Growth and yield model for non-timber forest product of kemenyan (Styrax sumatrana J.J. Sm) in Tapanuli, North Sumatra

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Abstract. Kemenyan is Styrax tree resin, the main of non-timber forest product commodity in Lake Toba catchment area, North Sumatra since hundreds years ago. However, there are lack of information about the growth and yield prediction for this tree species. The objective of study is to construct the growth and yield models for Styrax sumatrana in Tapanuli region, North Sumatra. Measurement data from 20 temporary plots were used to formulate stand diameter and height equations, and to project the incense production. The highest Current Annual Increment (CAI) of diameter occurs in the stand's age 21 to 25 years (1.00 cm/year). The growth of diameter declines significantly to 0.48 cm/year in age 46 to 50 years, and decrease to 0.26 cm/year at age 50 years up. The intersection of CAI and MAI curves occur in stand age 31 to 35 years. It shows that the optimal growth occurs in this period. The average of incenses production was 318.59 g/tree/year. The optimum incense production was achieved when the diameter growth was maximal and tapping scars accumulation was limited.

1. Introduction

Yield regulation is an important aspect in sustainable forest management. Estimation of growth, yield projection, and harvest intensity are some of regulatory tools that influence the silviculture options, length of management cycle, and effectiveness of forest management activities. These estimations are generally conducted by model approach. In timber management, the models are built on the mathematical relationships of stand parameters consist of stand density, age, and site productivity [1]. The growth model provides a quantitative description of forest stand development due to the influence of management actions which applied over a time period [2].

Over the last few decades, community forest management with non-timber forest products as the main commodity have not supported by the proper yield regulation [3, 4]. One of NTPFs management that have a long history in the Lake Toba catchment area, North Sumatra is the Kemenyan (Styrax) forests [5]. Kemenyan or incense is resin from Styrax tree. The resin contains compounds that used for industrial raw materials, medicines, cosmetics, natural insecticides, and food and beverage preservatives [5, 6,7]. It have cultivated by most communities in Tapanuli since hundred years ago. However, there are lack of information about the growth and yield prediction for this tree species.

The objective of study is to construct the growth and yield models for Styrax sumatrana in Tapanuli region, North Sumatra. The models can be applied projection of resin production and to determine an appropriate silviculture options.
2. Materials and Methods

2.1. Study sites
The research was conducted on Styrax forests in North Tapanuli and Humbang Hasundutan district, North Sumatra. These community forests are commonly grow in areas with hilly topography with varying altitude ranging from 933 to 1,488 m above sea level. The average of annual rainfall is 3200 mm, daily temperature during the day 22.2 to 30.3°C and relative humidity 55.59 to 82.90%. The development of measurement plots were conducted in May until November 2012.

2.2. Data collection
Growth data were obtained by measurement of diameter and height on 20 temporary plots. Plots 0.1 ha (20 m x 50 m) were constructed in several stand conditions with stand age range from 8 to 65 years old. All data were calculated as one population. There has been limited standardized calculation for NTFPs productivity [3, 4, 8]. In this study, the productivity was calculated by collecting the incenses from all tapping points from sample trees in a harvest period. The variables measured were diameter, height, number of tapping points and scars.

2.3. Data analysis
The age classes (AC) of stand is set by 5-year interval from AC I (<10 years) to AC X (> 50 years). The determination of AC I which start at tree age <10 years were due to the average of trees began to produce a productive incense at 8 years old. This interval refers to forest management of Pinus merkusii in Indonesia, and also applied by Calama et al. [8] to study ecological processes in measuring the NTPFs productivity such as flowering, leaf growth, and exudates production. In this study, the incense production ($W_{TIG}$) is calculated by summing the incenses from all the tapping points in a harvest period.

$$W_{TIG} = \sum_{i=1}^{n} W_{ig} \quad (1)$$
Remarks: $W_{TIG}$ = incense production (g/tree); $W_{ig}$ = incense production per tapping point (g)

Current Annual Increments (CAI) and Mean Annual Increments (MAI) of diameter, height and incense production are calculated by the formula:

$$CAI = Y_{t+1} - Y_t \quad (2)$$
$$MAI = \frac{Y_t}{t} \quad (3)$$
Remarks: $Y_t$ = diameter, height, and incense production at time $t$, $t$ = age.

The stand models were based on the mathematical relationship between diameter and height of stand with age using the equation $ln Y = a + b 1/X$ with nested regression analysis.

$$\ln D = a + b \quad \frac{1}{A} \quad (4)$$
$$\ln H = a + b \quad \frac{1}{A} \quad (5)$$
Remarks: $D$ = Dbh (cm); $H$ = total height (m); $A$ = Age (years).

Referring to various studies [9,10], the models were constructed base on the regression between resin productivity with stand’s parameters such as diameter, height and harvest intensity. The intensity of harvesting is a function of the number of tapping points measured and the accumulation of scars due to tapping.

$$W_{TIG} = f(Dbh, N_{NT}, N_{BL}) \quad (6)$$
Remarks: $D$ = Dbh (cm); $N_{BL}$ = Number of scars tapping (N); and $N_{NT}$ = Number of new tapping point.

Regression analysis was performed using the MINITAB 14 for Windows program. The built models were tested for their reliability through the variance of regression and coefficient of determination. Model validation performed on the Aggregate of Difference-AgD with criteria less than 1% and the Average of Percentage Deviation (AvR) was less than 10%.
3. Result and Discussion

3.1. Data distribution

The average of stand diameter and height of 463 sample trees derived from 20 temporary measurements plots are listed in Table 1. The mean of diameter ($D_{bh}$) is 21.4 cm, while the mean of trees height ($H_{tot}$) is 15.8 m.

| Age Class | Number of trees | Average of $D_{bh}$ (cm) | Average of Total Height (m) |
|-----------|-----------------|--------------------------|----------------------------|
| KU I < 10 years | 22 | 08.16 | 7.5 |
| KU II 11-15 years | 75 | 12.35 | 12.9 |
| KU III 16-20 years | 111 | 16.55 | 14.9 |
| KU IV 21-25 years | 88 | 21.56 | 15.9 |
| KU V 26-30 years | 86 | 26.55 | 16.9 |
| KU VI 31-35 years | 45 | 31.11 | 18.0 |
| KU VII 36-40 years | 23 | 35.23 | 20.3 |
| KU VIII 41-45 years | 8 | 39.23 | 21.9 |
| KU IX 46-50 years | 4 | 41.64 | 25.0 |
| KU X > 50 years | 1 | 42.93 | 26.0 |

**Total average**

| Average of $D_{bh}$ (cm) | Average of Total Height (m) |
|--------------------------|-----------------------------|
| 21.35                    | 15.8                        |

The distribution of stand diameter, height, age, incenses productivity and the relationship between each stand parameter are shown in Figure 1.

**Figure 1.** Distribution of stand diameter, height, age, incenses productivity and the relationship between each stand parameter. (a) $D_{bh}$ distribution by age; (b) $H_{tot}$ distribution by ages; (c) resin production by age; and (d) resin production by $D_{bh}$.
The relationship between diameter and stand age tend sigmoid, whereas stand height on age tends to logistics. It illustrates the principle of developmental biology of stand where growth would tend to increase in initial period and slowed down after a certain time period or when it reaches a certain growth point [2]. According to figure 1, the incense production tends to spread to stand age and diameter. These suggest that age (A) and diameter (Dbh) have a poor ability to explain the variance of incense production (\(W_{TG}\)). The difficulty to understanding the behavior of natural ecosystems, especially NTFPs lead to the prediction are often imprecise and difficult [10,11].

3.2. Growth of Diameter and Height
The standgrowth is shown in table 2 and figure 2. The highest CAI diameter occurs in CA IV at 1.00 cm/year, decreasing significantly in AC IX (46-50 years) at 0.48 cm/year, and the lowest at 0.26 cm/year in AC X (> 50 years). The MAI diameter ranging from 0.82 to 0.95 cm/year, thus the tree with diameter > 20 cm is achieved at age over 21 years. The MAI height ranges from 0.51 to 0.99 m/year.

Table 2. The stand growth for S. sumatrana in Tapanuli, North Sumatera

| Age Class (year) | Diameter at breast height (Dbh) | Total Height (m) |
|------------------|-------------------------------|------------------|
|                  | Average of CAI (cm/year) | MAI (cm/year) | Average of Htot (m) | CAI (m/year) | MAI (m/year) |
| AC I             | 08.16                        | 0.82           | 0.82                  | 7.50          | 0.80          | 0.80          |
| AC II            | 12.35                        | 0.84           | 0.95                  | 12.93         | 1.09          | 0.99          |
| AC III           | 16.55                        | 0.84           | 0.92                  | 14.96         | 0.41          | 0.83          |
| AC IV            | 21.56                        | 1.00           | 0.94                  | 15.88         | 0.18          | 0.69          |
| AC V             | 26.55                        | 1.00           | 0.95                  | 16.91         | 0.21          | 0.60          |
| AC VI            | 31.11                        | 0.91           | 0.94                  | 17.99         | 0.22          | 0.54          |
| AC VII           | 35.23                        | 0.82           | 0.93                  | 20.28         | 0.46          | 0.53          |
| AC VIII          | 39.23                        | 0.80           | 0.91                  | 21.88         | 0.32          | 0.51          |
| AC IX            | 41.64                        | 0.48           | 0.87                  | 25.00         | 0.63          | 0.52          |
| AC X             | 42.93                        | 0.26           | 0.86                  | 26.00         | 0.20          | 0.52          |

Figure 2. Curve of diameter growth (a) and CAI and MAI curves (b).

The diameter growth curve (figure 2a) illustrates the sigmoid pattern. The growth tends to be slow at the beginning of growth, increasing linearly to exponential at the mid-period, and slow down in late period. This pattern is also indicated by most of forest trees growth in various parts of the world. Furthermore, Figure 2b shows the intersection of CAI and MAI curves on 31 to 35 years old. In timber regulation, the intersection of these curves has important roles in determining the forest management rotation. This point represents the optimal growth, so that rotation is usually determined at that period. The incense productivity is influenced by several factors such as the intensity of harvesting (the number of tapping points and tapping scars). Therefore, the area of productive tapping is affected by
the tree diameter, thus intersection of CAI and MAI curves remains a concern. The decline in incense productivity may be thought to be due to a decrease in the growth rate.

3.3. Growth and Yield Model

Based on the regression analysis were obtained prediction model results as follows:

a. Equation of diameter estimation:

\[ \ln D = 3.88 - 18.0 I/A \]  \( R^2_{adj} = 90.3 \) \hspace{1cm} (7)

b. Equation of height estimation:

\[ \ln H_{tot} = 3.11 - 7.64 I/A \]  \( R^2_{adj} = 49.9 \) \hspace{1cm} (8)

\[ H_{tot} = 9.23 + 0.307 D \]  \( R^2_{adj} = 55.7 \) \hspace{1cm} (9)

b. Incense production estimation

\[ W_{TIG} = 23.4 + 0.895 Dbh + 11.4 N_{NT} - 0.604 N_{BL} \]  \( R^2_{adj} = 63.6 \) \hspace{1cm} (10)

Remarks: \( D \) = dbh (cm); \( H \) = Total height (m); \( A \) = Age (year); \( W_{TIG} \) = incense production (g/tree/year); \( N_{BL} \) = Number of scars tapping (N); and \( N_{NT} \) = Number of new tapping point.

The equation (9) is considered reliable in predicting the growth and projection the diameter at a certain age. Regards \( R^2_{adj} \) value = 90.3, the age explain variance of diameter with a confidence level 90.3%. The models have also met the validated model criterias with \( AgD<1\% \) and \( AvR<10\% \).

| No. | Equation | \( R^2_{adj} \) | \( R^2_{adj} \) | \( R^2_{adj} \) |
|-----|----------|----------------|----------------|----------------|
| 1   | \( \ln D = 3.88 - 18.0 I/A \) | 90.3 | 0.91 | 9.28 |
| 2   | \( \ln H_{tot} = 3.11 - 7.64 I/A \) | 49.9 | 1.31 | 11.90 |
| 3   | \( H_{tot} = 9.23 + 0.307 D \) | 55.7 | (-)0.03 | 11.50 |
| 4   | \( W_{TIG} = 23.4 + 0.895 Dbh + 10.4 N_{NT} - 0.604 N_{BL} \) | 63.6 | (-)0.21 | 11.76 |

According to \( R^2_{adj} = 49.9 \), \( AgD>1\% \) and \( AvR>10\% \), equation (8) has a relatively low reliability. The stand age can only explain 49.9% of the total height, whereas the remaining 51.1% of height can be affected by other variables. The \( R^2_{adj} = 55.7 \) on the equation (9), it consequences that height variance is only 57.7% influenced by diameter. Different to diameter, stand height is not affected by silviculture treatments such as stand density. These low values reflect variations in the quality of growing sites.

The equation (10) is considered quite reliable in estimating the incense production \( (R^2_{adj} = 63.6) \). Although it has an \( AvR \) value 11.76%, higher than validation criteria, considering the peculiarities of the incense characteristics as NTFPs and there are limited model for this commodity, the equation can be suggested as a reliable model. The equation indicates that tree diameter (Dbh) and harvesting intensity \( (N_{NT}) \) are directly proportional to incense productivity. However, increasing the unproductive surface area to the addition of tapping scars \( (N_{BL}) \) can be a limiting the productivity.

The optimal production is achieved at maximum diameter growth and minimal tapping scars accumulation. These conditions also have shown by the incense productivity of \( Boswellia papyrifera \) in Africa [10]. Increasing the tapping intensity in the short term will increase the resin productivity, especially in larger trees. However, Rijkers et al. [12] explains that high harvesting intensity will disrupt the vitality, reproductive system and stand productivity in long-term.

The highest productivity is found on larger diameter trees with the smallest number of tapping scars. In larger trees with little tapping scars, an increase in harvesting intensity by adding new tapping points will increase the resin productivity. But, It will decrease the proportion of productive tapping fields, and as the consequence it will disrupt the growth and productivity in the long term.

The average of incense production is 159.28 g/tree/harvest period. The harvesting carried out every six month or twice a year, where the average of resin productivity is 318.59 g/tree/year. The new tapping point is 5 to 10 points/harvest, where incense production is 11.37 g/point/harvest. The productivity is not vary with the previous studies. Sasmuko [13] obtained an average yield at 12.11
g/tapping point, while Waluyo [14] obtained a lower average at 9.54 g. This lower production is thought to be due to the smaller sample trees diameter (13 to 23 cm).

The low correlation between incense productivity to diameter \( r=0.27 \) also were showed by Waluyo (1993) for \( S. \ benzoin \) in North Tapanuli \( r=0.35 \). The prediction of \( Pinus \ heliopensis \) resin production in Greece also shown a relatively low correlation \( r=0.56 \) [9]. According to Purnomo [11], the reliable models for natural forest are limited due to their ecosystem behavior cannot be fully understood so that the predictions can be inappropriate and difficult.

4. Conclusion

The highest \( CAI \) occurs in 21-25 age class at 1.00 cm/year and decreases significantly to 0.26 cm/year in age class over 50 years. The intersection of \( CAI \) and \( MAI \) curves occurs in stand age 31-35 year old age. This indicates optimal diameter growth occurs over that time period. The stand age can describe the variance of diameter with high level of accuracy. Conversely, stand height cannot be explained by age. Accumulation of tapping scars becomes a limiting the incense productivity. The optimal incense production is achieved at maximum growth of diameter and minimal tapping scars accumulation. The average incense productivity is 159.28 g/tree/harvest period, and the average incense production is 318.59 g/tree/year. The average incense productivity is 11.37 g/tapping point/harvest.

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