Population Structures of Four Tree Species in Logged-Over Tropical Forest in South Papua, Indonesia: an Integral Projection Model Approach

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Papua University, West Papua, Indonesia
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POPULATION STRUCTURES OF FOUR TREE SPECIES IN LOGGED-OVER TROPICAL FOREST IN SOUTH PAPUA, INDONESIA: AN INTEGRAL PROJECTION MODEL APPROACH

Relawan Kuswandi[1,*] and Agustinus Murdjoko[2]

[1]Manokwari Forestry Research Institute
Jl. Inamberi-Pasir Putih, PO Box 159, Manokwari, West Papua, Indonesia
[2]Silviculture Departement, Forestry Faculty, The State University of Papua
Jl. Gunung Salju, Amban, Manokwari 98314 West Papua, Indonesia

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POPULATION STRUCTURES OF FOUR TREE SPECIES IN LOGGED-OVER TROPICAL FOREST IN SOUTH PAPUA, INDONESIA: AN INTEGRAL PROJECTION MODEL APPROACH. Selective logging has been taking place in Papua for several decades. In contrast, very little is known about the stand structure in post-logged forest. Hence, this paper investigates stand structures in logged-over area of tropical forest in South Papua. Four species were selected in three one-hectare permanent sample plots (PSPs): *Vatica rassak*, *Syzygium* sp, *Litsea timoriana* and *Canarium asperum*. PSPs were located in the forest concession area of PT. Tunas Sawaerma in Assiki, Boven Digul, in South Papua. Data sets comprised measurements made in 2005 and 2012 consisting of species, diameter at breast height (DBH), mortality and number of tree of each species. Integral Projection Models (IPMs) were developed, taking into account mortality, growth, recruitment and fecundity. Results show the pattern of stand structures of the four species were more or less similar, i.e. more individual trees were present in the small diameter classes than in the larger diameter classes. The general pattern of the individual distribution of the four species is the typical reverse-J shape. *Syzygium* sp. has a greater number of individuals in the small diameter classes than the other three species. Population growth rates (λ) are above one, indicating that the stand structures of the population dynamics of the four species are recuperating. Conclusively, these results suggest that species composition and population structure in these logged-over forests are recovering increasingly.

Keywords: Permanent sample plots, population growth rate, harvest activity

STRUKTUR POPULASI DARI EMPAT SPESIES POHON DI HUTAN BEKAS TEBANGAN, PAPUA SELATAN, INDONESIA: SEBUAH PENDEKATAN DARI INTEGRAL PROJECTION MODEL. Penebangan hutan masih berlangsung di Papua, namun informasi mengenai struktur tegakan masih belum banyak. Tulisan ini mempelajari struktur populasi dari tegakan pada hutan bekas tebangan di daerah Papua Selatan. Empat species yang tumbuh dalam Petak Ukur Permanen (PUP) diamati adalah Vatica rassak*,* Syzygium sp.*,* Litsea timoriana *dan* Canarium asperum. *PUP berlokasi di PT Tunas Sawerma, Asiki, Boven Digul, Papua. Dataset diperoleh dari pengukuran tahun 2005 dan 2012 yang terdiri dari jenis, jumlah individu dan diameter. Selanjutnya, Intergral Projection Models digunakan untuk menganalisis struktur tegakan dengan menggunakan mortality, pertumbuhan, recruitment dan fecundity ke dalam persamaan. Hasil simulasi model menunjukan bahwa model struktur tegakan dari keempat species adalah sama dimana banyak individu yang berada pada pohon dengan diameter kecil dibandingkan dengan jumlah individu pada pohon yang berdiameter besar. Secara umum, bentuk distribusi dari individu-individu dari kempat jenis tersebut adalah J terbalik. Selanjutnya,* Syzygium sp. *adalah species yang memiliki individu yang lebih banyak dibandingkan dengan ketiga species lainnya. Struktur populasi tegakan dari keempat species tersebut bergerak tumbuh setelah penebangan dimana ditunjukkan oleh nilai population growth rate (λ) di atas satu. Oleh karena itu, hutan bekas tebangan ini memiliki kemampuan untuk kembali pulih dan bisa mencapai fase klimaks.*

Kata kunci: Petak ukur permanen, population growth rate, kegiatan penebangan

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[*] Corresponding author: r_kuswandi@yahoo.co.id

I. INTRODUCTION

Indonesia's natural forests are globally significant, for both their ecosystem service and commercial wood production values (FAO, 2011). Indonesia has also been experiencing significant loss and degradation of its primary forests (Margono et al., 2014). These pressures mean that it is more important than ever to apply proper forest management in natural tropical forests managed for production (Putz & Romero, 2015). This include the implementation of the Annual Allowable Cut (AAC) principles which, if applied correctly, will allow sustainable harvests over time (Vanclay, 1996). There are also various other considerations in ensuring sustainable production, such as appropriate silvicultural management through selective harvesting, retention of a specified number of remaining trees, specification of a minimum cutting diameter (MCD) and certain cutting cycle, and post-harvest tending. The period of cutting cycle needs to be determined with both economic and ecological considerations in mind. As an example, Indonesia has a 40 year cutting cycle with a timber volume of about 67 m^3 ha^{-1}, which is economically profitable (Sist, Picard, & Gourlet-Fleury, 2003). As another example, in Brazil's natural forests, the total volume of commercial species can increase after logging and good management; the tree growth rates and tree density below the minimum cutting diameter play an important role in the productivity of the second cycle (Dauber, Fredericksen, & Pena, 2005). Moreover, growth rate of trees after logging will increase when silvicultural treatments are applied (Krisnawati & Wahjono, 2010; Murdjoko, 2013). Therefore, in order to understand and monitor the post-logging recovery process and forest dynamics, continuous inventory is needed both before and after harvesting (Vanclay, 1996).

Dynamic models are now increasingly being developed to facilitate this understanding and monitoring. The forest is modeled as a system that contains interrelated elements to simulate cause-effect relationships and to predict future population of forest (Vanclay, 1994). The models need periodical measurement data, which can be obtained from annual measurements of tree diameter and analysis of tree ring growth. Such data have already been used to carry out studies in forest modeling. For instance, in Bolivia sustaining timber yields for emergent species can be reached by applying silvicultural treatments based on the simulation of forest dynamics (e.g. Brienen & Zuidema, 2006). As another example, the structure of the stand can be modeled by forming a transition matrix to represent the growth of stands, including recruitment, fecundity and mortality (e.g. Rusolono, Parthama, & Rosmatika, 1997; Krisnawati, Suhendang, & Parthama, 2008).

Indonesia is one of the main producers of topical timber. Production forests covering about 61% of total forest area (Ministry of Forestry, 2010). One of the regions with a large area of tropical moist forests is Papua, with a forest extent of 41 million ha. These forests consist of 27 million ha of primary forest, 5 million ha of secondary forest, and 9 million ha of other forest. In primary forest, most part of the forests is used for production and conservation. (Forestry Department, 2007). Based on data from Indonesian Ministry of Forestry (2010), there are eight forest utilization companies that have been given permission to operate in Papua. Therefore, this level of harvesting means that it is important to monitor the recovery of logged-over forests in Papua.

However, valid information on how stand structures of populations are formed after logging is not generally completely. Therefore, this research has analyzed the periodic data-set of four species obtained from permanent sample plots in logged-over forests, using Integral Projection Models (IPMs) (Zuidema, Jongejans, Pham, During, & Schieving, 2010). IPMs are developed from estimated matrix models and still provide the same output as the matrix models (Easterling, Ellner, & Dixon, 2000; Zuidema et al., 2010). Furthermore, IPMs provide two advantages compared to the matrix model. Firstly, the IPMs take vital stand parameters (population growth, sensitivity, elasticity and age estimates) into account. Secondly, variations among individuals are integrated, while matrix models produce large variation (Zuidema et al., 2010). The IPMs are appropriate to describe long-term growth of trees (Zuidema, Brienen, During, & Guneralp, 2009; Zuidema et al., 2010; Zuidema, Vlam, & Chien, 2011). One output of IPMs is a stable population of individuals that can be used to describe stand structure. The purpose of the study is to predict stand structure of population in logged-over area in tropical forests in South Papua using IPMs.

II. MATERIAL AND METHOD

A. Study Area

This study was located in a forest concession area of PT. Tunas Sawaerma in Assiki, Boven Digul, Southern Part of Papua, where forest has been selectively harvested in 2004 (Figure 1).

The AAC in 2004 was 88.247 m^3 yr^{-1}. After logging, three hectares of the logged forest area were set aside for permanent sample plots (PSPs) of one ha each. The distance between plots was 100 m. Coordinates of this location was 6°37'14.0" South 140°39'43.6" East using datum WGS 84. In each PSP, 4 tree species were studied, as described below. The diameter of the trees was measured in 2005 and 2012, and the mortality and recruitment were recorded for the same years. To get an overview of the condition of this forest, all trees in PSPs were also measured to describe stand density, using basal area as presented in Table 1.

In PSPs, there is no enrichment planting, in order to allow remaining trees grow naturally. Multi layers in the canopy forming strata characterize this forest. Understories comprise shrubs, herb layers and associates with seedlings from trees along with epiphytes, ferny plants and climbing plants. The soil is primarily alluvial, and climatic conditions are characterized by a mean annual rainfall ranging from 3000 to 4000 mm and mean annual temperature of 32°C. Elevation is approximately 30 m above sea-level (PT Tunas Sawaerma, 2009).

B. Study Species

According to the report of PT Tunas Sawaerma (2009), the principal commercial species are meranti species including resak (*Vatica rassak*), kenari (*Canarium aspermum*), rimba campuran (*Syzigium* sp.) and medang

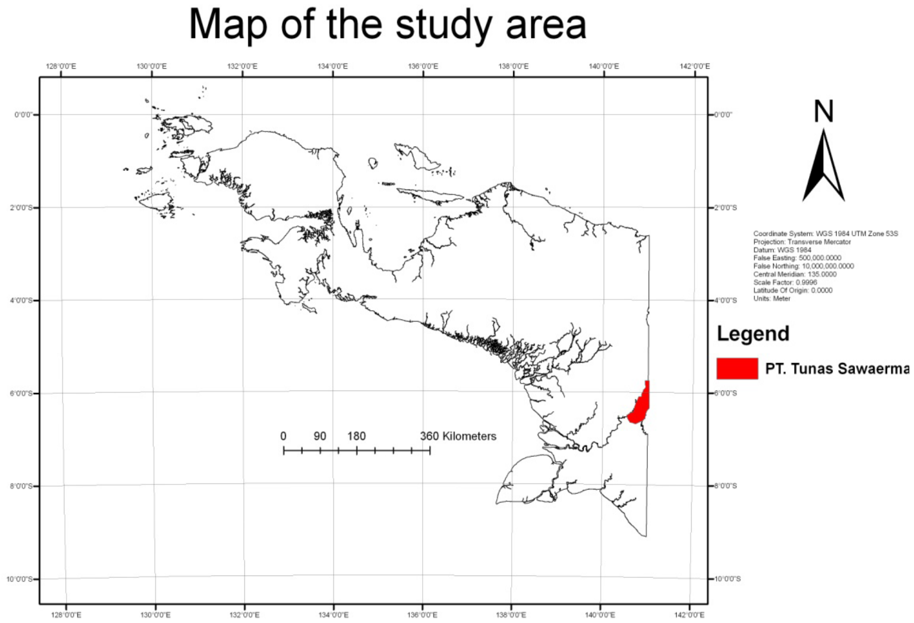


Figure 1. Map of the study area in PT. Tunas Sawaerma, Boven Digul, Papua

Table 1. Basal area of trees in PSPs based on diameter class and year

No.	Diameter Classes (cm)	Basal area (m^2 ha^{-1})		Standard deviation	
		2005	2012	2005	2012
1	10-19	4.21	6.93	0.55	0.09
2	20-29	4.62	7.43	0.41	0.35
3	30-39	4.46	5.71	0.38	1.41
4	40-49	2.92	3.53	1.26	0.77
5	50 +	4.73	5.33	3.83	3.94

(*Litsea timoriana*). The principal non-commercial species are *Actinodapne nitida*, *Beiscmedia* sp, *Blumeodendron amboinicum*, *Linociera macrophylla*, *Meduchantera* sp and *Pimeliodendron amboinicum*. The four dominant commercial species were selected for analysis in this study in Table 2.

C. Data

The data measured in 2005 and 2012 consisted of species, diameter at breast height (DBH), mortality and number of tree of each species. The minimum diameter of measured trees was 10 cm with an accuracy of measurement was 0.1 cm. DBH of the tree was measured to analyze growth. Mortality of the trees was recorded by counting number of dead trees in 2012. Recruitment was recorded by the number of trees that entered diameter class 10 cm in 2012.

D. Integral Projection Models

Integral Projection Model (IPMs) were developed to analyze populations of trees in the logged forest. To build IPMs, equations of survival probability, growth, variance of growth, and mean number of new individuals of trees were prepared. Easterling et al. (2000) demonstrated that the projection matrix is replaced by a projection by Kernel $K_{(y,x)} = P_{(y,x)} + F_{(y,x)}$. P is survival and growth from state x (*time t*) to state y (*time t+1*) and F is the production of state y of new individual trees. The Kernel function is written as:

$$n_{(y,t+1)} = \int_L^U K_{(y,x)} n_{(x,t)} dx$$

where (L, U) is the range of possible sizes, $n_{(x,t)}$ is the distribution function n in time t, $n_{(y,t+1)}$ is the distribution function n in time t+1, K is Kernel which is a non-negative surface as a possible transition from size x (*time 1*) to size y (*time t+1*) and describes survival, growth and fecundity.

The mesh points are defined by dividing the interval (L, U) equally into m size classes and setting xi, at the midpoint of the i class :

Where h= (U-L)/m. The midpoint rule

$x_i = L + (i\text{-}0.5)h$,

$i = 1,2,....m$,

approximation to first equation above is:

Then, the multiplication of matrix is:

$$n_{(xi,\, t+1)} = h \sum_{j=1}^{m} k_{(xi,\, xj)} n_{(x,\, j,\, t)}$$

Where K is the matrix whose $(i,j)^{th}$ entry is

$n_{(t+1)} = Kn_{(t)}$

$hK_{(xi,xj)}$ and $n_{(t)}$ is the vector whose i^{th} entry is $n_{(xi,\, t)}$ (Ellner & Rees, 2006).

Stand structures of population were built when lambda (λ) was stable, where n as width of matrix was tested using 50, 100 and 500. IPMs were run using R version 2.13.2. (R Development Core Team. 2005). The stand structures describe the proportional distribution of individual trees based on groups of diameter at breast height (DBH) as discrete data. Then, IPMs computation were able to produce continuous data.

E. Estimation versus observation result

Horvitz and Schemske (1995) have proposed a proportional similarity index as one of the methods to validate the results obtained from model with observed data. Results of IPMs were compared with observed data in 2005 and 2012 using the proportional similarity index. where in n stages and ai is the proportion

$$PS = \sum_{n}^{i-1} \min(a_i, b_i) \times 100$$

of individuals in the i^{th} stage of stable-stage distribution and bi is the proportion of individuals in the ith stage of the observed stage distribution. If Proportional Similarity Index (%) is close to 100%, it means that similarity is strong, and vice versa.

III. RESULT AND DISCUSSION

A. Stand structures of population

Figure 2 shows the distribution of individual trees of stands of each species proportionally over diameter.

In general, the distribution pattern of stand structures of the four species are more or less similar, where the number of trees declines as the diameter increases. The figure above shows the general pattern of individual distribution of trees which is characteristic of tropical forest (Fayolle et al., 2014). Moreover, in each population of each species, there is a greater number of individuals with diameter below 20 cm, and fewer individuals are present in diameter classes larger than 20 cm. Of the four species, *Syzigium* sp. has the largest number of small individuals, about 12 % of the population of this species; whereas for the other species, less than 8 % of the total individuals of the population is comprised of small individual trees. Further, the individuals of *Syzigium* sp have the widest diameter distribution. It can be seen from Figure 2 that their diameter is ranging from 10 cm to about 100 cm, while those of the three other species, namely *Canarium* sp., *Litsea timoriana* and *Vatica rassak*, have a diameter range of up to 50 cm only. There are also similar patterns in the stand structures of the

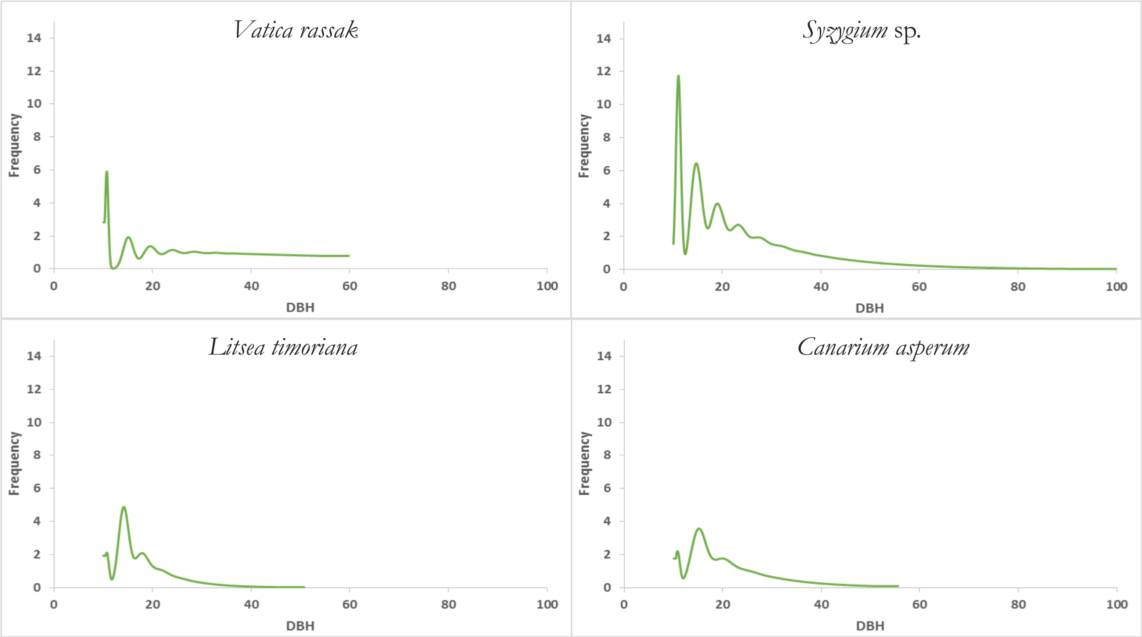


Figure 2. Stand structures with stable population of four species in logged forest. The stand structures were illustrated by plotting frequencies of individual trees over each diameter (cm) and n=500 number of matrices in simulation of IPMs when λ was stable

four species, where the number of individuals in diameter class just above 10 cm declines, and then increases. Finally, the number of individuals is reduced somewhat as the diameter of the individuals increases.

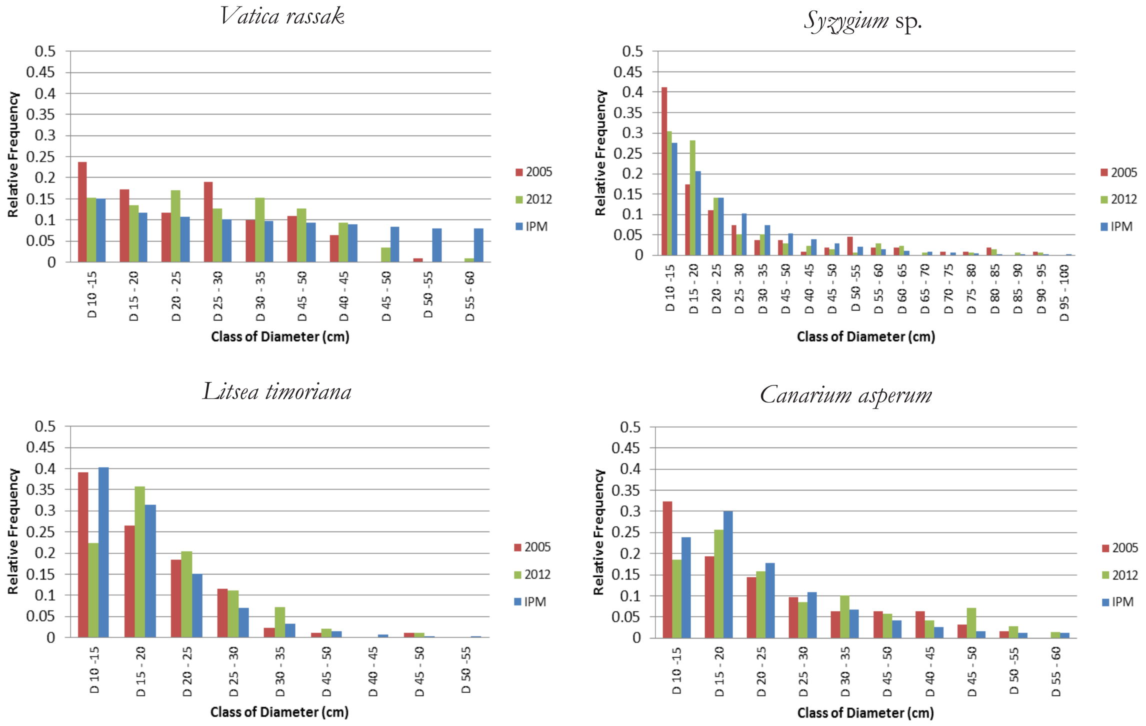
Besides the stand structures of the population, we also ran simulations to obtain population growth rate (λ). The population growth rates indicate how the stand structures of the population alters over time. In this study, we found that the population growth rates of the four species are greater than 1: 1.007, 1.28, 1.74 and 1.457 for *Vatica rassak*, *Syzygium* sp., *Litsea timoriana* and *Canarium asperum*, respectively. This indicates that stand structures of the population dynamics are increasing over time, and the pattern of population in the stand structures will be stable as displayed in Figure 2 where individuals of small diameter trees are more abundant than individuals of large diameter trees. The stand structures would probably change if disturbances such as windstorm or forest fire occurred in this area.

In this study, we were able to see how well the stand structures of each species predicted from IPMs compared to observed data in 2005 and 2012. In Figure 3, stand structures are illustrated as bar charts where each bar chart displays bar of IPM results and observed results (2005 and 2012). The bar charts were set by plotting relative frequencies against diameter classes with an interval of 5 cm.

The Proportional Similarity Index (%) of four species is presented in Table 3.

B. Stand dynamics after logging

The four tree species have similarities in the population shape of the stand structure, with individuals with small diameters more abundant than individuals with larger diameters. This phenomenon usually occurs in primary forest as a process of natural regeneration where a large tree produces many seeds. Then, the seeds germinate on the forest floor, producing seedlings which will grow and survive (Gorchov, Comejo, Ascorna, & Jaramillo, 1993; Plumptre, 1995). Then, the seedlings will possibly enter the next class as new individuals of trees.


Vatica rassak

Syzygium sp.

Litsea timoriana

Canarium asperum

Figure 3. Comparison of stand structures of four species between observed results and results of IPM models

Table 3. Proportional Similarity Index (%) comparing stand structures between IPM and observed results

Name of tree species	Proportional Similarity Index (%)	
	(IPM results vs. observed results in 2005)	(IPM results vs. observed results in 2012)
Vatica rassak	73.97	79.80
Syzygium sp	79.84	84.65
Litsea timoriana	91.51	81.15
Canarium asperum	83.47	86.02

In this logged forest, not all large trees are harvested during logging activity. Therefore, the remaining trees are available to contribute producing new individuals (Kuswandi, 2014). Further, the forest canopy is more open as a result of tree cutting. This condition will allow more sunlight to reach forest floor in which seedlings are growing, and then understory can grow faster (Kennard, 2002; Edwards & Mason, 2006; Duah-Gyamfi, Swaine, Adam, Pinard, & Swaine, 2014). The increased number of seedlings is usually correlated with the extent of forest fragmentation (Cusack & McCleery, 2014). Further, Soil Organic Matter (SOM) can be more available for growth of understory in forest gaps (Throckmorton, Bird, Monte, Doane, Firestone, & Horwath, 2015).

Syzygium sp. has large number of small individuals compared to those of the three other species. This may be due to the larger number of individuals in larger diameters results contributing to regeneration. According to Kammesheidt, Kohler, and Huth (2001), different species growing in the same area have differences in the speed of succession. It seems from these results that the succession ability of Syzygium sp is higher than that of the three other species.

In terms of the population dynamics of stand structures of the four species, the total population increased over the period 2005 to 2012, subsequent to logging. The increase of population is by reason of increase of growth rate as a response to individuals receiving more light. The light can hit forest floor because of the gaps in the canopy are more open as an impact of logging activity (Villegas et al., 2009; Sist & Nguyen-The, 2002; Toledo et al., 2012). In addition, growth rate of individual trees specifically occur for individuals with small diameters. Therefore, growth rate and recruitment of new individuals have significant contribution in the increase of population of the four species. That can be seen from the population growth rate (λ) of the four species above (Lieberman, Lieberman, Peralta, & Hartshom, 1985).

The stand structures of the population of the four species from 2005 and 2012 are very dynamic because forest stands have been changing for several years owing to fast growth and recruitment. This can be seen from the Proportional Similarity Index (%) in 2005 and 2012, where the results of IPMs of *Syzygium* sp. and Litsea timoriana were more similar to stand structures in 2005 rather than stand structures in 2012, while for *Vatica rassak* and *Canarium asperum* were more close to stand structure in 2012. This means that secondary succession is taking place in logged forest.

The competition of trees after harvest is an indicator that forest is able to grow after harvesting. As stated by MacPhersona, Schulzec, Cartera, & Vidala (2010), the seedlings can grow to be mature, if determining factors such as light are available. Even though stand structures of forest changed as a result of logging, the stand structures are able to recover through natural process. The data here suggest that species composition in logged forest will not alter, because of the four species which are dominant are predicted to regain their dominance. Ultimately, this process will support the sustainability of the forest (Sist & Ferreira, 2007; Huth & Ditzer, 2001)

IV. CONCLUSION

Patterns of stand structures of four species assessed are more or less similar, with more individuals of small diameter rather than large diameter present. *Syzygium* sp. has a greater number of individuals of small diameter compared to the three other species (i.e *Vatica rassak*, *Litsea timoriana* and *Canarium asperum*). The stand structures of population of the four species are increasing after harvest activity. Therefore, it seems that logged forest in this area would be able to recuperate and eventually return to pre-logging status.

IPMs have not been widely used in Indonesian tropical forest research. This research suggests that these model can be used to describe stand structures of forest, because the results of IPMs are close to observed results for the stands assessed.

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