) ratio (**c**) of 18 commercially valuable species (black-filled columns) and of 133 non-commercially valuable species (white-filled columns) in different DBH (diameter at breast height) classes in the Central Highland of Vietnam. Error bars indicate one standard error

(Fig. 1c). The <50 cm DBH classes accounted for 60.3% of the total basal area, and the 18 commercially valuable species accounted for 21.8% (Fig. 1b). In the ≥ 50 cm DBH classes, the stems of commercially valuable species accounted for 25.5% of the total basal area, which was nearly double that of non-commercially valuable species (14.2%). For AGB, the <50 cm DBH classes accounted for 51.3%, of which commercially valuable species accounted for 18.9% (Fig. 1c). In contrast, the stems of commercially valuable species accounted for 32% of the total AGB in the ≥ 50 cm DBH classes, which is double that of non-commercially valuable species (16.7%).

In all DBH classes, the stem density of the 133 non-commercially valuable species had an exponentially decreasing distribution and was significantly higher ($p=0.05$) than that of the 18 commercially valuable species (Fig. 1a). While, basal area had a bell shaped distribution (Fig. 1b) and a nearly normal distribution well represented distribution of AGB (Fig. 1.c) to DBH classes. Basal area and AGB of the commercially valuable species were significantly higher ($p=0.05$) than those of 133 non-commercially valuable species in the ≥ 70 cm DBH classes (Fig. 1b, c). Basal area of the 133 non-commercially valuable species was highest (10.3%) in the 20–30 cm DBH class, but not significantly ($p=0.05$) higher than that in 10–20 (9.7%), 30–40 (9.3%), or 40–50 (9.2%) cm DBH classes (Fig. 1b). The highest AGB (9.3%) of the 133 non-commercially valuable species was found in the 40–50 cm DBH class, but it was not significantly ($p=0.05$) higher than that in 30–40 (8.5%), 20–30 (8.2%), or 50–60 (7.3%) cm DBH classes (Fig. 1c).

For the 18 commercially valuable species, the stem density decreased in the larger DBH classes (Fig. 2), from 14% in the 10–20 cm DBH class to 2.2% in the 50–60 cm DBH class, and to 0.3% in the ≥ 100 cm DBH class. There was no clear pattern in the basal area and AGB distributions among the DBH classes. The highest ratio of basal area belonged to the 50–60 cm DBH class (7.66%), which decreased to 5.47% in the 20–30 cm DBH class, 5.19% in the ≥ 100 cm DBH class, and 1.42% in the 90–100 cm DBH class. The 50–60 cm DBH class had the highest AGB (8.39%), followed by the ≥ 100 cm DBH class (7.83%), 70–80 cm DBH class (6.47%), 40–50 cm DBH class (6.21%), and 90–100 cm DBH class (1.94%) (Fig. 2). The difference in the stem density, basal area, and AGB of the18 commercially valuable species among the DBH classes was significant ($p=0.05$).

Fig. 2 Ratios of stem, basal area (BA), and aboveground biomass (AGB) of 18 commercially valuable species compared with all species in different DBH (diameter at breast height) classes in the Central Highland of Vietnam



If stems of commercially valuable species with DBH of only ≥100 cm are logged, the stem density is reduced by 0.33%, basal area by 5.19%, and AGB by 7.83%. Conversely, logging all stems with DBH of ≥80 cm will reduce the stem density by 0.67%, basal area by 8.43%, and AGB by 12.17% (Fig. 1b, c).

Discussion

To meet timber demand, both locally and globally, natural forests outside protected areas will be logged. This generates income for countries and local people who engage in logging activities and timber processing as parts of their livelihood (Kien and Harwood 2017). Logging is mostly concentrated in natural forests with high densities of commercially valuable species, where it is most profitable. In the present study of Vietnam's Central Highland, logging had high economic value for the government and local people because 18 commercially valuable species accounted for nearly half of the basal area (47.1%) and AGB (50.8%) of its approximately 1.6 million ha of natural evergreen broadleaved forests (FIPS 2011). In Vietnam timber supply from domestic sources was 1.6 million m^3 in 2010, while 4.8 million m^3 were imported to serve for the wood processing industry (Phuc and Canby 2011).

Logging has been recently prohibited in most natural production forests of Vietnam because the country accepted the REED+ agreement, and currently, there is no logging system that guarantees sustainable forest management. In the meantime, 53 ethnic groups accounting for nearly 14.3% of Vietnam's population (GSOV 2009), who reside in mountainous areas, depend on forest resources for their income (Saunders 2014). In the Central Highland, the population was 5.3 million people in 2011 and there were 45 ethnic minorities accounting for 25.3% of the population. Although many training and job creation efforts to improve local incomes have been made by the government, local people still depend on forest resources for food through non-timber products and income from timber logging. Illegal logging by local ethnic people (Saunders 2014) continues in both protected and natural production forests as a way to sustain their lives, although they know that they may be fined or sent to prison. The current logging prohibition is negatively affecting sustainable forest management because illegal logging is negatively affecting or killing remaining trees as no care is considered when logging, and no post-logging silvicultural activities are applied to help promote the regrowth (Cannon et al. 1994; Pinard and Putz 1996; Bertault and Sist 1997; Sist et al. 1998; Putz et al. 2008).

Conventional logging where stems of commercially valuable species of > 30 or 40 cm DBH are logged was widely practiced in Vietnam. In conventional logging practice, pre-logging activities such as preliminary surveying, mapping tree positions, and identifying logged trees are not considered. In addition, post-logging activities such as cutting invasive climbing vegetation, cutting diseases and trees with poor growth forms, and managing logging residuals were also not carried out to support natural regeneration and growth of the remaining trees. If a harvest limit of > 40 cm DBH is applied in the present study forest, it will reduce stem density by 7%, basal area by 31.6%, and AGB by 38.2% and disturb the forest structure and diversity. These negative effects are even greater when logging of stems of > 30 cm DBH is applied, which is the case in many forests in Vietnam. Tran et al. (2018) indicated that the evergreen broadleaved forests in the Central Highland of Vietnam have, on average, an annual growth rate of 2.8% in terms of basal area and 3.6% in terms of AGB and an annual stem recruitment of 1.4% for all species. These values are lower than those in African moist forests (e.g., annual AGB recovery of 6%), where most logged forests recover to AGB of pre-logging within 30 years (Gourlet-Fleury et al. 2013); however, other studies showed lower recovery rates (Hall et al. 2003; Bonnell et al. 2011). Sist et al. (1998) indicated that it takes > 35 years for logged forests in Indonesia to recover to the status of pre-logged forests. These studied results suggest that Vietnam's forests logged using conventional methods will take much longer than 35 years to recover to a pre-logged state. The differences of recovery rates might be explained by differences in soil fertility, composition of tree species, absence or presence of invasive climbing vegetation, lianas, and/or shrubs, logging systems employed (conventional logging and reduced-impact logging), and natural conditions. With low recovery rates and no pre- and post-logging activities (Tran et al. 2018) applied in the conventional logging system and DBH limitations, natural forests in Vietnam will never be brought into sustainable management as per the REDD+ agreements, and forest carbon content and biodiversity will be highly deteriorated.

Reduced-impact logging benefits biodiversity and reduces carbon emissions (Miller et al. 2011; Putz et al. 2012). It includes pre- and post-logging guidelines, such as creating a pre-logging survey, mapping all canopy trees, climber cutting, directional felling, planning skid trails, and leaving mother trees for natural regeneration. These activities minimize impacts of logging on the remaining forest, promote the growth of remaining trees, and increase stem ratios of commercially valuable species. In addition, community and individual small-scale logging applied in tropical forests shows positive results for sustainable timber management (Lescuyer et al. 2016; Yu et al. 2017), as all activities are considered to minimize impacts on remaining forests and retain timbers for future generations. It is obvious that to achieve both biodiversity benefits and carbon emission reduction, logging intensity and DBH limitation must be carefully considered. Several studies indicated that species numbers increase after logging (Cannon et al. 1998; Berry et al. 2010; Imai et al. 2012), whereas others showed that they decline (Okuda et al. 2003; Brearley et al. 2004; Makana and Thomas 2006; Gutierrez-Granados et al. 2011); the pattern is dependent on regional biodiversity, natural conditions, and the scale at which logging occurs (Hamer and Hill 2000; Hill and Hamer 2004; Dumbrell et al. 2008). Many studies indicated that logging increases carbon emission (Miles and Kapos 2008; Miller et al. 2011; Pearson et al. 2014) by (1) removing carbon from the forest, (2) increasing dead organic matter in forests as logging residues, (3) disturbing soil that promotes the organic matter decomposition process, and (4) reducing forest cover that leads to higher soil surface temperature from increased solar radiation and may promote higher soil microorganism activity, causing an increase in the rate of heterotrophic respiration. However, some researchers indicated that logged forests have higher carbon sequestration rates compared with unlogged forests (Figueira et al. 2008; Gourlet-Fleury et al. 2013) because of the faster growth rate of young trees (influenced by an increased soil fertility and sunlight) to fill the available growing space. Therefore, reduced-impact logging should be introduced to Vietnam, although economics are lower in the short term than those of conventional logging. This change would ensure sustainable forest management and respect the REDD+ agreement. A well-planned reduced-impact logging system will generate national revenue and improve incomes for local people who engage in logging activities and wood processing to sustain their lives. As a result, illegal logging by local people should decrease, and forests will be more sustainably managed. However, even when there is a well-planned reduced-impact logging, implementation must be monitored and evaluated by authorities because timber logging enterprises prioritize financial profit over biodiversity conservation, carbon emission reduction, and sustainable forest management. In addition, the role and benefit to local people must be considered in a reduced-impact logging system. Ethnic people have been residing in forest areas for generations and regard forest resources as their own assets (To and Rickor 2013). Taking timber out of forests without sharing with the local people will lead to higher rates of illegal logging because the belief exists that if one can log timber from “our forest” then we can also log “our trees” without any permission.

Of the 18 commercially valuable species mentioned in Table 1, one species had a density of >20 stems ha^{-1}, nine species had 10–18 stems ha^{-1}, three species had 4–6 stems ha^{-1}, and five species of 1–2 stems ha^{-1}. For sustainable forest management and biodiversity conservation toward the REDD+ agreement, a logging plan must be carefully prepared where species with a low stem density (e.g., <6 stems ha^{-1}) should not be logged. These low density stems, even those in the 60–90 cm DBH class, must remain as mother trees for supporting natural regeneration. Non-commercially valuable species with >60 cm stem DBH were recorded (Table 1) and must be logged to provide growing space for commercially valuable species. In addition, diseased stems of both commercially and non-commercially valuable species should be cut and removed from forests for better growth of the surrounding trees.

Studies on reduced-impact logging systems must be carried out for practical application in Vietnam. However, it may take several decades for the full results. Therefore, in the meantime a reduced-impact logging system can be applied with some main points that must be strictly followed (1) pre-logging activities including preliminary surveys (status of pre-logged forest), mapping all canopy trees, identifying logging rotations (e.g. 20 years), identifying maximum amounts of logged timber (rotation/20 years × growth rate/1–2% (Tran et al. 2018) × current AGB) and logged trees (each remaining species with density ≥ 2 trees ha^{-1}), employing directional felling, planning skid trails (minimizing impact on remained trees and soil compaction), engaging local people in logging, planning benefit sharing with local people, and (2) post-logging activities including cutting poor growth forms and diseased trees (both commercial and non-commercial tree species), managing logging residuals, cutting invasive climbing vegetation, planting commercially valuable species in big gaps (e.g. > 300 m^2), conducting surveys in 5-year intervals, applying suitable silvicultural practices if remaining forest grows badly. For-profit forest enterprises may not follow pre- and post-logging guidelines as it is costly and therefore brings less benefits. Monitoring and supervising by local authorities must be strictly carried out and penalties should be applied to ones not fully following logging guidelines.

Logging natural forests is a key for sustaining the livelihoods of local people in many tropical areas (Luciana et al. 2012). If logging is not permitted, illegal logging will occur. For example, the area of illegally logged forests in Vietnam increased from 3061 ha in 2004 to 6199 ha in 2006 (Pham et al. 2012). In many tropical areas, natural forests are privately owned or communally owned on a small scale. These communally owned forests areas are mainly logged for house construction in the surrounding communities by Xơ Đăng, Ê Đê, Ba Na, Gia Rai ethnic groups and partly for timber trading. These communities have a long history of logging sustainably by cutting a limited number of trees in a rotation of several years (e.g. a newly established family is allowed to cut ten trees of less than 7 m^3 timber in a duration of 5–10 years and positions of cut trees are identified by communities), which prevents impacts on water supply downstream and provides local control. Such traditional knowledge should be expanded, and logging rights should be granted to small-scale private and communally owned forests, not only in Vietnam but also in other tropical areas (Sikor and To 2011). Sustainable forest management and biodiversity conservation toward the REDD+ agreement appear to be better achieved in communal, private, and/or small-scale forest managements because longtime owners try to manage their forests as sustainably as possible for future generations (Luciana et al. 2012), whereas large-scale forestry operations are owned by for-profit forest enterprises that may not prioritize sustainable management or biodiversity conservation.

In conclusion, reduced-impact logging natural forests for commercial timber species should be allowed as a foundation for sustainable management and to promote local communities. Allocating forests to households and communities on a small scale (several hectares, where it is applicable) will result in better sustainable forest management. A well-planned reduced-impact logging system should be employed, which includes both pre- and post-logging guidelines to reduce impacts on remaining forests and promote regrowth of commercially valuable trees. Logging natural production forests should be considered as a mean to sustainable lives of local people. However, monitoring and supervising on logging guidelines must be strictly carried out by local authorities. Only these can forests be managed sustainably to respect the REDD+ agreements with regard to protecting biodiversity and reducing carbon emissions.

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