CONSTRAINTS ON THE HARVEST OF LINE-PLANTED TIMBER TREES IN LOGGED AND ENRICHED DIPTEROCARP FOREST IN KALIMANTAN, INDONESIA

RK Niti Putro[1], F Yusro[2], Ruslandi[3, *], G Hardiansyah[2] & FE Putz[3]

[1]*PT Sari Bumi Kusuma, Seruyan and Katingan, Central Kalimantan, Indonesia*
[2]*Faculty of Forestry, Tanjungpura University, Pontianak, West Kalimantan, 78121, Indonesia*
[3]*Department of Biology, University of Florida, Gainesville, FL 32611 USA*

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NITI PUTRO RK, YUSRO F, RUSLANDI, HARDIANSYAH G & PUTZ FE. 2015. Constraints on the harvest of line-planted timber trees in logged and enriched dipterocarp forest in Kalimantan, Indonesia. Where enrichment planting of timber trees results in high densities of planted and naturally-regenerated trees larger than the minimum cutting diameter, e.g. 40 cm diameter at breast height, harvest of all those trees would result in major residual stand damage. One proposed harvest strategy for enriched dipterocarp forest that we studied was to cut only planted trees and to fell them down the 3 m wide planting lines so as to protect the intervening 17-m wide strips of regenerating natural forest. Based on crown and bole characteristics of line-planted dipterocarp trees, felling down the planting line should be possible for 90% of the trees. When felled, the other 10% of the planted trees would cross at least one strip of natural forest. A bigger concern was that at the time of the planned harvest (25 years after planting), 31% of the planted trees would not quite have reached harvestable size. To avoid excessive stand damage and destruction of future crop trees, alternative harvest strategies are needed. For example, enriched stands could be harvested in two phases with modified shelterwood system. Alternatives to chainsaws and crawler tractors should also be considered such as feller bunchers or mobile crane cable yarders.

Keywords: Silviculture intensification, enrichment planting, selective logging

INTRODUCTION

Enrichment planting along cleared lines is a frequently invoked silvicultural intervention for sustaining timber yields from selectively logged tropical forests (Mohammad-Samaun et al. 2004, Paquette et al. 2009, Soekotjo 2009). Although many millions of dollars have been wasted on planting seedlings that subsequently died (FE Putz, personal observation), enrichment planting works well if the rules spelled out by Dawkins in 1961 are followed. Basically, where healthy seedlings are carefully planted under canopy openings that provide them with sufficient light and those seedlings are liberated from vines and encroaching understorey vegetation for several years, survival and growth rates can be substantial. This finding is supported by plentiful data from experimental plots and in areas where intensive silviculture is heavily subsidised by external agencies (i.e. not paid for by property owners or concessionaires). Recent evidence from a timber concession in Indonesia indicates that under the appropriate economic and political conditions, self-funded and large-scale enrichment planting along cleared lines following Dawkins' rules can also be successful in terms of seedling growth and survival (Soekotjo 2009, Hardiansyah 2011). Here we considered some harvesting options and impacts when these successfully enriched stands mature and are harvested.

Prior to the harvest of the planted stands, biodiversity impacts of enrichment planting along cleared lines are small. Stand rehabilitation through enrichment planting of degraded forest in Sabah, for example, caused was associated with little change in bird species composition relative to primary forest (Ansell et al. 2011). What will be the consequences of harvests of heavily

*r.ruslandi@ufl.edu

enriched stands where harvests are constrained only by minimum felling diameter? With heights of 30–40 m and crown diameters of 14–18 m, harvest of > 40 dipterocarp trees ha^{-1} would result in substantial devastation, at least using currently accepted approaches to reduced-impact logging(RIL) with ground-based skidding.

Due to lack of markets for most trees in species-rich tropical forests, timber harvests are typically selective (Bertault & Sist 1997). Numerous studies have demonstrated that damage to residual stands and soil by selective logging can be substantially mitigated if RIL techniques are employed (Putz et al. 2008). However, RIL has its limits. Based on results of an experimental logging study in East Kalimantan, Sist et al. (1998, 2003) found that environmental benefits of RIL are lost if > 8 trees or 60 m^3 are harvested per ha. Based on simple linear projections of the first 14–15 years of growth of planted *Shorea leprosula* trees in our study site in Central Kalimantan, legally harvestable trees, i.e. > 40 cm diameter at breast height (dbh) will greatly exceed both those limits; harvestable volumes of 50–60 trees are predicted to exceed 200 m^3 ha^{-1} (Kusuma et al. 2014).

One frequently-discussed option for harvesting enriched stands in Indonesia is to harvest only trees along planted lines and retain the natural forest between the lines. Here we evaluated the viability of this option with data on enrichment-planted *S. leprosula* trees in twice-logged lowland dipterocarp forest in Kalimantan, Indonesia. To evaluate the likely impacts of this approach, we scored the planted trees on the basis of whether a trained feller with a chainsaw could fell them down the planted line. We supplemented the expert opinion of an experienced forest concession staff member whose duties included tree marking for directional felling with measurements of crown eccentricities and stem lean. We discuss these findings in light of the expected number of planted trees that would reach the 40 cm dbh threshold by the end of the 25-year rotation.

METHODS

Study site

The study was conducted at the Sari Bumi Kusuma (SBK) concession in Central Kalimantan, Indonesia (0° 56' N, 111° 68' E) at elevations of 356–425 m with undulating topography. Precipitation for 2001–2012 averaged 3631 mm year^{-1} (3024–4762 mm year^{-1}). No months averaged < 200 mm and temperatures averaged 30–33 °C at midday and 22–28 °C at night (Suryatmojo et al. 2013). Soil is deep red-yellow clay loam with good internal drainage. From 1999 till 2014, SBK applied the Indonesian selective cutting and strip enrichment planting silvicultural system (locally, *tebang pilih tanam jalur*—TPTJ) to 49,000 ha in its 147,600 ha concession. The minimum cutting cycle under TPTJ is 25 years; the oldest plantations will therefore be eligible for harvest of trees > 40 cm dbh 10 years after we conducted this study. TPTJ guidelines continue to evolve, but in the 14- to 15-year-old plantations we sampled, nursery-grown seedlings of *S. leprosula* and four other congeneric species were planted at 5-m intervals along parallel 3-m wide lines cleared at 20-m intervals through twice-logged forest. We studied *S. leprosula* because it was the most commonly planted species.

Field data collection

We measured the dbhs of 500 planted *S. leprosula* planted trees that were 14 to 15 years old. Groups of five trees were selected for measurement in a stratified random fashion. From each group, the tree with the largest dbh was selected for more detailed assessment (N = 100). Dbh of sampled trees ranged between 19 and 38 cm. To estimate whether a trained feller could fell each of the selected trees within 5° of the planting line in both directions, the range of possible felling directions for each of these 100 trees was assessed on the basis of the expert judgment of a forest worker whose regular job was to mark trees for directional felling. For each of the selected trees we measured the terrain slope perpendicular and parallel to the planting line 5 m from the trunk, crown radii in four directions (perpendicular to and along the planting line), and the degree of the trunk lean perpendicular to the planting line.

Data analysis

A binomial code was used to describe whether the felling expert thought each tree could be felled within 5° of the planting line. Crown eccentricity was calculated as the ratio of longest crown radii perpendicular to and parallel to the planting line. The same method was used for the slope ratio. As the response variable was binomial, generalised linear model analysis using the binomial family was used to assess effects of dbh, slope ratio, crown ratio and tree lean on the probability of the tree to be felled down the planting line. The parameter estimates of model and their confidence intervals are presented on the graph. The centre dots indicate predicted values, the thick horizontal bands show the 68% confidence intervals and the thinner, wider bands indicate the 95% confidence intervals. A predictor is significant if its confidence interval does not contain 0. All predictors were scaled to a standard deviation of 1 and centred around 0 to improve interpretability of the relative strength of influence of the predictor on the predicted variable compared with the other predictors (Schielzeth 2010). Statistical analysis was conducted in R (R core Development Team 2013).

To estimate how many of the line-planted trees would be harvestable at the end of the planned 25 year rotation, the minimum rotation duration stipulated by governmental regulations (MoF 2009), we used average rates of dbh increment up to the age of the trees at the time of our measurement (14 or 15 years since planting) to extrapolate to 25 years. This simple approach is fraught with assumptions but does reflect the typically strong temporal autocorrelation in growth rates of moderately light-demanding tropical trees like our study species (Brienen et al. 2006).

RESULTS AND DISCUSSION

Based on the expert opinion of the forester whose normal job was to mark trees for directional felling as part of pre-harvest planning, at age 14–15 years and dbhs of 19–38 cm, 90 of the 100 planted trees sampled could be directionally felled down the planting line. The probability of a tree being classified as fellable in either direction down the planting line decreased with increased dbh ($p = 0.860$), slope ratio ($p = 0.319$), crown eccentricity ratio ($p = 0.666$) and stem lean ($p < 0.001$) (Figure 1). Graphically, while the expected success of directional felling decreased with increasing dbh, slope ratio and crown ratio, tree lean was the only predictor that decreased the probability of felling down the planting line to < 0.5 across the range of observed values (Figure 2).

Of the 100 planted trees sampled, 58 had the largest crown diameter perpendicular to the planting line, 26 displayed the opposite condition while remainder had symmetrical crowns. Open spaces lateral to the planting lines that were mostly down slope provided opportunities for crown expansion. In contrast, along the planted lines, the nearest neighbour was only 5 m away. These findings also suggested that 5-m intertree spaces along planting lines did not allow full crown formation in more than half of the planted trees. When considering the crown space available to trees planted at such close spacing, it is important to recognise that the actual available space is further constrained because dipterocarp crowns do not interdigitate but instead are surrounded by bare areas of about 0.5 m, referred to as crown shyness gaps (Ng 1977). Although at the current age of 14–15 years, dbh was not strongly related to crown eccentricity (Figure 3). Given that mean crown diameter of a 40-cm dbh *S. leprosula* tree in a dominant canopy position in natural forest was about 16 m (T Inada, unpublished data), it was likely that crown eccentricity would increase in the final 10 years before the planned harvest.

Although our data on 14- to 15- year-old line-planted *S. leprosula* trees suggested that the measured crown characteristics did not affect the capacity to directionally fell trees down planted lines, thinning might both promote growth and provide space for the development of more circular crowns. Thinning of planted trees is listed as a required treatment in TPTJ stands starting 5–10 years after planting. However, it has not been carried out in SBK or, to our knowledge, in any other concession. Insofar as thinning would reduce crown competition and might increase growth of the retained trees, it should at least be tested experimentally. Alternatively, given the high survival rates of well-tended planted trees, perhaps trees should be planted at intervals > 5 m.

Although at age 15 years and dbhs that averaged 24.2 cm, 91% of the planted trees were judged to be fellable down the planting line. However, it was not clear that this would be the optimal direction. In particular, if the average rate of dbh increment of each planted tree over

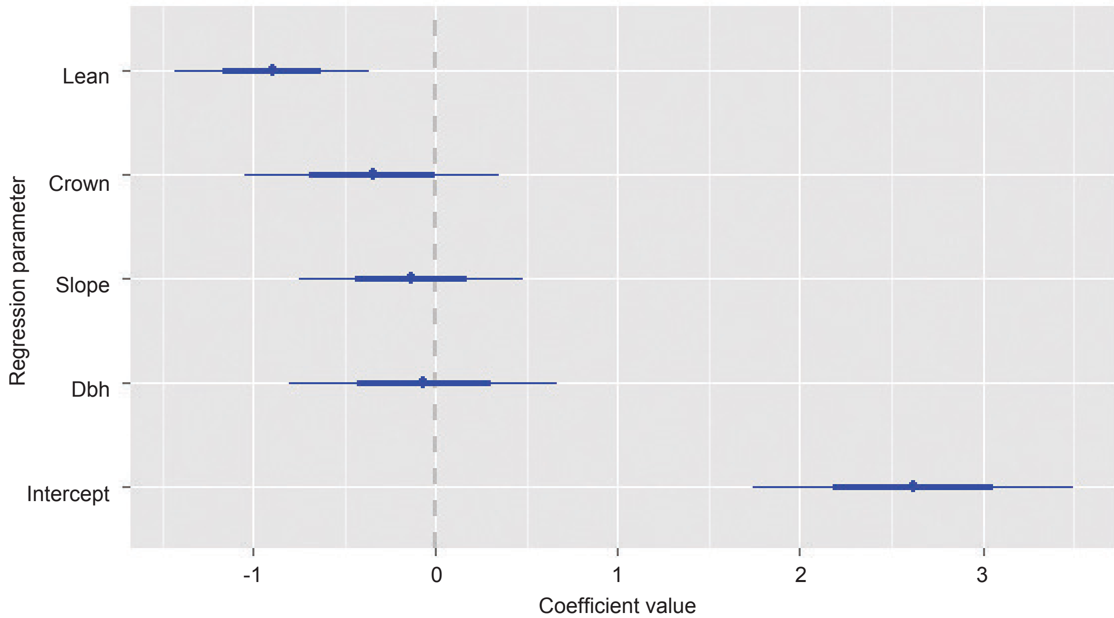

Figure 1 Expected success of directional felling planted trees down the planting line as a function of dbh and measured variables that contrast tree characteristics perpendicular and parallel to the planting line (stem lean, crown ratio and slope ratio); lean is a significant predictor and crown, marginally-significant, a negative estimate indicates that higher values of that predictor correspond to lower likelihood of the tree being successfully felled down the planting line in either direction; dbh = diameter at breast height

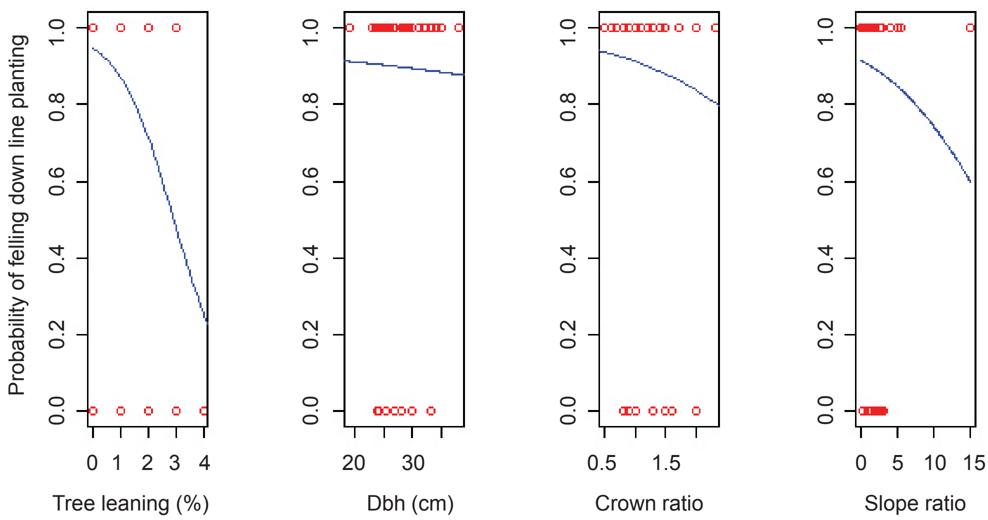

Figure 2 Predicted (line) and observed (dots) probabilities of planted trees being felled down the planting line as function of lean, dbh (diameter at breast height), crown ratio and slope ratio; probability decreased to < 0.5 only for stem lean angle perpendicular to the planting line

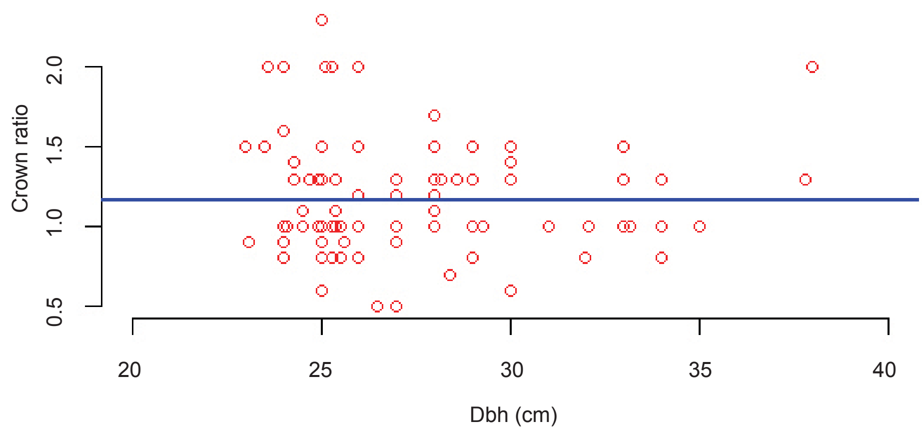

Figure 3 Ratio of the longest crown radii perpendicular and parallel to planting line as function of tree dbh (diameter at breast height); crown ratio = 1.1963715 – 0.0008323 × dbh ($p = 0.9383$, $r^2 = 0.0006$)

the last 14—15 years is used to predict its dbh at age 25, 31% of the planted trees will not have reached harvestable diameter by harvest time (Figure 4). Felling all trees that attain dbh of > 40 cm will therefore almost unavoidably result in damage or death of 24 future crop trees (i.e. trees of commercial species of 20–40 cm dbh) ha^{-1} if the planted trees are felled down the planting lines. With an average cost of TPTJ over the first 3 years being USD700 ha^{-1} and average density of 80 trees planted ha^{-1} (Hardiansyah 2011), that means that in each planted tree the concession invested about USD10. If all 24 future crop trees are destroyed during the harvest, that will represent a loss of USD240 ha^{-1} to which foregone future revenues from growth and subsequent harvest of these trees should be added. These economic estimates are only approximates but make clear that alternatives to clearcutting the line-planted trees should be sought. At the very least, efforts should be made to avoid felling or damaging trees that

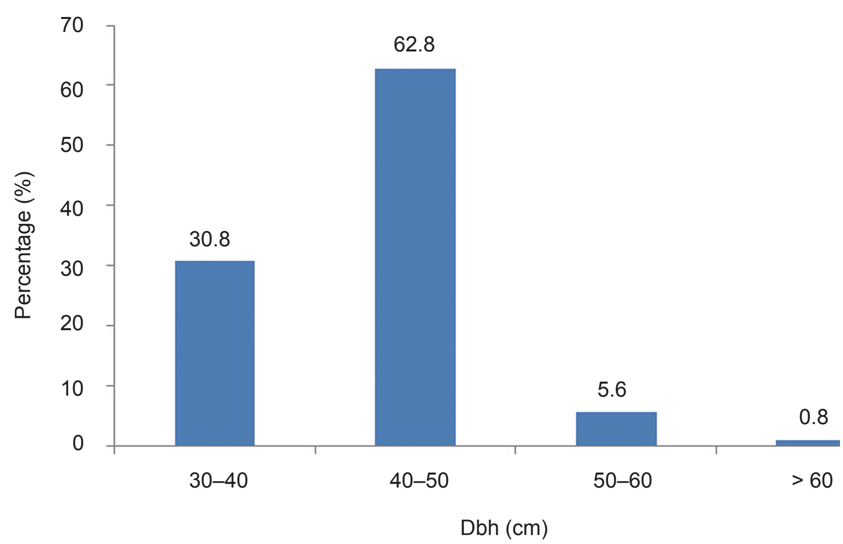

Figure 4 Distribution of projected planted tree diameter at breast height (dbh) (N = 500) at the end of the planned rotation (25 years) as predicted by a linear extrapolation of growth of each tree during the first 15 years after planting

have not yet passed their peak mean annual increments. To avoid excessive stand damage and economic losses, we recommend that there be limits on the number of trees harvested per ha at any one entry. Experiments with shelterwood cuts would seem warranted given that even at 15 years, we observed that some of the planted trees were reproductive. Natural regeneration of commercial species is likely to be abundant when the stands are harvested. Alternatives to the current practice of timber yarding with crawler tractors should also be considered including long-line cable yarding with mobile towers. Most fundamentally, to avoid the dilemma of over-stocking, we suggest that management guidelines be modified to benefit more from natural regeneration and to anticipate the constraints on harvesting by planting mixtures of species that grow at different rates and provide timbers of a wider range of values.

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