ISSN 1341-562X

JOURNAL OF FOREST PLANNING

Vol. 16 No. 2
February, 2011

Japan Society of Forest Planning

JOURNAL OF FOREST PLANNING

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JOURNAL OF FOREST PLANNING is pubished halfyearly. The subscription for one year is 5,000 yen and the single issue price is 2,500 yen. Subscription orders can be sent to following office.

Toho Shoten
343 Yamabuki-cho
Shinjuku-ku, Tokyo 162-0801, Japan
Phone: +81-3-3269-2131, Fax: +81-3-3269-8655
http://www.toho-shoten.co.jp

JOURNAL OF FOREST PLANNING is published by
Japan Society of Forest Planning
University Forests, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan

JOURNAL OF

FOREST PLANNING

Vol.16, No.2 February, 2011

Japan Society of Forest Planning

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Articles

Article

Modeling Survival and Destruction of Teak Plantations in Java, Indonesia

Tatang Tiryana*[1,2], Satoshi Tatsuhara*[1] and Norihiko Shiraishi*[1]

ABSTRACT

Teak plantations in Java show severely declining productivity due to various disturbances. The risk of stand destruction, however, is still ignored in determining annual allowable cuts, partly due to the lack of reliable methods to estimate the rate of stand destruction. This study therefore proposed an alternative method, based on the theory of survival analysis coupled with forest register data, for estimating survival probability and destruction rate of teak plantations. We used the forest register data of teak plantations in Kebonharjo, Central Java, for the period 1977–2007. Survival and destruction of plantations were modeled using probability distribution models. To estimate model parameters, we used the maximum likelihood estimation method designed for left-truncated and right-censored data. Results showed that survival probability and destruction rate varied over stand age and planning period. Rates of stand destruction were relatively low (< 2% per year) in the period 1977–1987, but increased up to 3% and 14% per year in the period 1987–1997 and 1997–2007, respectively. The highest rate of destruction mostly occurred in young stands (≤ 30 years old), indicating an alarming condition for the sustainability of teak plantations. The survival and destruction models are useful for forest managers to quantify the range of historical variability in forest disturbances and to support the development of alternative harvest scheduling methods that incorporate the risk of stand destruction for teak plantations in Java. The proposed method can also be applied to other regions, especially when only forest register data are available.

Keywords: teak, destruction rate, survival analysis, Weibull, log logistic

INTRODUCTION

Teak (*Tectona grandis* L.f.), the main plantation species in Java, has been managed for over 100 years to produce high-quality timber. Javanese teak plantations account for 62.3% (about 1.1 million ha) of the total area of plantations in Java (Perum Perhutani, 2006) and about 31% of the total area of teak plantations in the world (Pandey and Brown, 2000). Such a great resource has obviously provided many benefits not only for generating national income, but also for supporting the livelihoods of rural communities located in surrounding forests in Java.

Recently, teak plantations in Java, which are managed by Perum Perhutani (PP, a state-owned forestry enterprise), have been facing the serious issue of declining productivity of stands. Between 1994 and 2004, total productive stands decreased from 586,982ha to 479,106ha, a loss of 18.4% (Ichwandi, 2008). This loss was caused by disturbance agents such as illegal logging, forest fire, and grazing (Bailey and Harjanto, 2005; Ichwandi, 2008; Perum Perhutani, 2006). Forest disturbances, which accelerated during the period of economic crisis (1998–1999), have caused severe destruction that has drastically changed the age structure of teak plantations. Current teak plantations are mostly dominated by young stands (≤ 30 years old), which account for approximately 81% of the total productive stands (Perum Perhutani, 2006).

Although the effect of forest disturbances on teak plantations is obvious, the potential risk of stand destruction is still ignored in current forest management planning, especially when PP determines annual allowable cuts (AAC) for a certain forest management unit (FMU). Smartwood (2000) argued

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that ignoring the risk of stand destruction in determining AAC using the existing harvest scheduling method, which is a combination of area and volume controls (Perum Perhutani, 1974), may not ensure the sustainability of teak plantations. Currently, PP is seeking an alternative harvest scheduling method that takes the risk of stand destruction into account in order to support sustainable forest management of teak plantations. Thus, estimating survival and destruction of teak plantations is required for supporting the development of alternative harvest scheduling methods. A number of researchers have also noted the importance of estimating survival probability or destruction rates of forest stands for determining harvest levels at risk of destruction. Among others, Reed and Errico (1986) made several assumptions about fire destruction probabilities in their proposed harvest scheduling model to determine optimal harvest levels. Armstrong (2004) derived fire destruction probability from a lognormal model to evaluate the effect of catastrophic disturbances on optimal timber harvesting. Bettinger (2010) also emphasized that disturbance rates have commonly been used in forest planning models.

Currently, there are still few methods or models to estimate survival probability and destruction rate of teak plantations. Commonly, PP uses a geometric mean of the proportions of damaged stand areas in each age class as an estimate of 10-year destruction rates (Perum Perhutani, 2007a). Such a simple calculation of destruction rates has limitations in assessing the trend and dynamics of forest disturbances (see Woodall *et al.*, 2005) that might depend on stand age (see Moritz *et al.*, 2009 for an example of age-dependent fire destruction rates). In addition, such approach cannot provide a means to derive destruction rates for any time step (e.g., 1-year or 5-year destruction rates), which are often desirable for evaluating the effect of disturbances on forest resources. For example, Armstrong *et al.* (2003) used an annual burn rate derived from a lognormal distribution to project the development of forest structures, while Armstrong (2004) used a decadal burn rate derived from such lognormal distribution to evaluate the sustainability of timber harvest at risk of wildfire. Thus, an alternative method that provides parametric models for estimating survival probability and destruction rate is required to support better management of teak plantations.

A promising method to estimate survival probability or destruction rate of teak plantations is survival analysis, a statistical method for analyzing the lifetime of biological organisms or mechanical systems (Collett, 2003; Klein and Moeschberger, 2003; Lawless, 2003). This method has been widely used in medical and biological sciences and other fields, for example, engineering sciences (called reliability or renewal theory) and social sciences (called event history analysis), but relatively few studies have used this method to model the survival or destruction of forest stands. The principle of renewal theory was first adopted by Suzuki in Japan in 1959 (see Randall and Gadow, 1990; Suzuki, 1984), who developed the theory of *gentan* (a Japanese word meaning reduction or diminution) probability, which is defined as the probability that forest stands will be harvested within a certain period after planting (Suzuki, 1984; Yoshimoto, 2001). Suzuki developed the *gentan* probability theory in an attempt to revise the concept of normal forest (an ideal forest condition with the same area for each age class) by considering that forest stands may experience clear-cutting at a specific age class. A similar attempt was made by Kouba (1989; 2002), who also proposed a revision of the concept of normal forest by considering the probability of stand destruction due to calamities (e.g., snow, wind, and other natural disturbances). Although Kouba (1989; 2002) used reliability theory for modeling the survival of forest stands, a need remains to improve the estimation method of survival models (Gadow, 2000). Moreover, the estimation of parametric models for deriving *gentan* probability has been a research issue for several decades in Japan. Among others, Blandon (1991) introduced censored sample theory, which is widely used in survival analysis, to improve the estimation method of *gentan* probability. Fujikake (2003) further discussed the applicability of survival analysis for estimating *gentan* probability by taking into account the issue of censoring and truncation of forest register data.

Few studies have attempted to use the theory of survival analysis for addressing natural resource management problems in tropical countries. Vance and Geoghegan (2002) used survival analysis linked with satellite imagery and socioeconomic data to investigate deforestation in southern Mexico. Similarly, Greenberg *et al.* (2005) used survival analysis and satellite imagery to estimate deforestation rates over time in the lowland rain forests of eastern Ecuador. To our knowledge, no studies to date have used survival analysis for modeling the survival or destruction of plantation forests at the FMU level in tropical countries using forest register data obtained from standard forest inventory techniques. We consider that survival analysis as demonstrated by Fujikake (2003) could be extended for modeling survival and destruction of teak plantations.

This study focused on developing survival and destruction models as a first attempt to support the development of alternative harvest scheduling models of teak plantations. Specifically, the objectives of this study were: 1) to demonstrate the applicability of survival analysis coupled with forest register data as an alternative method for estimating the survival and destruction of teak plantations, 2) to develop models for estimating destruction rates of teak plantations in a selected FMU located in Central Java, Indonesia, between 1977 and 2007, and 3) to discuss the applicability of the proposed method for supporting the management of teak plantations.

MATERIALS AND METHODS

Study Area

The study was conducted at Kebonharjo FMU, which is one of 57 FMUs managed by PP, located in Central Java, Indonesia (6°37'15"–6°58'8" S, 111°26'29"–111°43'11" E; Fig. 1). The total area of Kebonharjo FMU is 17801.3ha, divided into four forest divisions: Balo (5,544.0ha), Merah (5,610.1ha), Tuder (4,001.9ha), and Gunung Lasem (2,645.3ha). While the first three divisions are managed for teak production, Gunung Lasem is managed for conservation purposes because it is a habitat for various flora and fauna with high conservation value. This FMU has a dry season of 5 months (May–September), with annual rainfall (during the period 2002–2005) of 720–1,155mm (PERUM PERHUTANI, 2007a).

Teak is the main plantation species in the FMU, accounting for 71.2% (12,678.8ha) of the total area, which is managed for producing high-quality timber. The plantations are managed by clear-cutting with an artificial regeneration system. Before 2007, the rotation period was 80 years and regeneration was conducted by involving forest villagers through a *tumpangsari* program (PERUM PERHUTANI, 2007a). *Tumpangsari* is a type of agroforestry whereby forest villagers can use forest land for planting agricultural crops (e.g., rice, corn, cassava, soybean, and tobacco) for 2 years, if they also plant and maintain teak trees during this period (PELUSO, 1992). This program is widely implemented in Java for establishing plantation forests and can provide mutual benefits for forest villagers and FMUs.

Data Collection and Preparation

To analyze the survival of teak plantations, using long-term life history data of teak plantations would be more appropriate, but such data were not available. As an alternative, this study used forest register data of Kebonharjo FMU (consisting of Balo, Merah, and Tuder forest divisions) for the period 1977–2007 (PERUM PERHUTANI, 1977; 1987; 1997; 2007b). These data were also used by PP to develop a 10-year management plan for teak plantations for the planning periods 1977–1987, 1987–1997, and 1997–2007.

The forest register data, which came from periodic forest inventories (10-year measurement cycle), contained reliable information about teak stands in each sub-compartment, e.g., the size of stands (in hectares), stand variables (e.g., top height, basal area, and age), and a brief description of stand conditions. PP classified the condition of teak stands in each sub-compartment into productive or unproductive stands based on the basal area density index (GDI), which is defined as the ratio between the current basal area (from forest inventory) and normal basal area (from normal yield tables). The productive stands consist of teak stands with a GDI of at least 0.60 (regardless of stand age), which would survive into the future. The unproductive stands consist of three categories: bare land (stands with GDI < 0.05 regardless of stand age), undergrowth (stands ≤ 40 years old and GDI from 0.05 to 0.59 or stand > 40 years old and GDI from 0.05 to 0.30), and understocked (stands > 40 years old and GDI from 0.31 to

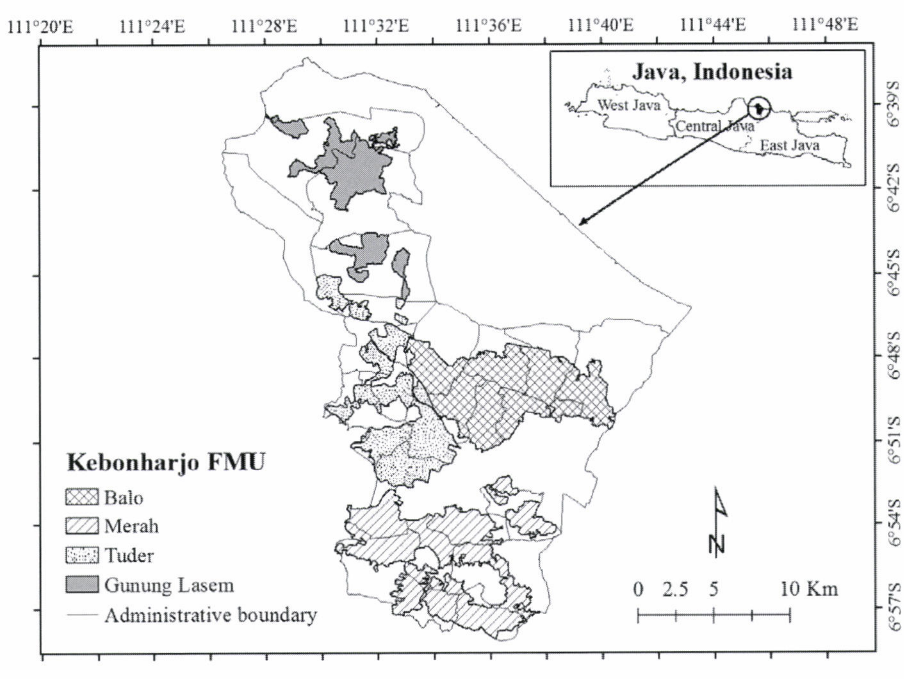

Fig. 1 Kebonharjo FMU, Central Java, Indonesia

0.59), which resulted from various forest disturbances that occurred during a certain planning period. These unproductive stands would be harvested (called salvage-cutting) and regenerated as soon as possible within a 10-year planning period (PERUM PERHUTANI, 1974). While the productive stands of a specific age class moved to the next age class, the harvested unproductive stands of any age class returned to the first age class in the next planning period.

To perform a survival analysis, it was necessary to define an observation unit. Following some previous studies (e.g., BLANDON, 1991; 1993; FUJIKAKE, 2003; HOLECY and HANEWINKEL, 2006; RANDALL and GADOW, 1990), this study used stand area (in hectares) as the observation unit by assuming that 1 ha of stand represents one observation unit. The number of sub-compartments could not be used as an observation unit, because the boundary and number of sub-compartments after salvage-cutting would change in the following planning period. As a result, the number of sub-compartments varied among planning periods, although the total area of teak plantations remained relatively constant.

To easily calculate the number of damage stands from the forest register data, we summarized the productive stands into seven age classes with 10-year intervals by considering that the FMU actually harvested some stands at ≥ 71 years old, which PP calls a minimum cutting age for a rotation of 80 years. Such an age class limitation also aimed to ensure that the loss of productive stands in each age class was merely caused by disturbances that occurred before the final cutting. As a result, we obtained a so-called forest resource table (FUJIKAKE, 2003), which tabulated total standing areas for each age class during the period 1977–2007. By comparing total standing areas at the beginning of one planning period to another (i.e., 1977 and 1987, 1987 and 1997, and 1997 and 2007), the area of damaged stands (i.e., unproductive stands according to PP's classification) between age t and $t+10$ years ($1 \leq t \leq 60$), $d_{\delta t}$, was calculated as follows (see also FUJIKAKE, 2003):

$$d_{\delta t} = r_{\delta t} - c_{\delta t} \quad (1)$$

where $r_{\delta t}$ is the standing area (ha) of age t to $t+10$ years at the beginning of the first period (e.g., 1977) and $c_{\delta t}$ represents surviving stand areas (i.e., productive stands according to PP's classification, ha) of age t to $t+10$ years in the first period that move to the next age class in the beginning of the second period (e.g., 1987). These data were then used for survival analysis of teak plantations.

In addition to the forest register data, we also used supporting documents (e.g., management plans and research papers) to explain possible causes of stand destruction that could not be revealed from the forest register data. Field observations and interviews with the FMU staff were also carried out to obtain a better understanding of stand destruction in the study area.

Developing Survival and Destruction Models

We adopted the theory of survival analysis to model the survival and destruction of teak plantations. Comprehensive discussions about this method are available in numerous statistical books, e.g., COLLETT (2003), KLEIN and MOESCHBERGER (2003), LAWLESS (2003), and NELSON (1982). Here, we only discuss an appropriate method for developing survival and destruction models based on forest register data.

Several methods developed in survival analysis are suitable for specific types of data. FUJIKAKE (2003) pointed out that data summarized into a forest resource table are left-truncated and right-censored (LTRC). As in our case, the forest resource table did not represent complete information about the lifetime of teak plantations from planting until to the end of their life. The 10-year periodical forest inventory observed the lifetime of existing stands during a 10-year period, so that it only represented a partial snapshot of the lifetime of stands from age t to $t+10$ years (Fig. 2). For a specific age class, no information was available about stands that experienced damage before age t years (e.g., 21 years for age class 3), implying that the lifetime of existing stands was left-truncated at the lower limit of an age class (FUJIKAKE, 2003; LAWLESS, 2003). During the 10-year period, some stands in an age class were damaged by various disturbance agents, although we did not know the exact time when destruction occurred between age t and $t+10$ years; however, some other stands would still survive until a specific time in the future. Because the surviving stands were only observed until age $t+10$ years for each age class (e.g., 30 years for age class 3), the

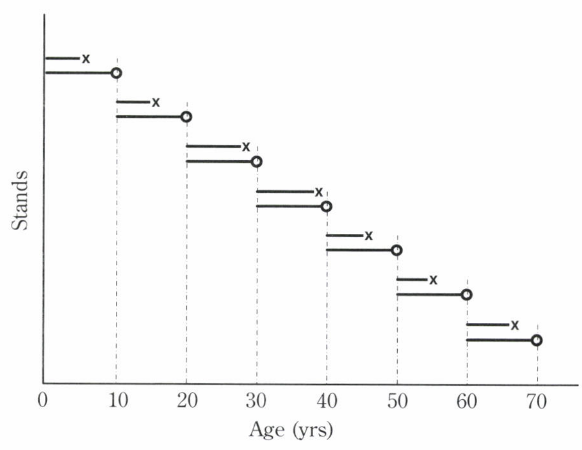

Fig. 2 Illustration of the construction of the survival function for teak plantations based on left-truncated and right-censored (LTRC) data (adapted from FUJIKAKE, 2003) The horizontal line with crosses (**−x**) indicates stands experiencing damage in the interval between age t and $t+10$ years, while the horizontal line with circles (**−o**) indicates stands that are probably still alive beyond age $t+10$ years. The lifetime of stands is left-truncated at age t years and right-censored at age $t+10$ years.

lifetime of these stands was right-censored at the upper limit of an age class (Fig. 2). Based on the snapshots of the lifetime of existing stands from age t to $t+10$ years, we reconstructed the survival function of teak plantations that showed a continuous trend in survival from age 1 to 70 years, as we were following the fate of entire teak stands from planting until the end of rotation (see also SKALSKI *et al*., 2005). Following KOUBA (1989) and HOLECY and HANEWINKEL (2006), we modeled the survival and destruction of teak plantations according to stand ages in order to provide survival and destruction models that can be used to derive destruction rates for any time step within a 10-year period. Such age-based models could be incorporated into an alternative harvest scheduling model (see e.g., ARMSTRONG, 2004; REED and ERRICO, 1986).

The probability of an individual stand surviving beyond age t, implying that stand destruction has not occurred by age t, can be expressed by the survival function, $S(t)$, as follows (COLLETT, 2003; KLEIN and MOESCHBERGER, 2003; LAWLESS, 2003; NELSON, 1982):

$$S(t)=P(T\geq t)=1-F(t)=\int_t^{\infty} f(t)dt \quad (2)$$

where T is a continuous random variable of the lifetime or age of stands with a certain probability density function ($f(t)$) and cumulative distribution function ($F(t)$). The instantaneous rate of destruction at age t, given that the stand survives up to age t, is quantified by the following function:

$$h(t)=\lim_{\Delta t\to 0}\frac{P(t\leq T<t+\Delta t\mid T\geq t)}{\Delta t}=\frac{f(t)}{S(t)} \quad (3)$$

This latter function is commonly termed a hazard function in the theory of survival analysis (see e.g. KLEIN and MOESCHBERGER, 2003), but for the purpose of this study, we termed it a destruction function (see also HOLECY and HANEWINKEL, 2006; KOUBA, 1989).

To estimate the survival and destruction functions of teak plantations, we used the maximum likelihood estimation (MLE) method (see e.g., KLEIN and MOESCHBERGER, 2003; LAWLESS, 2003). For LTRC data, the likelihood function consisted of two components: the density function of stand that are damaged at a certain age in the interval (t, $t+10$), $d_{\delta t}$, conditional on that stands survived to age t, and the survival function of stands that survive beyond age $t+10$, $c_{\delta t}$, conditional on stands having survived to age t, which was formulated as follows (FUJIKAKE, 2003; LAWLESS, 2003):

$$L=\prod_{0\leq t\leq 60}[P(t\leq T<t+10\mid T\geq t)]^{d_{\delta t}}[P(T\geq t+10\mid T\geq t)]^{c_{\delta t}} = \prod_{0\leq t\leq 60}\left[\frac{S(t)-S(t+10)}{S(t)}\right]^{d_{\delta t}}\left[\frac{S(t+10)}{S(t)}\right]^{c_{\delta t}} \quad (4)$$

The number of damaged stands ($d_{\delta t}$) and surviving stands ($c_{\delta t}$) in this likelihood function was calculated using Eq. (1). We used five probability distribution models: gamma, Weibull, exponential, log logistic, and lognormal (Table 1) in the likelihood function (Eq. (4)), which are commonly used in survival analysis. Appropriate survival models for each planning period were selected based on Akaike's information criterion (AIC; KLEIN and MOESCHBERGER, 2003):

$$AIC=-2logLik+2p \quad (5)$$

where $logLik$ is the log-likelihood value of the likelihood function (Eq. (4)) and p is the number of model parameters ($p=1$ for the exponential model, $p=2$ for the gamma, Weibull, log logistic, and lognormal models). Models with lower AIC

Table 1 Probability distribution models used in the survival analysis of teak plantations (adapted from KLEIN and MOESCHBERGER, 2003; LAWLESS, 2003; NELSON, 1982)

Model	Probability density function ($f(t)$)	Survival function ($S(t)$)	Destruction function ($h(t)$)
Gamma	$\frac{1}{\beta^{\alpha}\Gamma(\alpha)}t^{\alpha-1}\exp(-(t/\beta))$	$1-I(\beta t,\alpha)$	$\frac{f(t)}{S(t)}$
Weibull	$\frac{\alpha}{\beta^{\alpha}}t^{\alpha-1}\exp(-(t/\beta)^{\alpha})$	$\exp(-(t/\beta)^{\alpha})$	$\frac{\alpha}{\beta^{\alpha}}t^{\alpha-1}$
Exponential	$\lambda\exp(-\lambda t)$	$\exp(-\lambda t)$	λ
Log logistic	$\frac{\alpha t^{\alpha-1}\lambda}{(1+\lambda t^{\alpha})^2}$	$\frac{1}{1+\lambda t^{\alpha}}$	$\frac{\alpha t^{\alpha-1}\lambda}{1+\lambda t^{\alpha}}$
Lognormal	$\frac{\exp\left(-\frac{1}{2}\left(\frac{\ln t-\mu}{\sigma}\right)^2\right)}{\sigma t\sqrt{2\pi}}$	$1-\Phi\left(\frac{\ln t-\mu}{\sigma}\right)$	$\frac{f(t)}{S(t)}$

α, β, λ, μ, σ are model parameters; t is stand age (years); $I(\beta t,\alpha)=\left(\int_0^t x^{\alpha-1}\exp(-x)dx\right)/\Gamma(\alpha)$ is a gamma density function; $\Phi(x)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x}\exp(-u^2/2)du$ is the cumulative density function for standard normal distribution.

values and having simpler forms were considered appropriate for estimating the survival probabilities and destruction rates of teak plantations.

RESULTS

The age structure of teak plantations during three planning periods (1977–2007; Fig. 3) clearly showed that these plantations never reached normal forest conditions where all age-classes are represented by equal areas. The plantations were mostly dominated by younger stands, especially those in age classes 1–3. The damaged stands were relatively few (about 11% of total stand area of age classes 1–7) in the first planning period (1977–1987, Fig. 3a), but then increased (to about 24% of the total stand area) in the second planning period (1987–1997, Fig. 3b). The most severe damage occurred in the third planning period (1997–2007, Fig. 3c), in which 56% of the total stand area was damaged by various factors. For each planning period, younger stands (≤ 30 years old) tended to experience more severe damage than older stands.

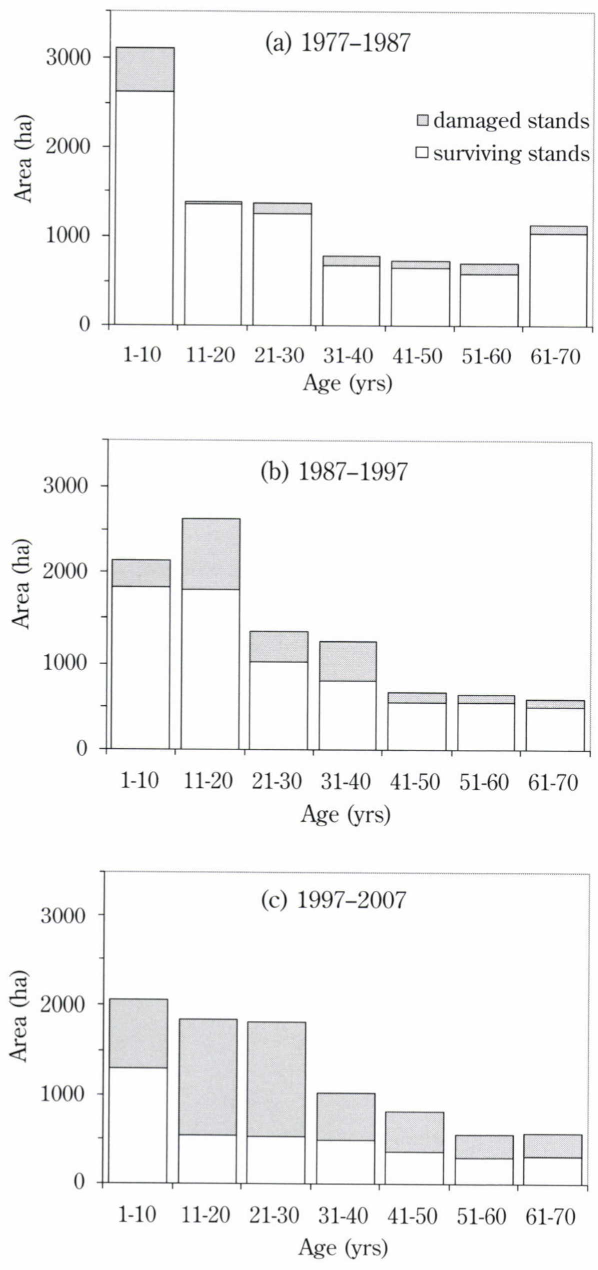

Fig. 3 Age structure of teak plantations in Kebonharjo FMU for the period 1977–2007

The surviving and damaged stand data (Fig. 3) were modeled using the gamma, Weibull, exponential, log logistic, and lognormal distributions (Table 2). The resulting AIC values indicated that no single model was applicable for all planning periods. For the first planning period, the gamma model was the best-fitting model with the lowest AIC value (6,405.583). However, this model was only slightly better than the Weibull model (AIC = 6,413.091) that had simpler functions. Thus, the Weibull model was used to estimate survival probability and destruction rate of the first planning period. For the second and third planning periods, the survival probability and destruction rates were well estimated by the log logistic model. This model consistently produced the lowest AIC values (9,973.193 and 11,220.475) compared to the

Table 2 Parameter estimates and AIC values of the gamma, Weibull, exponential, log logistic, and lognormal models used to estimate the survival probability and destruction rate of teak plantations

Model	Estimates	Period		
		1977–1987	1987–1997	1997–2007
Gamma	α	0.783	1.291	1.627
	β	130.348	28.132	8.997
	logLik	−3,200.791	−5,070.961	−5,799.571
	AIC	6,405.583	10,145.921	11,603.141
Weibull	α	0.847	1.113	1.165
	β	96.793	37.704	14.653
	logLik	−3,204.546	−5,084.570	−5,856.759
	AIC	6,413.091	10,173.141	11,717.518
Exponential	λ	0.012	0.027	0.082
	logLik	−3,219.937	−5,097.833	−5,919.560
	AIC	6,441.874	10,197.666	11,841.120
Log logistic	α	1.00573	1.74212	3.18770
	λ	0.01511	0.00359	0.00034
	logLik	−3,226.706	−4,984.596	−5,608.237
	AIC	6,457.413	9,973.193	11,220.475
Lognormal	μ	4.164	3.248	2.483
	σ	1.695	0.957	0.630
	logLik	−3,242.556	−4,989.233	−5,625.168
	AIC	6,489.112	9,982.466	11,254.337

Note: *logLik* is the log-likelihood value (see Eq. (4)).

other models.

The Weibull and log logistic models resulted in different survival curves (Fig. 4a). The survival probabilities were high in the first planning period, but drastically decreased in the following planning periods. For example, the survival probabilities of teak stands at age 30 years were 0.69, 0.43, and 0.05, meaning that only about 69%, 43%, and 5% of newly planted teak stands could survive to age 30 years if the damage trends, which were similar to those of the first, second, and third planning periods, respectively, constantly continue into the future. The steepest fall of the survival curve at age ≤ 30 years in the third planning period indicated that most young stands failed to survive beyond age 30 years.

The risks of stand destruction during the period 1977–2007 are well illustrated by the destruction rates derived from the Weibull or log logistic models (Fig. 4b). The destruction rates of teak plantations varied with stand age and seemed to increase from one planning period to another. In the first planning period, destruction rates monotonically decreased with increasing stand age (i.e., from 0.018 to 0.009 per year, or from about 2% to 1% per year) when teak stands reached age 1 and 70 years, respectively. In the second and third planning periods, however, the destruction rates formed hump-shaped patterns in which they initially increased until a certain peak and then decreased with increased stand age. The destruction rates reached peaks of 3.5% per year when stands reached 21 years old at the second planning period, and 14% per year when stands reached 16 years old at the third planning periods. During the last two planning periods, the destruction rates of young stands (≤ 30 years old) were higher than those of mature stands.

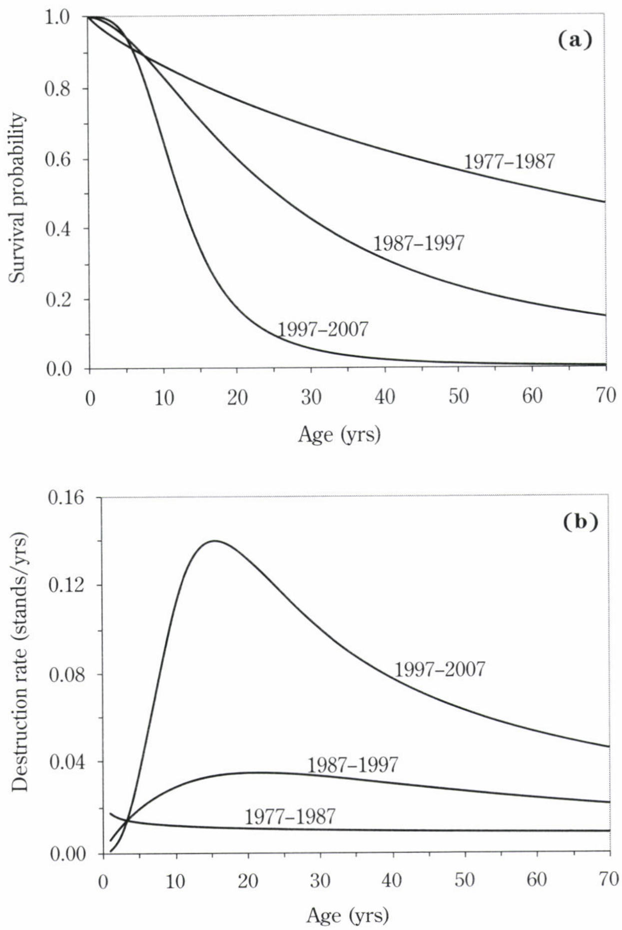

Fig. 4 Survival probability (a) and destruction rate (b) curves for teak plantations in Kebonharjo FMU between 1977 and 2007
The curves of survival probability and destruction rate for the period 1977–1987 were derived from the Weibull model, while those for the periods 1987–1997 and 1997–2007 were derived from log logistic models.

DISCUSSION

The results showed that the Weibull and log logistics models were appropriate for modeling the survival and destruction of teak plantations. The Weibull model is the most widely used probability distribution model for survival analysis (LAWLESS, 2003). This model offers a flexible shape of probability distribution; it reduces to an exponential model if the shape parameter $\alpha = 1$, which is also a unique property of the gamma model (KLEIN and MOESCHBERGER, 2003; LAWLESS, 2003; NELSON, 1982). Compared to the gamma model, which has gained popularity in the study of *gentan* probability (see e.g. BLANDON, 1991; 1993; FUJIKAKE, 2003), the Weibull model has more simple probability functions (Table 1) that facilitate easier calculation of the survival probability or destruction rate. Previous studies also showed that the Weibull model was suitable for modeling stand destruction due to calamities (e.g., HOLECY and HANEWINKEL, 2006; KOUBA, 1989; 2002), and RANDALL and GADOW (1990) suggested it as an alternative model for estimating *gentan* probability in lieu of the gamma model.

The Weibull and log logistic models show that the destruction risk of teak plantations is age-dependent, meaning that the rates of stand destruction vary over stand ages. Damage to young teak stands might be caused by forest fire, grazing, and/or fuelwood collection. Forest fire, which occurs every year and is caused by humans and natural factors, has greater potential to damage young stands (< 5 years old) than older stands because older stands are more resistant to fire (SYAUFINA *et al.*, 2007). Grazing of villager's livestock (e.g., cows, buffalos, and goats) and fuelwood collection are serious problems for young teak stands. Cattle cause damage by browsing and trampling young trees while they feed (BAILEY and HARJANTO, 2005), resulting in broken stems and soil compaction in young teak stands. Similarly, fuelwood collection conducted by villagers damages young teak stands because villagers tend to slash branches of smaller trees that are easier to handle (BAILEY and HARJANTO, 2005) instead of collecting fallen branches of mature trees. Moreover, damage in mature stands is mostly caused by illegal logging or timber theft (PERUM PERHUTANI, 2007a), which has been recognized as the most important factor for stand destruction of teak plantations in Java for hundreds of years (PELUSO, 1992).

Unlike some studies on *gentan* probability that commonly used a gamma model for fitting data of multiple time periods (e.g., BLANDON, 1991; 1993; FUJIKAKE, 2003), this study suggests that a certain probability distribution model may not applicable for modeling stand destruction of teak plantations at different time periods. The use of different models is reasonable because forest disturbances may change over time. MCCARTHY *et al.* (2001) argued that different probability distribution models should be considered when modeling fire interval distributions, because the probability of fire can be affected by various biological factors that might change over time. In our case, the Weibull model was only applicable for estimating survival and destruction of teak plantations in the period 1977–1987, while the log logistic models were applicable for the period 1987–1997 and 1997–2007. The forest register data for the period 1977–1987 (Fig. 3a) show that younger stands (≤ 10 years old) experience more damage than older stands. Such a damage trend was well modeled using the Weibull model because this model can represent destruction rates that monotonically decrease as stand age increases (see LAWLESS, 2003). However, the other periods (1987–1997 and 1997–2007; Fig. 3b and 3c) had different damage trends, with damage increasing until a certain peak in younger stands and then decreasing toward older stands. These unimodal damage trends were well represented by the log logistic models rather than the Weibull model. The differences in intensity of forest disturbances during the three planning periods are a possible reason for the difference in survival and destruction models. PERUM PERHUTANI (2005) reported that after the economic crisis (1998–1999) the total loss of standing trees due to illegal logging in the study area was about 60 times more than before (1995–1997), resulting in severe damage during the period 1997–2007 compared with the other periods (Fig. 4b). Unfortunately, comprehensive historical data on forest disturbances in the FMU are not available (see also SMARTWOOD, 2000), making it difficult to quantify and compare the amount and intensity of each disturbance agent (i.e., illegal logging, forest fire, grazing, and fuelwood collection) for each period.

The models (Table 2) provide useful tools for forest managers to quantify the range of historical variability (LANDRES *et al.*, 1999) in forest disturbances of teak plantations. Compared to the existing approach used by PP (i.e., using a geometric mean of the proportions of damaged areas), the destruction rate curves (Fig. 4b) offer a better understanding of the variability of destruction rates. Such destruction rate curve may allow a broad comparison of destruction rates (WOODALL *et al.*, 2005) among stand ages and planning periods. The results clearly show that young stands always experience higher destruction than mature stands, suggesting that forest managers should conduct appropriate management activities (e.g., controlling disturbance agents and implementing appropriate silvicultural treatments) for ensuring the sustainability of teak plantations. In addition, the destruction rate curves may also provide better insights into the trend and dynamics of forest disturbance over time. The destruction rates could be considered low (< 2% per year), medium (up to 3.5% per year), and high (up to 14% per year) for the periods 1977–1987, 1987–1997, and 1997–2007, respectively. Such destruction rate levels may represent the variability of historical disturbances of teak plantations during 30 years, which can be used to develop forest management plans based on natural variability concepts (see LANDRES *et al.*, 1999).

More importantly, as stated in the study objectives, the models can be used to support development of alternative harvest scheduling methods for teak plantations in Java that incorporate the risk of stand destruction. ARMSTRONG (2003) argued that quantifying destruction rates is an important aspect in determining harvest levels that incorporate the rate of forest disturbances. Because the potential risk of forest disturbances cannot be predicted precisely (BETTINGER, 2010; KOUBA, 1989), historical destruction rates derived from previous planning periods may provide reasonable measures for assessing the effect of stand destruction on harvest levels. Some previous studies have proposed alternative harvest scheduling methods for integrating the risk of stand destruction into harvest levels. Among others, REED and ERRICO (1986) were one of the researchers who initially developed methods that incorporate stand destruction due to wildfire into a linear programming framework for determining optimal harvest levels. Similarly, KOUBA (1989) demonstrated the applicability of survival models coupled with linear and stochastic programming models for determining optimal harvest levels with an attempt to achieve a normal forest condition. Such proposed harvest scheduling models can be further developed for determining optimal harvest levels of teak plantations at risk of destruction. In this case, the survival or destruction models of this study can be integrated in such alternative harvest scheduling models.

This study proposes a promising method based on the theory of survival analysis coupled with forest register data to estimate the survival probability and destruction rate of teak plantations. The use of forest register data to assemble the complete age structure of plantations is an appropriate way to analyze survival or destruction of long-rotation plantations such as teak, because time series data on the fate of plantations from the time of their planting to the end of rotation are very difficult to obtain. Although the forest register data may only represent the age structure of plantations at a specific time, these data are easier to obtain from the existing forest inventory. Such data are also commonly used in fire frequency analysis (MORITZ *et al.*, 2009), survival analysis of wildlife (SKALSKI *et al.*, 2005), and survival analysis in large clinical trials (NELSON *et al.*, 2008). More importantly, the estimation of model parameters using the MLE method designed for LTRC data (Eq. (4)) provides an improvement to the estimation method proposed by KOUBA (1989; 2002). The proposed method, however, has a limitation because survival probability or destruction rate may not constant over time (SKALSKI *et al.*, 2005). The results also show that stand destruction varied over planning periods (Fig. 4), and thus the population age structure may change over time (SKALSKI *et al.*, 2005). The survival and destruction models developed from this method should be used to evaluate the risk of stand destruction for a particular site and time period. Nevertheless, the models will provide useful tools for improving the existing harvest scheduling method of teak plantations that still ignores the potential risk of stand destruction.

CONCLUSIONS

This study demonstrated the applicability of survival analysis coupled with forest register data to evaluate the survival and destruction of teak plantations during three planning periods (1977–2007). The Weibull and log logistic models showed that the survival probability and destruction rate of teak plantations were vary over stand age and planning period. The survival models estimated that only about 69%, 43%, and 5% of newly planted teak stands could survive to age 30 years if the damage trends, which were similar to those of the periods 1977–1987, 1987–1997, and 1997–2007, respectively, constantly continue into the future. In addition, the destruction models indicated that rates of stand destruction were relatively low (< 2% per year) during the period 1977–1987, but increased up to 3% and 14% per year in the period 1987–1997 and 1997–2007, respectively. The models also showed that the destruction rates of young teak stands were higher than those of older stands. These findings confirmed that teak plantations have always faced a high risk of stand destruction, suggesting that forest managers should conduct appropriate management activities to ensure the sustainability of teak plantations. The survival and destruction models can be used by forest managers to quantify the range of historical variability in forest disturbances, which can be integrated into alternative harvest scheduling methods for teak plantations. While the results of this study might be site-specific, the proposed method is applicable to other regions.

ACKNOWLEDGMENTS

We thank Perum Perhutani, especially the Division of Forest Planning in Rembang, for permission to use the forest register data, and the staff at Kebonharjo FMU who provided supporting documents. We also thank Dr. Teddy Rusolono of Bogor Agricultural University for valuable discussion about the management of teak plantations in Java. We appreciate the valuable comments and suggestions from anonymous reviewers that greatly improved the content of this manuscript.

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(Received 5 May 2010)
(Accepted 30 November 2010)

Article

Farmers' Traditional Management of Trees Outside Forests in Bangladesh

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ABSTRACT

A study has been conducted on management operations followed by rural farmers in their homestead agroforestry systems. Despite high socio-economic contribution, the management of this farming system is traditional in nature; scientific knowledge and techniques are lacking. Analysis of field data showed that an average of 16.9 seedlings were planted per farm in the preceding year and of those 15.6 were fruit species and 1.4 were timber species. The overall seedling survival rate was 77%. The farmers depended mostly on internal inputs although supplementary external inputs are also fed used. The farmers reported that they manually carried out cultural operations like weeding, mulching and fencing. Of the tree level management, pruning, pollarding, and thinning were done. For maintaining homestead forest production and its efficient management the study recommended judicious incorporation of drought tolerant native species at the farm level, creating appropriate institutional mechanisms within the forest department and development of market systems for homestead grown products.

Keywords: external inputs, homegardens, internal inputs, planting materials, silviculture

INTRODUCTION

Most of the natural forests of Bangladesh are distributed along southwestern, northeastern, and southeastern territorial boundary. Northwestern part lacks any natural forest cover. Weather of this region is very harsh with frequent incidence of drought-spells and a trend of desertification (Center For Environment And Geographic Information Cervices, 2006). Reduced or complete loss of agricultural production is a common phenomena (Food And Agriculture Organization, 2007). Life has become harder and food security became a matter of question for poor for whom agriculture is the only source of maintaining livelihood. In such a scenario it is important to identify and adopt measures to combat, reverse and adapt to the existing drought resulted from long-term climate variability and change. Homegardening in such an environment is regarded as a household-based coping strategy that can increase vegetation cover through plantation of trees in the vacant spaces, thereby impacting microclimate besides creating an option for livelihood adaptation to drought-caused disasters (Alam and Furukawa, 2008; Government Of Bangladesh, 2001).

Homestead agroforestry system (hereafter referred to as HAS), also popularly known as homegarden in literature, exists throughout the tropics in different names, for example *Pekarangan* in Indonesia (Christanty *et al.*, 1986), *Shamba* and *Chaga homegardens* in West Africa (Kumar and Nair, 2004). In these farming systems multipurpose trees, shrubs and herbaceous species are deliberately grown and managed within the compounds of individual homes (Fernandes and Nair, 1986). HAS of Bangladesh is similarly characterized by multi-storied vegetation of shrubs, bamboos, palms and trees surrounding homesteads that produce materials for a multitude of purposes, including fuel, shelter, structural materials, fruits and other foods, fodder, resins and medicines (Douglas, 1981). The vegetation are established and maintained for family consumption, additional family income (when products are sold in the market), and environmental services (e.g., microclimate amelioration).

Most of the available empirical studies from various countries deal with the system description and structure (e.g.

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Peyre *et al.*, 2006; Sood and Mitchell, 2008), and species diversity (e.g. Sunwar *et al.*, 2006; Acharya, 2006). Studies on the HAS of Bangladesh followed a similar trend; specific emphasis on management aspects are limited. In most literature authors point out that HAS management is traditional in nature although detailed management information extends sporadically from a few lines to a paragraph. Hence this article attempts to solely explore traditional HAS management operations followed by the farmholders in this tropical farming management system. The goal of this study is to inform how smallholder farmers of the drought-prone region adopted various management operations for their homestead farms. The article specifically explores collection and planting techniques of reproduction materials; farm inputs; and silvicultural operations, and further explores how those farmer adopted practices vary across landholding categories.

RESEARCH METHODS

A survey was conducted in the northwestern region (located between 24°54' and 25°06' north latitude and between 88°24' and 88°39' east longitude) of Bangladesh, as part of an ethnobotanical research project. Farm surveys were conducted in three randomly selected villages of Porsha *thana* (sub-district) of Naogaon district. It has a population of 97,279 with a number of ethnic nationals such as Kurmi, Munda, Pahan, Mura and Mal included. Agriculture is the main occupation (48.27%) followed by agricultural labour (29.01%). Among Peasants 20% are landless, 14% small and marginal, 30% medium and 36% rich (Banglapedia, 2010). Agroecologically, the study area belongs to Agroecological Zone-26 (High Barind Tract) (Food And Agriculture Organization, 1988), which is the largest Pleistocene physiographic unit of Bengal Basin. In Bengali, it is spelled and pronounced as *Verandra Bhumi* and known as the most drought-prone area of Bangladesh.

Data were generated through structured questionnaire survey at farm level, key informants interview with semi-structured questionnaire, informal group discussion and strategic field observation. Interviews with structured questionnaire generated information on collection, planting and survival of planting materials, rotation of trees and silvicultural treatments adopted for the various species cultivated within the HAS. Ninety-six randomly selected smallholder farmers from various land holding categories (marginal, < 0.4ha; small, 0.41-1.01ha; medium, 1.02-3.03ha; and large, > 3.03ha), slightly modifying the criteria of BBS (2001), were personally interviewed for this purpose. Data collected in this way were analyzed and presented in a crosstab format using descriptive statistics according to landholding size classes along with chi-squared (χ^2) tests of significance and Cramer's phi (φ) as a measure of strength of relationship between column and row variables.

RESULTS

Seedlings Plantation and Survival

Farmers were found to plant seedlings of various fruit and timber species all year round. Analysis of survey data showed that 16.9 seedlings on average were planted in the previous year per farm, and of those 15.6 were fruit species and 1.4 were timber species (Table 1). The farm-holders were found to have strong preference for planting fruit species. Overall survival rate was 77%, which is highest (89%) in marginal farms and lowest (68%) in large farms (Table 2). Mortality of planted seedlings was reported to be caused by inappropriate planting and sowing, lack of mechanical protection measures (e.g. fencing) at the early stage, insect or disease attack and natural calamity such as floods and storms (Table 3). Hocking *et al.* (1996), however, recorded the main causes of seedling mortality as damage by livestock, diseases and pests.

Findings presented in Table 1 further reveals, total number of planted seedlings increases, but the percentage of seedling survival falls as size of the farms increases. Such findings could be due to the fact that although marginal and small farms plant fewer seedlings, they take intensive care to make them survive, because they might not be able otherwise to replace seedlings that requires additional 'hard to manage'

Table 1 Seedling plantation in one year

	Marginal	Small	Medium	Large
Timber	1.3	1.1	1.6	1.8
Fruit	5.1	8.8	21.1	27.4
Total	6.4	9.9	22.7	29.2

Table 2 Survival rates of planted seedlings

	Marginal	Small	Medium	Large
Number	5.7	8.3	18.6	19.5
% of seedlings planted	89	85	82	68

Table 3 Causes of seedling mortality as reported by the farmers

Causes	Farmers reported (%)
Inappropriate planting and sowing	15
Insect or disease attach	35
Natural calamity	18
Cattle browsing	25
Damage by children	30
Unknown cause	32

money. It is noteworthy that although survival percentage is lesser, growth of survived seedlings is still better in the larger farms because of application of more intensive silvicultural treatment and management practices.

Farm Inputs and Planting Materials

The farmers mostly depend on internal inputs, with some supplementation from external sources. Family itself is a major source of farm labour throughout the year for simple management operations. Small-scale planting and fencing do not warrant hired labour force and is usually carried out by the household head. Other cultural practices including watering and weeding are carried out by other capable family members. However, hired labour is essential for cultural operations like pruning and pollarding. Sanitation pruning (as is done in case of coconut palms) also warrants specialized hired labour, as does tree felling. Farm inputs like manure, fertilizer, pesticides and planting materials are provided from both internal and external sources. Homestead-produced cow dung, corn straw and kitchen and agricultural residues are major sources of organic manure. Farmers purchase only small quantities of artificial fertilizers and pesticides when required. Fig. 1 depicts percentage of farmers who responded positively about use of fertilizers and pesticides, even if the quantity is small. The figure shows that larger farmers use higher amount of fertilizers and smaller farmers use higher amount of pesticides.

Seedlings, seeds, cuttings and clonally propagated materials all are used as planting materials. Selection of any particular type depends on the quality, availability, price and growth rate of that particular type. However, seedlings are most popular among all planting materials because of its ready availability, ease of maintenance and cost effectiveness. Seeds are used in the cases when the farmers wish that mother characteristics (e.g. sweetness and taste of fruits) be inherited to the offspring. Cuttings and other clonally propagated materials are popular for horticultural species (e.g. *Citrus* spp.).

There were four options to answer the question 'what is the source of planting materials' during the questionnaire survey. In answer, almost all respondents (92.5%) reported that they bought planting materials (particularly seedlings) from private nurseries. However, for fruit species grown in the homesteads, farmers are mostly dependent on self-saved seeds. After eating the fruits, the family members throw out seeds hither and thither for the sake of disposing off. Sprouting occur from many of those disposed seeds. Some plants are also propagated by dispersal of seeds and propagules by birds and animals. These thrown and dispersed seeds become tall fruit bearing trees in due course of time.

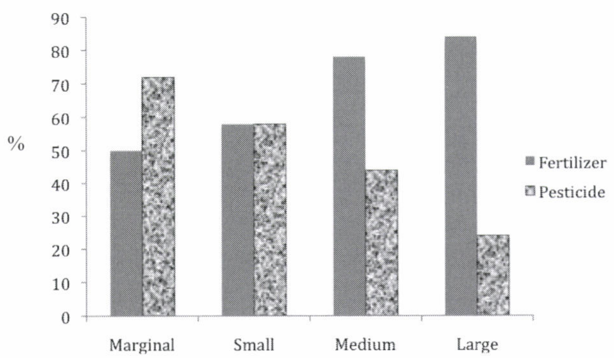

Fig. 1 Percentages of respondents using pesticide and fertilizer use in the homesteads

Silvicultural Treatments

The HAS is subject to light to moderate silvicultural treatments. Regarding various cultural operations, farmers reported that they manually carried out soil working, weeding, watering, mulching, and fencing for better survival and establishment of the plants, especially in the early stages of garden establishment. Table 4 presents the findings of the survey, along with chi-square and Cramer's statistics. Findings in the table reveal that most farmers practice weeding and soilwork, watering, fencing, mulching and fertilizing or manuring. To maintain growth of the seedlings planted, farmers usually apply manure. Fertilizers and pesticides, in contrast, are applied only in fewer instances. However, it can be noticed that both the application of fertilizers and pesticides increases with the increase of landholding size. Significant differences are observed in the χ^2 tests across farm size classes in the use of pesticide ($\chi^2=11.46$, $p=0.009$, df 3), fertilizer ($\chi^2=7.5$, $p=0.05$, df 3) and fencing ($\chi^2=9.78$, $p=0.02$, df 3).

Of tree level management, farmers carry out cultural practices such as thinning, pruning, and pollarding. It appears from Table 5 that the farmers carry out pruning with higher instances while thinning and pollarding are done with much fewer instances. However, it was found that the percentage of pruning increased with the increase in farm size. In addition, sanitation pruning is done for some species like coconut and betel nut in the hope of reducing disease susceptibility. Dead branches and debris are also removed for the same reason. Light pollarding is done to induce flowering and fruiting of some horticultural trees like jujube (*Ziziphus jujube*). Generally, pruning and pollarding both is done before the onset of monsoon so that new shoots can come out in the beginning of the growing season. Thinning is not very popular as a silvicultural operation among the farmers. In some cases, like in bamboos, however, selection felling of matured individuals is done that simultaneously relief the grove from congestion while giving the farmer an additional interim income. The χ^2 test statistics show no significant differences amongst the owners of various landholding size classes for these tree level management activities. The associated values

Table 4 Ground operations followed by the farmers in their homegardens

Silvicultural Operation	Alternative answers	Frequency	Total	χ^2	*p*-value	df	Cramer's φ
		N	73				
	Yes	%	76				
		N	23				
Soil working	No	%	24	0.17	0.9823	3	0.0421
		N	66				
	Yes	%	69				
		N	30				
Watering	No	%	31	0.97	0.8085	3	0.1005
		N	71				
	Yes	%	74				
		N	25				
Mulching	No	%	26	2.33	0.5068	3	0.1558
		N	73				
	Yes	%	76				
		N	23				
Fencing	No	%	24	9.78	0.0205	3	0.3192
		N	64				
	Yes	%	67				
		N	32				
Fertilizer application	No	%	33	7.5	0.0576	3	0.2795
		N	49				
	Yes	%	51				
		N	47				
Pesticide application	No	%	49	11.46	0.0095	3	0.3455

Table 5 Tree-level management techniques followed by the farmers

Management	Alternative answers	Frequency	Total	χ^2	*p*-value	df	Cramer's φ
		N	23				
	Yes	%	35				
		N	62				
Thinning	No	%	65	2.37	0.4992	3	0.1649
		N	71				
	Yes	%	74				
		N	25				
Pruning	No	%	26	1.03	0.794	3	0.1036
		N	29				
	Yes	%	30				
		N	65				
Pollarding	No	%	68	2.65	0.4488	3	0.1679

of Cramer's phi (φ) are also relatively lower indicating weaker relationships between column and row variables.

Rotation and Tending

Farmers opted for, as they reported, different rotations for different tree crops. Usually the rotation is determined based on intended end-use of a particular species. Timber species like teak (*Tectona grandis*), mahogany (*Swietenia macrophylla*), and silk trees (*Moris alba*) are maintained for medium to longer rotation while some fast growing species like acacia (*Acacia auriculiformis*) and eucalyptus (*Eucalyptus*

Table 6 Preference of rotation among the respondent farmers

Rotation	Farmers' preferred (%)
<12 years	12
12-20 years	26
> 20 years	52
No preference	10

camaldulensis), particularly grown for fuelwood, and bamboos are harvested on a rather shorter. Fruit bearing species like mango (*Mangifera indica*), jackfruit (*Artocarpus heterophyllus*), coconut (*Cocos nucifera*), and litchi (*Litchi chinensis*) are maintained for long rotation until these are naturally dead, wind thrown, or disease and insect attacked. The field survey revealed that majority of farmers preferred longer rotation (>20years) for fruit bearing and timber species while others preferred medium (12-20 years) and short rotation (<12 years) (Table 6). A small group of farmers remained indifferent of any choice of rotation. The findings further revealed that choice of rotation did not vary significantly across the farm size classes. It is noteworthy that the farmers used to fell aged fruit trees that have ceased to bear fruit after the fruit harvest and usually supplement the newly created space by planting several seedlings. Sometimes they were found to fell trees in case of family emergencies like need for cash money for wedding ceremony, treatment of ailment and buying land parcels or other valuable properties.

DISCUSSION

The farmers are well aware of the importance of pruning from silvicultural point of view. It is also popular because a substantial amount of fuelwood can be collected to meet the year round requirement for cooking. Fewer instances of thinning operation, on the other hand, may partly be attributed to the farmers' natural affinity to grow more plants in scarce land base. Moreover, adequate technical knowledge of necessity of thinning, species silviculture and crop interactions are also lacking among the farmers.

The farmers were not found to pay equal attention to all the species grown in the homestead premises. Those species, which generate cash income, are generally taken more care of. For instance, if a farmer has a number of mango trees from which mangoes are sold in the market, he takes good care of those. If, in contrast, the farmer has one or two mango trees used for family consumption, he may not be interested to provide higher attention. Some species, however, regardless of planting purpose, warrant intensive care as in the case of coconut trees. Additionally, when a farmer grows a species in commercial scale, intensive management practice is surely done.

Farmers' preference for fruit bearing species over timber and ornamental ones has become an established event (ABEDIN *et al.*, 1988; ALAM and MASUM, 2005; RAHMAN *et al.*, 2005; SNEDER *et al.*, 2007). This study is not an exception. The reason of such preference can be attributed to the cause that fruit trees in most cases are multipurpose in nature. Besides contributing to household food and nutritional security fruit species also produce timber, firewood and fodder for household consumption as well as for commercial purpose.

HAS management knowledge and techniques as adopted by the farmers can be regarded as 'internal input' to the system since virtually no government intervention exists to improve the systems (RAHMAN, 2006). In fact high dependency on the internal inputs is a characteristic feature of most tropical homegardens (PANDEY *et al.*, 2007; KEHLENBECK and MAASS, 2004; GAJASENI and GAJASENI, 1999), and such characteristics contribute to homegarden sustainability and resilience to an extent (KEHLENBECK and MAASS, 2006). Viability and sustainability of homegardens can also be attributed to labour force originated from family sources. KABIR and WEBB (2008) reported that family source provides a median of 4h/week of labour in management of HAS in Bangladesh. Labour investment from family source is also reported from other regions (e.g. MÉNDEZ *et al.*, 2001; NIÑEZ, 1987). However, farmers depended mostly on external sources to collect propagation materials. Although the government's policy is to supply high quality seedling in low price to the farmers, this policy is rarely implemented in the village-level where there lacks forest department's institutional support to address local demand. As a result, farmers were found to depend on private nurseries for planting materials with comparatively high price (sometimes as high as 3 times of government seedlings) and many poor farmers who were willing to plant trees could rarely afford to buy from private nurseries. The farmers were also found to sow seeds that they stored after consumption of fruits. Self-saved seed is also reported as a major source of planting materials in other tropical countries as in Nepal (SUNWAR *et al.*, 2006).

CONCLUSION AND POLICY IMPLICATIONS

Findings of the study reveal that the farmers manage their homestead resources based on traditional knowledge that they inherited from their previous generations and the current state of management is a result of on-farm trial and error practice. They are to depend on both external (e.g. fertilizer, pesticide) and internal (e.g. labour, self-saved seeds) sources for farm establishment and management. Light to moderate silvicultural operations are applied in plant management. Pruning is deliberately done since the branches can be used as fuel for household cooking; however, thinning is practiced with lower instances. Rotation of trees depends on the intended end-use of a particular tree species and family emergencies. In general, however, rotation for timber species is longer and for fuel and fruits comparatively shorter.

Findings of this study can be reviewed in improvement of HAS management throughout Bangladesh and in similar socio-economic and environmental scenario elsewhere. Government policy should focus on the promotion and development of HAS particularly in the drought-prone areas. It is also important to find out drought tolerant and less water consuming species and varieties, which can well-adapt to the extreme climatic situation. Incorporation of locally adapted drought tolerant species like *Mangifera indica*, *Ziziphus jujube*, *Acacia catechu*, *Acacia nilotica*, *Phoenix sylvestris*, *Borassus flabellifer*, *Litchi chinensis*, *Acacia auriculiformes*, *Swietenia macrophylla*, and *Dalbergia sissoo* can be considered for extensive plantation in the homesteads and other vacant spaces to bring the barren area under vegetation cover. Secondly, the Forest Department has established a 'Social Forestry Wing' to accommodate and promote social and participatory forestry activities in the country. Similarly, a 'Homestead Forestry Cell' is also recommended to create to address HAS management issues. The cell can support farmers with scientific knowledge and technology in improving their production system. In addition, a 'HAS management plan' needs to be prepared in consultation with the farmers, HAS researchers and other stakeholders. Finally, market system can be developed and improved for HAS grown products. This is not a direct intervention in improvement of management but it can be done in the belief that better market access enhances intensity of management among the farmers (Abebe, 2005). Additionally, during fieldwork it was observed that middlemen play a major role in the villages and they used to deprive the farmers by offering lower prices and giving incorrect market information. Hence appropriate market system can make the farmers more confident to sell the products more quickly and in better prices.

ACKNOWLEDGEMENTS

We acknowledge Japanese Government Scholarship (Monbukagakusho) granted to the first author for doctoral research. We thank S.K. Sarker of Department of Forestry at Shahjalal University of Science and Technology, Bangladesh for his all-out support to accomplish the study. The cooperation of respondent farmers during fieldwork is also gratefully acknowledged.

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(Received 8 July 2010)
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