Short communication

Stand Dynamics of Tropical Seasonal Evergreen Forest in Central Cambodia

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ABSTRACT

Information on tree and stand growth is essential to ensure sustained timber yield in tropical natural forests, but very little is known about stand dynamics of tropical seasonal forests, especially in the mainland Southeast Asia. Stand dynamics of seasonal evergreen forest in central Cambodia were estimated from 20 sample plots measured in 1998 and 2003. Data for all trees with diameter at breast height (DBH) ≥ 10 cm and for commercial species DBH ≥ 10 cm or DBH $\geq$ minimum diameter cutting limit (MDCL) were evaluated. In 1998, 67 species, of which 19 were commercial trees with DBH $\geq$ MDCL, were found at tree densities of 544.5 and 23.4 trees/ha, basal areas of 23.8 and 6.3m²/ha, and stem volumes of 192.9 and 64.3m³/ha. The mean diameter increment between 1998 and 2003 was 0.33 for all species and 0.32cm for commercial species; mean mortality rates were 2.4% and 0.5%, mean recruitment rates were 2.5% and 1.4% and volume increments were 1.09 and 0.86m³/ha. These values are similar to those reported from tropical rain forests in Amazon and Southeast Asia. Estimated volume increment (0.86m³/ha/year) for commercial trees with DBH $\geq$ MDCL was significantly larger than the figure (0.33m³/ha/year) previously used in Cambodian management systems.

Keywords: tropical seasonal forests, volume increment, recruitment, mortality, commercial species

INTRODUCTION

There is increasing concern about the effect of selective logging in tropical natural forests on sustainability, the global carbon budget (e.g., MALHI and GRACE, 2000) and biodiversity conservation (e.g., MYERS *et al.*, 2000). Information on tree and stand dynamics is required to evaluate silvicultural options for sustainable timber yield. Cutting cycles and minimum diameter cutting limits are often based on diameter increment and/or volume increment of commercial species (e.g., SILVA *et al.*, 1995; SIST *et al.*, 2003; SIST and FERREIRA, 2007).

Although there are data for some tropical rain forests, especially in Brazilian Amazonia (e.g., SILVA *et al.*, 1995; van GARDINGEN *et al.*, 2006; VALLE *et al.*, 2006) and in Borneo (e.g., SIST and NGUYEN- THE, 2002; PHILLIPS *et al.*, 2002; KAMMESHEIDT

et al., 2003), very little is known about the stand dynamics of tropical seasonal forests in mainland Southeast Asia, such as those in Cambodia, where strong seasonality of precipitation is found (KUMAGAI *et al.*, 2005 and KUMAGAI *et al.*, 2009).

About 59% of Cambodia is covered by forest. There are three dominant forest types, evergreen (22.2%), deciduous (25.8%) and semi-evergreen forest (7.5%) (FA, 2007), in two classes, production forest (34% of total land area) and protection forest (25%). A selective logging system with a 25- to 30-year cutting cycle has been adopted in evergreen and semi-evergreen forests (KIMPHAT *et al.*, 1999) and the annual allowable cut has been calculated using an assumed volume increment of 0.33m³/ha/year (DFW, 2001). This value was derived from the average of virgin forest studies reported by the FAO in 1962 (DFW, 2001) and is considered to be too low (DFW, 2001). However there are no data to verify the volume

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increment value.

The present study was designed to measure stand dynamics of seasonal evergreen forest in Kampong Thom Province, central Cambodia using two consecutive measurements of 20 permanent sample plots (PSPs) in 1998 and 2003. The main questions are: 1) whether tree growth, mortality and recruitment in Cambodian forests differ from tropical rain forests elsewhere, especially in Amazon and Southeast Asia; and 2) whether volume increment is significantly higher than $0.33\text{m}^3/\text{ha}/\text{year}$.

MATERIALS AND METHODS

Study Site and Data Collection

Kampong Thom Province in central Cambodia lies

Fig.1 Location of 20 permanent sample plots (PSPs) distributed in 5 different places, each of which includes 4 plots

The sequence plot number of each location is shown; e.g., PSP25-28 indicates the plot number 25, 26, 27 and 28.

Source: Forestry and Wildlife Research Institute, Forestry Administration, Cambodia

between $12^{\circ}11'$ and $13^{\circ}26'$ north and $104^{\circ}12'$ and $105^{\circ}44'$ east. The total area is 1,244,763ha, about 7% of the country (FA, 2007). The climate is tropical monsoon; the rainy season extends from May to October and the dry season from November to April. Between 1996 and 2000, the mean annual rainfall and temperature were 1,700mm and 28°C (TOP *et al.*, 2009).

Twenty PSPs were located in dense evergreen forests on flat terrain 9-100m above sea level (Fig. 1). Although these PSPs in this evergreen forest have not been heavily disturbed, they have been subject to some illegal extractions of fuelwood and timber (TOP *et al.*, 2009). The plots were established in April 1998 and the trees measured in 1998 and December 2003. Each main plot was $50 \times 50\text{m}$ and contained a $20 \times 20\text{m}$ sub-plot. All trees with diameter at breast height (DBH) of 7.5-29.9cm in the sub-plot and $\geq 30\text{cm}$ in the main plot were measured and recorded. In 2003, new trees in each of the main plot and sub-plot with $\text{DBH} \geq 30\text{cm}$ and $\geq 7.5\text{cm}$ were also measured. Missing or dead trees were recorded as natural death or human disturbance (illegal logging).

Data Analysis

As with selective logging systems in other tropical countries, only commercial species with DBH more than the predetermined Minimum Diameter Cutting Limit (MDCL) may be harvested. A Cambodian Government decree (RGC, 2005) sets different MDCLs for each commercial species ranging from 30 to 60cm. The stand-level attributes (stand structure in 1998 and 2003, mortality, recruitment, illegal cut and volume increment) for the two sampling years were examined separately for all trees with $\text{DBH} \geq 10\text{cm}$ and all commercial trees with $\text{DBH} \geq \text{MDCL}$. The annual rates of mortality, recruitment and illegal cut were estimated by using the widely used logarithmic equation (e.g. LEWIS *et al.*, 2004 a):

$$Y = 100 * \{ \ln N_i - \ln (N_i - X) \} / t,$$

where Y is the rate of mortality, recruitment or illegal cut, N_i is the number of trees measured in 1998, X the number of mortality, recruitment or illegal cut, and t the time (5.75 years = December 2003 – April 1998). Diameter increments of individual trees were examined for all trees and commercial trees with $\text{DBH} \geq 10\text{cm}$. Although the minimum DBH of field measurements was 7.5cm, a DBH of 10cm was selected to be consistent with other studies (VALLE *et al.*, 2006; SILVA *et al.*, 1995; RICE *et al.*, 1998). Two outliers with unrealistically large annual diameter increments (10.3 and 10.4cm/year) were excluded from the analysis. These unrealistic values may have been due to misidentification of the trees to be measured or mistakes in data recording.

Volume increment is defined as the net annual production of the forest from growth, mortality and recruitment (VALLE *et al.*, 2006). In the present study, we calculated volume increment for all trees with $\text{DBH} \geq 10\text{cm}$ and commercial trees

with $DBH \geq MDCL$, defined by:

$$I = (V_2 - V_1 + C) / (t_2 - t_1)$$

where I is the volume increment ($m^3/ha/year$), V_2 the volume at measurement in 2003 (m^3/ha), V_1 the volume at measurement in 1998 (m^3/ha), C the volume of illegally logged trees (m^3/ha) and $t_2 - t_1$ the time (in years) between the 2003 and 1998 measurements. In this formula, volume gains from the growth of existing stems and recruitment into the size class of interest ($\geq 10cm$ or $\geq MDCL$), as well as losses due to mortality, are condensed into one increment value for the entire observation period (VALLE *et al.*, 2006), while excluding illegally logged trees from the calculation. Volume (m^3) of individual trees was estimated as a function of DBH (cm) developed for different DBH classes and species groups (Table 1, FA, 2003).

RESULTS AND DISCUSSION

Stand Structure

For all trees with $DBH \geq 10cm$ in 1998, 67 species were found across all of 20 0.25-ha sized plots (a total of 5ha), and the mean values ($\pm SD$; standard deviation) of the 20 plots were 544.5 ± 106.3 trees/ha of tree density, $23.8 \pm 5.1m^2/ha$ of basal area and $192.9 \pm 46.4m^3/ha$ of stem volume (Table 2). For commercial trees with $DBH \geq MDCL$ in 1998, 19 species were found across all the plots, resulting in 23.4 ± 9.7 trees/ha of tree density, $6.3 \pm 3.4m^2/ha$ of basal area, and $64.3 \pm 36.9m^3/ha$ of stem volume. There was no significant difference ($P > 0.05$, the two-tailed paired t-test) in the mean values of

stand structure between 1998 and 2003 (Table 2).

There were fewer species and a lower stocking rate (basal area/ha) in this seasonal forest than in other primary tropical rain forests, despite the similar tree density recorded in the present study. About 200 species/ha are reported from primary lowland dipterocarp forests in Borneo (SIST and SARIDAN, 1999) and Amazonian rain forests (PHILLIPS and GENTRY, 1994; BREWER and WEBB, 2002) compared with 67 in 5ha in the present study. Similarly, the mean basal area ($23.8m^2/ha$) in this study is lower than reports from primary tropical rain forests; $31.5 \pm 4.2m^2/ha$ in East Kalimantan (SIST and NGUYEN-THÉ, 2002), 35.5 ± 2.8 ($\pm SE$; Standard Error) m^2/ha for 11 locations in Borneo and Peninsular Malaysia, 34.4 ± 1.4 ($\pm SE$) m^2/ha for 15 plots in Central Kalimantan (van GARDINGEN *et al.*, 2003) and 28.1 ± 12.0 (95% CI; Confidence Intervals) m^2/ha in Amazonia (LEWIS *et al.*, 2004), while being closer to values reported for logged-over forests; $25.2m^2/ha$ in East Kalimantan (van GARDINGEN *et al.*, 2003), $26.0 \pm 6.4m^2/ha$ and $24.1 \pm 7.1m^2/ha$ in Sarawak, Malaysia (KAMMESHEIDT *et al.*, 2003), 20.3 and $25.9m^2/ha$ in Brazilian Amazon (SILVA *et al.*, 1995).

On the other hand, tree densities of all trees with $DBH \geq 10cm$ in this study were similar to values documented for primary lowland dipterocarp forests elsewhere in Southeast Asia; 521 ± 36 ($\pm SE$) trees/ha in Borneo and Peninsular Malaysia, and 583 ± 19 ($\pm SE$) trees/ha in Central Kalimantan (van GARDINGEN *et al.*, 2003), 531 trees/ha in East Kalimantan (SIST and NGUYEN-THÉ, 2002), as well as to 581 ± 16 ($\pm 95\%CI$) trees/ha obtained from 50 plots distributed over rain forests in South America (LEWIS *et al.*, 2004).

Table 1 Volume equations by species group, DBH range and forest type (FA, 2003)

Tree Species Group	Diameter class	Evergreen forest
Dipterocarp	Below 15cm	Volume = $0.022 + 3.4 DBH^2$
	Above 15cm	Volume = $-0.0971 + 9.503 DBH^2$
Non-dipterocarp	Below 30cm	Volume = $0.03 + 2.8 DBH^2$
	Above 30cm	Volume = $-0.331 + 6.694 DBH^2$

DBH, diameter at breast height.

Table 2 Stand structure in 1998 and 2003

Year	Group	Number of species	Density (trees/ha)		Basal Area (m^2/ha)		Volume (m^3/ha)		
			Mean $\pm$ SD ^a	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	
1998	All trees $\geq 10cm$	67	544.5 ± 106.3	408.0~814.0	23.8 ± 5.1	14.6~32.8	192.9 ± 46.4	103.8~	259.1
	Commercial $\geq MDCL^b$	19	23.4 ± 9.7	8.0~44.0	6.3 ± 3.4	1.3~13.0	64.3 ± 36.9	11.1~	127.4
2003	All trees $\geq 10cm$	67	531.6 ± 147.0	185.0~793.0	23.9 ± 5.4	15.9~34.8	193.9 ± 49.1	102.1~	274.9
	Commercial $\geq MDCL$	20	24.4 ± 9.8	8.0~44.0	6.5 ± 3.6	1.4~14.2	66.3 ± 39.2	12.0~	137.9

^a SD: standard deviation

^b MDCL: Minimum diameter cutting limit

Diameter Increment

Table 3 shows the periodic annual diameter increment, which was calculated from individual trees and summarized for all trees and only commercial trees. There are not large differences in the results between all trees and commercial trees, with the total mean values ($\pm$ SD) being 0.33 ± 0.09 and 0.32 ± 0.08 cm/year, respectively. There was no significant difference between growth rates for commercial and all trees (the two-tailed t-test, Table 3). The lowest increment values were recorded from the smallest DBH classes (10-19 cm and 20-29 cm), and there was no significant correlation between DBH class and increment for classes with DBH ≥ 30 cm (Table 3).

In tropical forests, diameter increments in any class of trees may vary greatly due to environmental conditions (SILVA *et al.*, 1995), silvicultural treatments (de GRAAF *et al.*, 1999; KAMMESHEIDT *et al.*, 2003) and other reasons. Nevertheless, the mean values found in this study are similar to reported values for tropical rain forests. For example, SILVA *et al.* (1995) reported 0.3 and 0.4 cm/year for all trees and commercial species 11 years after logging and 0.2 cm/year for unlogged trees in Brazilian Amazonian rain forest. In East Kalimantan, SIST and NGUYEN-THÉ (2002) reported trees grew about 0.39 cm/year in logged dipterocarp forest and 0.22 cm/year in

unlogged control plots. DAUBER *et al.* (2005) reported a mean annual diameter increment of between 0.22 and 0.41 cm/year from PSPs in different eco-regions of Bolivia.

Recruitment, Mortality and Illegal Cut

Table 4 presented the annual density and percentage of recruitment, mortality and illegal cut for all trees ≥ 10 cm and $\geq$ MDCL. For all trees, mean annual mortality $\pm$ SD was 12.2 ± 14.6 trees/ha ($2.4 \pm 4.3\%$ of total number of trees in 1998), similar to the recruitment rate of 12.6 ± 9.3 trees/ha ($2.5 \pm 2.2\%$). On the other hand, the recruitment of commercial trees with DBH $\geq$ MDCL, 0.3 ± 0.4 trees/ha ($1.4 \pm 4.9\%$), was larger than the mortality of 0.1 ± 0.3 trees/ha ($0.5 \pm 1.3\%$). Human disturbances were 1.0 ± 1.8 trees/ha ($0.2 \pm 0.4\%$) and 0.03 ± 0.2 trees/ha ($0.1 \pm 0.9\%$) annually for all trees with DBH ≥ 10 cm and commercial trees with DBH $\geq$ MDCL, respectively, due to the collection of timber and/or non-timber forest products.

Although mortality and recruitment may vary between species and diameter class, the mean rates for the present study were very similar to or well within the range of reported values from tropical rain forests in Amazon and Southeast Asia (CLARK and CLARK, 1992; CONNELL *et al.*, 1984; KAMMESHEIDT *et al.*, 2003; SIST *et al.*, 2003; BUNYAVEJCHEWIN, 1999). PHILLIPS *et*

Table 3 Annual diameter increment (cm/year) for diameter classes

DBH class (cm)	Commercial species trees at DBH ≥ 10 cm						All species trees at DBH ≥ 10 cm					
	n	Max	Mean	Min	SD	CV%	n	Max	Mean	Min	SD	CV%
10 - 19	129	0.85	0.21	0.00	0.10	45	258	0.85	0.22	0.00	0.07	31
20 - 29	36	1.17	0.25	0.02	0.17	70	65	1.17	0.31	0.00	0.25	81
30 - 39	60	1.10	0.42	0.00	0.19	44	156	2.94	0.46	0.00	0.20	42
40 - 49	46	1.39	0.44	0.00	0.39	87	77	1.39	0.39	0.00	0.32	82
50 - 59	17	1.32	0.36	0.00	0.27	76	24	1.32	0.35	0.00	0.21	62
60 - UP	40	1.18	0.41	0.03	0.22	546	67	1.98	0.42	0.00	0.17	41
Total	328	1.39	0.32	0.00	0.08	26	647	2.94	0.33	0.00	0.09	28

n, number of observations; CV, coefficient of variation; SD, standard deviation; Max, maximum; Min, minimum

Table 4 Annual values of recruitment, mortality and illegal cut

Group	Density (trees/ha/year)		Percentage of 1998 (% of 1998)	
	Mean $\pm$ SD ^a	Range	Mean $\pm$ SD	Range
All trees ≥ 10 cm				
Recruitment	12.6 ± 9.3	0.0~30.4	2.5 ± 2.2	0.0~6.5
Mortality	12.2 ± 14.6	0.0~54.3	2.4 ± 4.3	0.0~17.2
Illegal cut	1.0 ± 1.8	0.0~5.0	0.2 ± 0.4	0.0~1.1
Commercial trees $\geq$ MDCL ^b				
Recruitment	0.3 ± 0.4	0.0~1.4	1.4 ± 4.9	0.0~19.1
Mortality	0.1 ± 0.3	0.0~1.4	0.5 ± 1.3	0.0~4.4
Illegal cut	0.03 ± 0.2	0.0~0.7	0.1 ± 0.9	0.0~3.9

^aSD: standard deviation

^bMDCL: Minimum diameter cutting limit

al. (2004) compiled data for tree mortality in mature rain forests throughout the Amazon Basin, reporting mean values ($\pm$ SE) of $2.30 \pm 0.14\%$ per year (number of sample (n)=31) for mortality and $2.33 \pm 0.13\%$ per year (n =32) for recruitment. PHILLIPS and GENTRY (1994) collected data from mature South East Asian rain forests, reporting mean values ($\pm$ SD) of $1.72 \pm 0.70\%$ per year (n =9) for mortality and $1.75 \pm 0.66\%$ per year (n =9) for recruitment. SIST and NGUYEN-THÉ (2002) found that logging and yarding increase mortality in undisturbed primary at a rate of 1.5% per year.

Volume Increment

The mean ($\pm$ SD) volume increment for all trees with DBH ≥ 10 cm was $1.09 \pm 3.35\text{m}^3/\text{ha}/\text{year}$ and that for commercial trees with DBH $\geq$ MDCL was $0.86 \pm 1.33\text{m}^3/\text{ha}/\text{year}$. The value for commercial trees ($0.86\text{m}^3/\text{ha}/\text{year}$) was significantly greater ($P < 0.05$, one tailed one sample t-test) than the value ($0.33\text{m}^3/\text{ha}/\text{year}$) presently used in Cambodia as the standard figure for the calculation of cutting level. However, the value for all trees with DBH ≥ 10 cm ($1.09\text{m}^3/\text{ha}/\text{year}$) was not significantly larger than $0.33\text{m}^3/\text{ha}/\text{year}$ ($P > 0.05$, one tailed one sample t-test). The coefficient of variation for all trees among different plots was 300%.

Volume increment may change substantially depending on minimum threshold DBH used for measurements or calculations, monitoring length (VALLE *et al.*, 2006) and species (SILVA *et al.*, 1995). Therefore, data from the present study cannot be directly compared to other studies. Nevertheless, our mean values (1.09 and $0.86\text{m}^3/\text{ha}/\text{year}$) are well within the range between 0.5 and $2.0\text{m}^3/\text{ha}/\text{year}$ reported from most tropics mixed forests (RICE *et al.*, 1998) and the ranges obtained from the Brazilian Amazon (VALLE *et al.*, 2006).

CONCLUSION

Information on forest stand dynamics is essential to ensure sustainable yield, and there are abundant data for tropical rain forests, especially those in mainland of Southeast Asia; however, there have been few reports on tropical seasonal evergreen forest. From the preliminary results presented here, we conclude:

- 1) While species richness and stocking level in terms of basal area are smaller in tropical seasonal forest than in tropical rain forest, tree density, recruitment, mortality and volume increment are similar.
- 2) The measured mean annual volume increment ($0.86\text{m}^3/\text{ha}/\text{year}$) for commercial trees with DBH $\geq$ MDCL was significantly larger than the value ($0.33\text{m}^3/\text{ha}/\text{year}$) that has been used in Cambodian management systems; however, this cannot be confirmed for the values for all trees with DBH ≥ 10 cm.

Further data from longer periods and other locations are required to provide reliable estimates of sustainable yield to

forest managers and planners.

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LITERATURE CITED

- BREWER, S. and WEBB, M.A.H., (2002): A seasonal evergreen forest in Belize: unusually high tree species richness for northern Central America. *Botanical Journal of the Linnean Society*. **138**: 275-296
- BUNYAVEJCHEWIN, S., (1999): Structure and dynamics in seasonal dry evergreen forest in northern Thailand. *Journal of Vegetation Science* **10**: 787-792
- CLARK, D.A. and CLARK, D.B., (1992): Life history diversity of canopy and emergent trees in a neotropical rain forest. *Ecology Monographs*. **62**: 315-344
- CONNELL, J.H., TRACEY, J.G. and WEBB, L.J., (1984): Compensatory recruitment, growth and mortality as factors maintaining rain forest tree diversity. *Ecology Monographs*. **54**: 141-164
- DAUBER, E., FREDERICKSEN, T.S. and PEÑA, M., (2005): Sustainability of timber harvesting in Bolivian tropical forests. *Forest Ecology and Management*. **214**: 294-304
- de GRAAF, N.R., POELS, R.L.H. and VAN RAMPAY, R.S.A.R., (1999): Effect of silvicultural treatment on growth and mortality of rainforest in Surinam over long periods. *Forest Ecology and Management*. **124**: 123-135
- DFW (Department of Forestry and Wildlife), (2001): Forest Concession Management Planning Manual. Forest Administration, Phnom Penh, Cambodia
- FA (Forestry Administration), (2003): Development of growth and yield studies and establishment of permanent sample plots. Project credit No. 3365-KH. Forestry Administration, Phnom Penh, Cambodia, pp. 132
- FA (Forestry Administration), (2007): Cambodia: Forestry Statistics 2006: Planning and accounting Finance Office, Forestry Administration, Phnom Penh, Cambodia, pp. 80
- KAMMESHEIDT, L., DAGANG, A.A., SCHWARZWALLER, W. and WEIDELT, H., (2003): Growth patterns of dipterocarps in treated and untreated plots. *Forest Ecology and Management*. **174**: 437-445
- KIMPHAT, N., OUK, S., UOZUMI, Y. and UEKI, T., (1999): Forest management problems in Cambodia—a case study of forest management of F company. *J. Jpn. For. Plan.* **5**: 65-71
- KUMAGAI, T., SAITOH, T.M., SATO, Y., TAKAHASHI, H., MANFROI, O.J., MOROOKA, T., KURAJI, K., SUZUKI, M., YASUNARI, T. and KOMATSU, H.,

- (2005): Annual water balance and seasonality of evapotranspiration in a Bornean tropical rainforest, *Agricultural and Forest Meteorology*. **128**: 81-92
- KUMAGAI, T., YOSHIFUJI, N., TANAKA, N., SUZUKI, M. and KUME, T., (2009): Comparison of soil moisture dynamics between a tropical rain forest and a tropical seasonal forest in Southeast Asia: Impact of seasonal and year-to-year variations in rainfall. *Water Resource Research*. **45**: 1-14
- LEWIS, S.L., PHILLIPS, O.L., BAKER, T.R., LLOYD, J., MALHI, Y., ALMEIDA, S., HIGUCHI, N., LAURANCE, W.F., NEILL, D.A., SILVA, J.N.M., TERBORGH, J., TORRES LEZAMA, A., VASQUEZ MARTINEZ, R., BROWN, S., CHAVE, J., KUEBLER, C., NUNEZ VARGAS, P. and VINCETI B., (2004): Concerted changes in tropical forest structure and dynamics: evidence from 50 South American long-term plots. *The Royal Society*. **359**: 421-436
- LEWIS, S.L., PHILLIPS, O.L., SHEIL, D., VINCETI, B., BAKER, T.R., BROWN, S., GRAHAM, A.W., HIGUCHI, N., HILBERT, D.W., LAURANCE, W.F., LEJOLY, J., MALHI, Y., MONTEAGUDO, A., VARGAS, P.N., SONKE, B., SUPARDIM M.N., TERBORGH, J.W. and MARTINEZ, R.V., (2004a) Tropical forest tree mortality, recruitment and turnover rates: calculation, interpretation and comparison when census intervals vary. *Journal of Ecology*. **92**: 929-944
- MALHI, Y. and GRACE, J., (2000): Tropical forests and atmospheric carbon dioxide. *Trends Ecol. Evol.* **15**: 332-337
- MYERS, N., MITTELMEIER, R.A., MITTELMEIER, C.G., DA FONSECA, G.A.B. and KENT, J., (2000): Biodiversity hotspots for conservation priorities. *Nature*. **403**: 853-858
- PHILLIPS, O. L., BAKER, T. R., ARROYO, L., HIGUCHI, N., KILLEEN, T.J., LAURANCE, W.F., LEWIS, S.L., LLOYD, J., MALHI, Y., MONTEAGUDO, A., NEILL, D.A., VARGAS, P., SILVA, J.N.M., TERBORGH, J., VASQUEZ MARTINEZ, R., ALEXIADES, M., BROWN, S., CHAVEL, J., COMISKEY, J.A., CZIMCZIK, C.I., FIORE, A. DI., ERWIN, T., KUEBLER, C., LAURANCE, S.G., NASCIMENTO, H.E.M., OIVIER, J., PALACIOS, W., PATINO, S., PITMAN, N.C.A., QUESADA, C.A., SALDIAS, M., TORRES LEZAMA, A. and VINCETI, B., (2004): Pattern and process in Amazon tree turnover, 1976-2001. *R. Soc. Lond.* **359**: 381-407
- PHILLIPS, O.L. and GENTRY, A.H., (1994): Increasing turnover through time in tropical forests. *Science* **263**: 954-958
- PHILLIPS, P.D., YASMAN, I., BRASH, T.E. and van GARDINGEN, P.R., (2002): Grouping tree species for analysis of forest data in Kalimantan (Indonesia Boreno). *Forest Ecology and Management*. **157**: 205-216
- RGC (Royal Government of Cambodia), (2005): Sub-degree No. 089. Minimum Diameter Cutting Limit (MDCL). Date 14 February 2005. Forestry Administration. Ministry of agriculture, forestry and fisheries, Phnom Penh, Cambodia. (In scientific and Khmer names by tax classes)
- RICE, R.E., SUGAL, C.A., RATAY, S.M. and FONSECA, G.A.B., (1998): Sustainable forest management: a review of conventional wisdom. *Adv. Appl. Biodiver. Sci.* **3**: 1-29
- SILVA, J.N.M., de CARVALHO, J.O.P., LOPES J. do, C., de ALMEIDA, B.F., COSTA, D.H.M., OLIVEIRA, L.C., VANCLAY, J.K. and SKOVSGAARD, J.P., (1995): Growth and yield of a tropical rain forest in Brazilian Amazon 13 years after logging. *Forest Ecology and Management*. **71**: 267-274
- SIST, P. and FERREIRA, F.N., (2007): Sustainability of reduce-impact logging in Eastern Amazon. *Forest Ecology and Management*. **243**: 199-209
- SIST, P. and NGUYEN-THÉ, N., (2002): Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan (1990-1996). *Forest Ecology and Management*. **165**: 1-3
- SIST, P., PICARD, N. and GOURLET-FLEURY, S., (2003): Sustainable cutting cycle and yields in a lowland mixed dipterocarp forest of Borneo. *Ann. For. Sci.* **60**: 803-814
- SIST P. and SARIDAN A., (1999): Stand structure and floristic composition of a primary lowland dipterocarp forest in East Kalimantan, J. Trop. For. Sci. **11**: 704-722
- TOR, N., MIZOUE, N., ITO, S., KAI, S., NAKAO, T. and TY, S., (2009): Effects of population density on forest structure and species richness and diversity of trees in Kampong Thom Province, Cambodia. *Biodivers Conserv.* **18**: 717-738
- VALLE, D., SCHULZE, M., VIDAL, E., GROGAN, J. and SALES, M., (2006): Identifying bias in stand level growth and yield estimations: a case study in eastern Brazilian Amazonia. *Forest Ecology and Management*. **236**: 127-135
- van GARDINGEN, P.R., McLEISH, M.J., PHILLIPS, P.D., FADILAH, D., TYRIE, G. and YASMAN, I., (2003): Financial and ecological analysis of management options for logged-over Dipterocarp forests in Indonesian Borneo. *Forest Ecology and Management*. **183**: 1-29
- van GARDINGEN, P.R., VALLE, D. and THOMPSON, I., (2006): Evaluation of yield regulation options for primary forest in Tapajo's National Forest, Brazil. *Forest Ecology and Management*. **231**: 183-195

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