POST-LOGGING REGENERATION AND GROWTH OF COMMERCIALLY VALUABLE TREE SPECIES IN EVERGREEN BROADLEAF FOREST, VIETNAM

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DO TV, CAM NV, SATO T, BINH NT, KOZAN O, THANG NT & MITLÖHNER R. 2016. Post-logging regeneration and growth of commercially valuable tree species in evergreen broadleaf forest, Vietnam. The regeneration and growth of commercially valuable tree species after selective logging are important for sustainable management of forest. This study compared density of seedlings (height < 2 m), saplings (height ≥ 2 m and diameter at breast height (dbh) < 10 cm) and trees (dbh ≥ 10 cm) of 18 commercially valuable tree species in Vietnam after 30 years of selective logging. Data were collected in high impact (where 30 to less than 50% standing volume was extracted), low impact (less than 30% standing volume was extracted) and unlogged forests. Results indicated that tree density in high impact forest was significantly higher than that in low impact and unlogged forests. Basal areas in high and low impact forests were significantly lower than that in unlogged forest. Density of ≥ 5 cm dbh saplings in high impact forest was significantly higher than that in low impact and unlogged forests. Seedling density in high impact forest was highest between the three forest stands. We concluded that a duration of 30 years was insufficient for logged forests to recover to the status of unlogged forest, regardless of logging intensities.

Keywords: Basal area, logging intensity, sapling, seedling, recover

INTRODUCTION

Selective logging is the most popular and widely employed approach for commercial timber production in natural forests of South-East Asia (Okuda et al. 2003). Using machines, logging considerably affects forest structure and tree species composition (Chen & Wang 2006). Selective logging promotes the remaining forest to regenerate naturally (Bawa & Seidler 1998). Natural regeneration has concerned forest managers and ecologists (Felton et al. 2006). There are evidences that selective logging can damage remaining trees, compact soils and alter habitats for natural regeneration of tree species (Uhl & Guimaraes-Vieira 1989, Slik et al. 2002, Win et al. 2012). Sustainable management of selectively logged forests requires that felled trees be replaced by recruitment and growth of valuable tree species (Nabe-Nielsen et al. 2007, Zimmerman & Kormos 2012). Selective logging is sustainable only when tree removal is balanced by increases in recruitment and growth (Zimmerman & Kormos 2012) or tree regeneration (Schwartz & Caro 2003). Therefore, sustainable logging should aim at improving regeneration of concerned species (Fredericksen & Mostacedo 2000, Win et al. 2012).

A number of studies have dealt with natural regeneration of tree species after selective logging (Pinard 1996, Slik et al. 2002, Howlett & Davidson 2003, Berry et al. 2008, Win et al. 2012). There was significant rise in seedling and sapling densities after selective logging in Bolivian forest (Fredericksen & Mostacedo 2000), Kabung reserved forest in Myanmar (Win et al. 2012) and Sabah forest, Malaysia (Howlett & Davidson 2003). Eight years after selective logging in Bornean forest, Malaysia, species richness of the forest was significantly lower than before logging (Cannon et al. 1998). On the contrary, species richness of a selectively-logged Brazilian forest was higher than before logging (Magnusson et al. 1999). No significant effect of selective logging was found on the diversity of tree species in Sabah forest, Malaysia (Berry et al. 2008). However, species composition in Sabah forest was different between logged and unlogged forests as the former had more small dipterocarps and large pioneers (Berry 2008). More large dipterocarps were found in unlogged forest. Floristic composition of forests in India takes about 20 years to recover to the status of unlogged forest (Pelissier et al. 1998). It took 50 years for selectively-logged forest in the Philippines to recover to the status of unlogged forest (Luna et al. 1999), while a lowland dipterocarp forest in East Kalimantan, Indonesia required 15 years (Slik et al. 2002). However, such studies have never been reported for evergreen broadleaf forest in Vietnam, especially for commercially valuable tree species, whose timber are widely used locally and exported.

The objective of the present study was to describe and analyse the changes in stem density and basal area of selective logged-forests after 30 years treatment with special reference to 18 commercially valuable tree species. We hypothesised that the most abundant density of commercially valuable tree species occurred on sites that experienced higher intensity of selective logging, while basal area was higher in unlogged forest.

MATERIALS AND METHODS

Study site description

This study was conducted at Kon Ha Nung experimental forest (KEF) (14° 30' N–108° 44' E), belonging to the Vietnamese Academy of Forest Sciences. KEF has a total area of 1400 ha which are covered by evergreen broadleaf forests. In the core zone of KEF, there is an area of around 100 ha which has been well preserved and is considered as old-growth forest (Dong 2005). The difference in elevation in KEF is less than 20 m, leading to homogeneous topographical conditions in soil moisture, depth and fertility at the research site (Dong 2005).

Climate data from 1990–2010 indicates that the study site has annual temperature of 23.6 °C with minimum and maximum temperatures of 13.6 and 29.6 °C in January and June respectively (Huong 2011). Rainy season starts from April till November and dry season from December till March. Annual precipitation is 2042 mm, with lowest monthly precipitation of 23 mm in February and highest in October, at 318 mm. There is about 130 rainy days per year. Mean monthly air humidity is 82% and lowest value of 75% occurs in July. There are 2462 sunny hours per year. Rhodic ferralsols are the dominant soil type at the study site, which were developed on neutral to alkaline Magma parent rocks with deep soil layer and high humus ratio (Le 1996).

Selective logging was carried out in KEF in the 1980s (Soa 1999). The natural forests, which had standing volume > 130 m^3 ha^{-1}, were selectively logged with two intensities, namely, < 30% standing volume extracted (low impact forest) and 30–50% standing volume extracted (high impact forest). Unlogged forest was treated as control. Minimum diameter at breast height (dbh) for felling was ≥ 45 cm and cutting was controlled and carried out along or across skid tracks for the advantage of transportation and minimising disturbance on remaining stems and forest floor. The loggers engaged bulldozers for construction of roads, skid tracks and timber landings as well as transporting timber out of the site by winch system. A total of 18 commercially valuable tree species was logged (Appendix). After logging, no further treatments such as climber-cutting, poison girdling of non-commercially valuable tree species and removing branches of logged stems were carried out.

Data collection

In each of the forest stand (high impact, low impact and unlogged forests), two permanent sampling plots (100 m × 100 m) were established. Data were collected in 2012, 30 years after conducting selective logging. Each of the permanent sampling plot was further divided into 25 plots (20 m × 20 m), which were used for tree (dbh ≥ 10 cm) census. In the center of a 1-ha plot, a circle plot of 15-m radius (707 m^2; Figure 1) was established for sapling (dbh < 10 cm and height ≥ 2 m) census. For seedling census, 12 square plots of 2 m × 2 m each were further established inside the circle plot. All trees, saplings and seedlings were identified to species level, measured for dbh and recorded separately.

Data analysis

Two data series were considered, namely, pool of all species and commercially valuable tree species found in the study plots. Commercially valuable tree species are species widely used by local people for housing (Le 1996, Soa 1999). Of the total 201 tree species found at the study site, 18 are considered as commercially valuable tree species (Appendix). Tree densities and basal areas of all stems (dbh ≥ 10 cm) and of large stems (dbh ≥ 45 cm) were calculated as means and their standard errors determined for 400 m^2 plots. Sapling densities of height (< 4, ≥ 4–< 8 and ≥ 8 m) and dbh classes (< 5 and ≥ 5 cm) were calculated for 707 m^2 plots. Seedling densities were calculated for two height classes (< 1 and ≥1–< 2 m) based on 4 m^2 plots. Means of stem density and basal area between the three forest stands were compared using ANOVA analysis and Tukey's post hoc test at p = 0.05. All data analyses were conducted using SAS 9.2.

RESULTS

Tree stratum

A total of 144 tree species belonging to 46 families was found in six 1-ha plots in this study. Of these, 93 were found in high impact forest, 102 in low impact forest and 98 in unlogged forest. The number of commercially valuable tree species was 15, 14, and 17 respectively (Appendix). Density and basal area of dbh ≥ 10 cm stems for all species were significantly different between the three forest stands (Table 1). However, density of stems with dbh ≥ 45 cm was not significantly different, but basal area in unlogged forest was significantly higher than that in high and low impact forests (Table 1). Similarly, for the 18 commercially valuable tree species, density of trees with dbh ≥ 45 cm was not significantly different, but density and basal area of trees with dbh ≥ 10 and ≥ 45 cm were significantly different (Table 1). The exponential shape obtained for dbh frequency distribution of trees for all species (Figure 2a) and that of the 18 commercially valuable tree species (Figure 2b) in the three forest stands suggested that number of stems decreased gradually towards larger diameter classes.

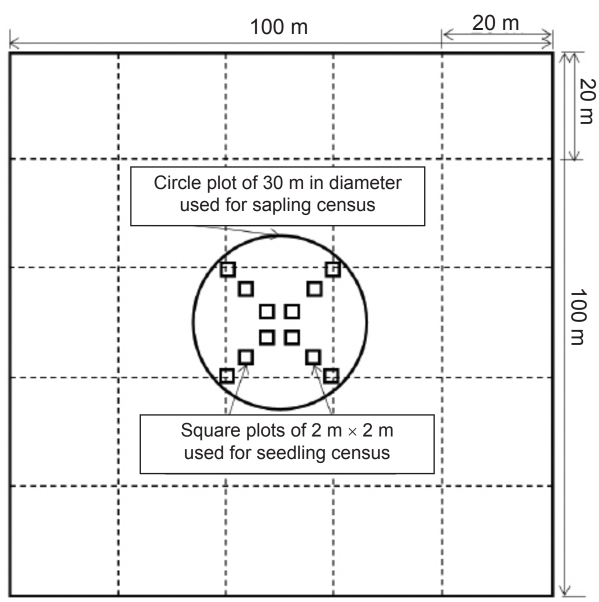

Figure 1 Plot design for stem census

Table 1 Tree density and basal area in three forest stands

Forest stand	Stem density (stems 400 m^{-2})				Basal area (m^2 400 m^{-2})			
	All species		Commercially valuable tree species		All species		Commercially valuable tree species	
	Dbh ≥ 10 cm	Dbh ≥ 45 cm	Dbh ≥ 10 cm	Dbh ≥ 45 cm	Dbh ≥ 10 cm	Dbh ≥ 45 cm	Dbh ≥ 10 cm	Dbh ≥ 45 cm
HIF	19.3 ± 0.7 a	2.2 ± 0.2	8.1 ± 0.4 a	1.2 ± 0.2	1.4 ± 0.08 a	0.7 ± 0.07 a	0.7 ± 0.06a	0.6 ± 0.13 ab
LIF	25.1 ± 0.8 b	2.6 ± 0.2	6.8 ± 0.4 b	1.1 ± 0.2	1.6 ± 0.08 b	0.8 ± 0.08 a	0.6 ± 0.05 a	0.4 ± 0.07 a
UF	22.5 ± 0.7 c	2.8 ± 0.2	6.1 ± 0.4 b	1.4 ± 0.2	1.9 ± 0.10 c	1.2 ± 0.11 b	1.0 ± 0.10 b	0.8 ± 0.10 b

All values of $F_{(2, 147)} > 4.0$, $p < 0.05$, different letters within the same column indicate significant difference between forest stands by Tukey's post hoc test at p = 0.5; HIF = high impact forest, LIF = low impact forest, UF = unlogged forest, dbh = diameter at breast height

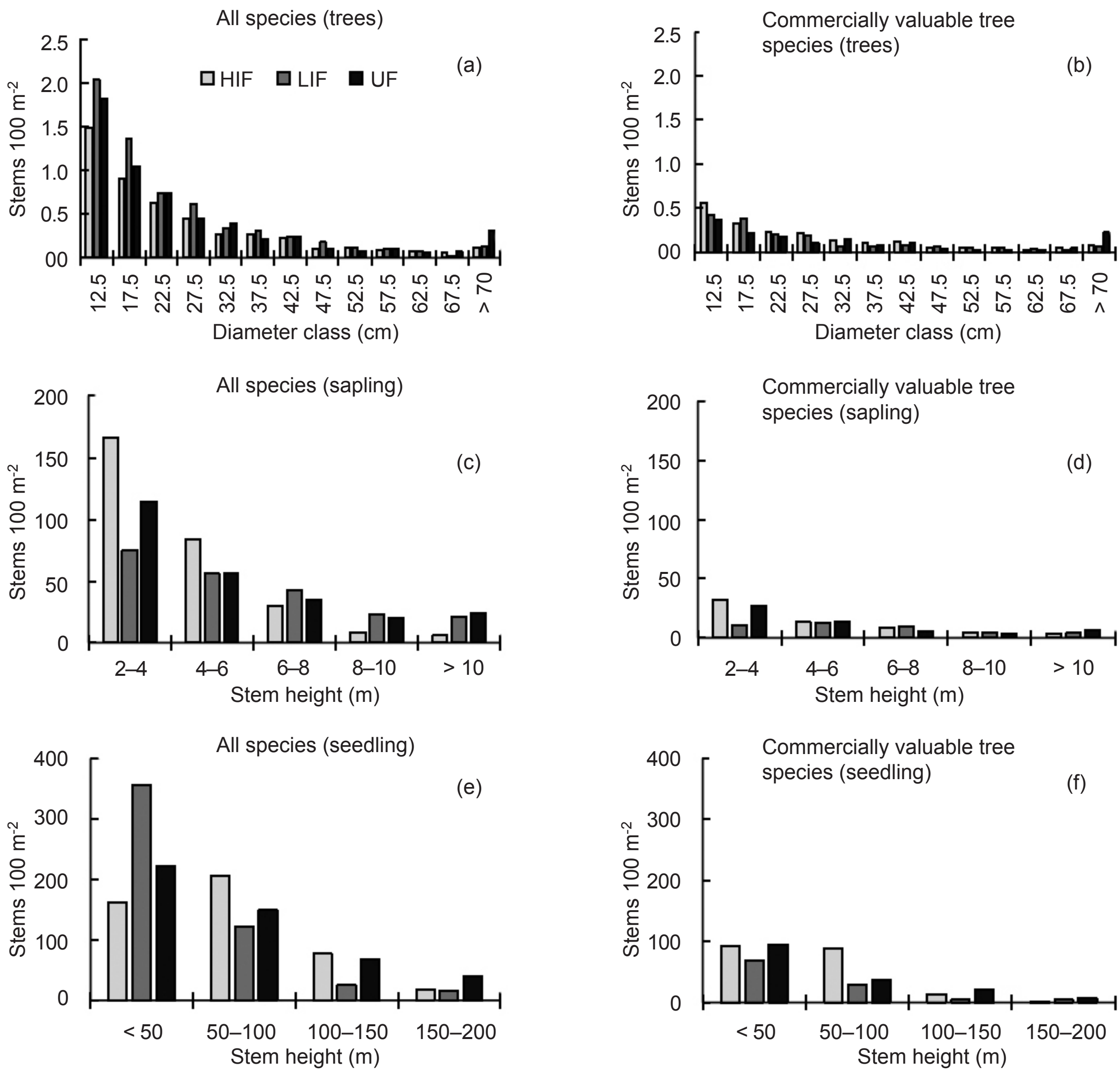

Figure 2 Distribution of stems for all species and 18 commercially valuable tree species; HIF = high impact forest, LIF = low impact forest, UF = unlogged forest

Sapling stratum

A total of 107 tree species belonging to 37 families was recorded in the sapling stratum of which, 55 appeared in high impact forest, 73 in low impact forest and 77 in unlogged forest. The number of commercially valuable tree species was 10, 8 and 11 in the respective forests (Appendix). Sapling density of all species was significantly different between the three forest stands regardless of height classes (Table 2), but it was highest in the high impact forest (34.1 stems 100 m^{-2}). For the 18 commercially valuable tree species, density of saplings < 4 m high was significantly different between the three forest stands and was highest in the high impact forest (3.4 stems 100 m^{-2}). However, densities in the other two forest classes were not significantly different for height ≥ 4 m (Table 2). Density of saplings with dbh < 5 cm was significantly higher in high impact forest (5 stems 100 m^{-2}) compared with low impact forest (3.3 stems 100 m^{-2}) but not significantly different with unlogged forest (5.2 stems 100 m^{-2}). Sapling density species with dbh ≥ 5 cm in high impact forest (1.6 stems 100 m^{-2}) was significantly higher than that in low impact (1.2 stems 100 m^{-2}) and unlogged (1 stems 100 m^{-2}) forests.

Saplings were most abundant in height class of 2–4 m, decreasing gradually towards taller height classes (Figure 2c). Density of the commercial tree species was also highest in this class, i.e. 2–4 m (Figure 2d). Sapling density of the 18 commercially valuable tree species in height classes of 4–6, 6–8 and 8–10 m was not significantly different between the three forest stands (Figure 2d, Table 2). Sapling density of saplings in height class > 10 m increased gradually from high impact forest to low impact forest and to unlogged forest (Figure 2d).

Seedling stratum

A total of 90 tree species was recorded in the seedling stratum. Of this, 54 species were found in high impact forest, 66 in low impact forest and 56 in unlogged forest. The number of commercially valuable tree species was 13, 13 and 12 respectively (Appendix). Seedling density of all species was not significantly different between the three forest stands but that of the 18 commercially valuable tree species was significantly different (Table 3). The highest seedling density was found in high impact forest (202 stems 100 m^{-2}), followed by unlogged (160 stems 100 m^{-2}) and low impact (108 stems 100 m^{-2}) forests. Density of seedlings of 18 commercially valuable tree species with stem height between 1 and 2 m was not significantly different compared with high (15 stems 100 m^{-2}) and low impact (10 stems 100 m^{-2}) forests, but it was significantly lower than that in unlogged forest (33 stems 100 m^{-2}). In all three forest stands, seedlings were most abundant in height class < 0.5 m and then reduced gradually in higher height classes (Figure 2e and f).

Ecological guild

Of the 18 commercially valuable tree species, 14 were shade intolerant species, 1 was shade tolerant and 3 were pioneer species (Table 4, Appendix). The ratios of seedlings to tree were higher than ratios of saplings to tree in all ecological guilds and forest stands (Table 4). In the high impact forest, pioneer species had the highest ratios for seedlings (294 stems $tree^{-1}$) and saplings (59 stems $tree^{-1}$), followed by shade-intolerant (68 and 25 respectively) and shade-tolerant (30 seedlings $tree^{-1}$) species. In the low impact forest, ratios of seedlings (82 stems $tree^{-1}$) and saplings (30 stems $tree^{-1}$) were highest for shade-intolerant species followed by pioneer (77 and 27 respectively) and shade-tolerant (35 and 29 respectively) species. In unlogged forest, highest seedling ratio was for shade-tolerant (365 stems $tree^{-1}$) followed by pioneer (141 stems $tree^{-1}$) and shade-intolerant (136 stems $tree^{-1}$) species. Highest sapling ratio was for pioneer species, followed by shade-intolerant and shade-tolerant species, with values of 51, 48 and 32 stems $tree^{-1}$ respectively.

DISCUSSION

A well-known characteristic of tropical forests is heterogeneity in topography which produce different edaphic conditions in soil fertility, moisture and depth (Le 1996, Pinard 1996, Soa 1999, Win et al. 2012). However, this was not observed in the present study, where the elevation difference was less than 20 m. Impacts of seed rain on natural regeneration might not

Table 2 Sapling density of different height and dbh classes in three forest stands

Forest stand	All species (stems 707 m^{-2})					Commercially valuable tree species (stems 707 m^{-2})				
	Stem height (m)			Dbh (cm)		Stem height (m)			Dbh (cm)	
	< 4	4–8	≥ 8	< 5	≥ 5	< 4	4–8	≥ 8	< 5	≥ 5
HIF	127.0 ± 7.0 a	87.5 ± 2.5 a	11.0 ± 1.0 a	241 ± 56.0 a	34.5 ± 1.5 a	24.0 ± 0.0 ac	16.5 ± 1.5	6.0 ± 1.0	35.0 ± 2.0 ac	11.5 ± 0.5 a
LIF	57.5 ± 2.5 b	76.0 ± 6.0 bc	33.5 ± 0.5 bc	122.5 ± 7.5 bc	44.5 ± 1.5 bc	8.5 ± 1.5 b	16.5 ± 1.5	6.5 ± 0.5	23.0 ± 2.0 b	8.5 ± 0.5 bc
UF	89.0 ± 1.0 c	70.5 ± 4.5 bc	34.0 ± 4.0 bc	154.5 ± 17.5 bc	39.0 ± 7.0 bc	21.5 ± 2.5 ac	14.5 ± 1.5	7.5 ± 0.5	36.5 ± 9.5 ac	7.0 ± 0.1 bc

$F_{(2, 6)} > 9.6$, $p < 0.05$, different letters within the same column indicate significant difference between forest stands by Tukey's post hoc test at $p = 0.5$; HIF = high impact forest, LIF = low impact forest, UF = unlogged forest, dbh = diameter at breast height

Table 3 Seedling density of different height classes in three forest stands

Forest stand	All species (stems 4 m^{-2})		Commercially valuable tree species (stems 4 m^{-2})	
	H < 1 m	2 m > H ≥ 1 m	H < 1 m	2 m > H ≥ 1 m
HIF	19.1 ± 1.95	4.0 ± 0.82 ac	8.1 ± 1.79 a	0.6 ± 0.22 ab
LIF	21.1 ± 2.09	1.6 ± 0.29 b	4.3 ± 0.53 b	0.4 ± 0.13 ab
UF	19.6 ± 1.39	4.3 ± 0.67 ac	6.4 ± 1.28 c	1.3 ± 0.30 c

$F_{(2, 69)} > 3.7$, $p < 0.03$, different letters within the same column indicate significant difference between forest stands by Tukey's post hoc test at $p = 0.5$; HIF = high impact forest, LIF = low impact forest, UF = unlogged forest, H = stem height

Table 4 Ratio of saplings and seedlings to trees (stems tree^{-1}) in three different ecological guilds for 18 commercially valuable tree species

Ecological guild	Species number	HIF		LIF		UF	
		Sapling	Seedling	Sapling	Seedling	Sapling	Seedling
Shade-intolerant	14	25	68	30	82	48	136
Shade-tolerant	1	-	30	29	35	32	365
Pioneer	3	59	294	27	77	51	141

HIF = high impact forest, LIF = low impact forest, UF = unlogged forest

be present in the current study because of high density of commercially valuable tree species with dbh ≥ 45 cm of (Table 1), which are known as mother trees (Tran et al. 2011, Cam 2015). Nutrient availability in natural forest has no significant impact on seed germination and seedling growth (Soa 1999, Howlett & Davidson 2003). Therefore, impacts on regeneration and growth of seedlings and saplings of the 18 commercially valuable tree species in the present study site may come mainly from intensities of selective logging (Cam 2015, Vo et al. 2015), differences in edaphic conditions and seed rain. High intensity of logging created more gaps and more growing spaces for recruitment and growth of seedlings and saplings, leading to significantly higher density of saplings (Table 2) and seedlings (Table 3) in high impact forest compared with low impact forest (Le 1996, Soa 1999). Tree density of commercially valuable tree species in high impact forest was significantly higher than that in low impact and in unlogged forests. However, basal areas in high and low impact forests were still lower than that unlogged forest. Thus, 30 years is not enough for commercially valuable tree species to recover its basal area to that of unlogged forest in both logging intensities. This is due to the rather low diameter growth of tree species in natural forest (Le 1996, Tran et al. 2010, 2011). There was no significant difference in basal area of commercially valuable tree species between high and low impact forests. This indicated that more trees were recruited in high impact forest (Table 1) after selective logging which extracted 30 to less than 50% standing volume. In the low impact forest, less than 30% standing volume was extracted, resulting in less growing space.

Distribution of diameter frequency of trees in the three forest stands followed a general exponential shape in natural forests (Le 1996, Tran et al. 2010). However, densities of trees with dbh > 70 cm in high and low impact forests were much lower than that in unlogged forest (Figure 2b) as a result of extracting large stems of commercially valuable tree species in the past. Generally, dbh of stems in high impact forest was higher than that in low impact forest (Figure 2b) especially for classes of < 45 cm, indicating that logging intensities did not have significant impact on stem density after 30 years. Meanwhile, lower density of saplings (height < 4 m) of commercially valuable tree species in low impact forest compared with that in high impact and unlogged forests (Figure 2d) was due to competition of short vegetation layer which obstructed growth of small seedlings (Soa 1999, Marod et al. 2002).

Logging techniques applied in the present study site might have significant impact on generation and growth of seedlings and saplings. Bulldozer was used for construction of roads, skid tracks and log landings, and winch transported timber out of the site. However, manual labour was dominant which resulted in less detrimental impact on the forest floor (Soa 1999). No further silvicultural treatments such as climber-cutting, poison girdling of non-commercially valuable tree species or removal of branches of logged stems were applied after logging. Termites decomposing remaining materials on forest floor usually attack and obstruct regeneration and growth of seedlings, saplings and tree stems (Dalling & Hubbell 2002, Dupuy & Chazdon 2008).

Ratios of seedlings and saplings to trees in high impact forest were highest for pioneer species (Table 4). This showed that more and sufficient sunlight reached the forest floor in high impact forest 30 years after selective logging compared with low impact and unlogged forests. Reduced amount of light reaching the forest floor is the main reason for mortality and low seedling recruitment in less disturbed forest in the tropics (Whitmore 1983). Ratios of shade-intolerant and pioneer species to trees in both low impact and unlogged forests were similar due to less open canopy of these two stands. However, ratio of seedlings to trees for shade-tolerant species in unlogged forest was much higher than that in high and low impact forests (Table 4), indicating that unlogged forest had the highest canopy closure which favoured germination and growth of seedlings/saplings of shade-tolerant species (Ackerly 1996).

In summary, recruitment of commercially valuable tree species is important for sustainable management of natural forest for timber production. In Vietnam, most commercially valuable tree species for timber production are shade intolerant. High intensity of selective logging promotes seed germination and growth of seedlings and saplings of pioneer and shade-intolerant species but not shade-tolerant species. However, in the present study only one commercially valuable tree species was considered shade tolerant. Therefore, selective logging generally promoted recruitment of 17 pioneer and shade-intolerant commercially valuable tree species. Thirty years after selective logging, densities of trees, saplings and seedlings of commercially valuable tree species were higher in high impact forest compared with that in low impact and unlogged forests. However, its basal area was lower. Therefore, further data collection is required to determine how long the selectively logged forests can recover its basal area to that of unlogged forest. Suitable guidelines for sustainable selective logging system should be recommended for natural evergreen broadleaf forests in the Central Highland, which has the highest timber production in Vietnam.

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Appendix Trees, saplings, and seedlings of 18 commercially valuable tree species

Species	Ecological guild*	Dispersal mode*	HIF				LIF				UF			
			Tree (stems 2 ha^{-1})		Sapling (stems 1414 m^{-2})	Seedling (stems 96 m^{-2})	Tree (stems 2 ha^{-1})		Sapling (stems 1414 m^{-2})	Seedling (stems 96 m^{-2})	Tree (stems 2 ha^{-1})		Sapling (stems 1414 m^{-2})	Seedling (stems 96 m^{-2})
			Dbh < 45 cm	Dbh ≥ 45 cm			Dbh < 45 cm	Dbh ≥ 45 cm			Dbh < 45 cm	Dbh ≥ 45 cm		
Aglaia gigantea	SI	A, SF	12	3	10	7					1			2
Aglaia silvestris	SI	A, SF	44	8	13	55	28	1	13	11	19	1	9	2
Artocarpus parva	SI	A, SF	7				17		3	1	8		1	
Canarium subulatum	SI	A, SF	4	4	1	1		1	3		1	1		
Canarium tonkinensis	SI	A, SF	4				7	1	1		4	3		
Castanopsis poilanei	SI	A	29	4			26	8	1	7	12		1	4
Dacryodes dungii	SI	A, SF				4	17	6	13	9	10	18	24	61
Michelia mediocris	SI	A, SF	30	5	3						1	1		
Dialium cochinchinensis	SI	A, SF	29	5	8	7	13	3	3	10	13	20	9	10
Paramichelia braianensis	SI	A, SF	21	14	5	2	29	13	2	7	24	21	2	10
Podocarpus imbricatus	SI	A						1	2	1		4	3	
Pometia lecomtei	SI	A	81	1	5	3	33		2	5	39		4	6
Ormosia balansae	SI	A, SF	18	3		5	9	6		5	22		3	9
Ormosia hoaensis	SI	A, SF			11	1							6	
Cinnamomum obtusifolium	ST	A	7	2		1	18	2	4	3	4		1	7
Machilus odoratissima	P	A	33	7	14	1	50	5	15	20	29	1	21	5
Pasania ducampii	P	A	13	3		10	10	6		18	17	2	1	8
Nephelium bacsasense	P	A, SF	35	3	17	95	26	2	1	8	30	5	2	35
Number of stems of commercially valuable tree species	367	62	87	192	284	56	61	105	238	76	84	159		
Number of stems of all species	849	113	454	458	1,127	130	336	507	981	144	384	469		
Number of commercially valuable tree species	15	10	13	14	8	13	17	11	12					
Number of total species	93	55	54	102	73	66	98	77	56					

*From Tran (2002), Le and Le (2000) and field observation; SI = shade-intolerant, ST = shade-tolerant, P = pioneer, A = animal, SF = self-falling; all cells without number indicate no stems found; HIF = high impact forest, LIF = low impact forest, UF = unlogged forest