CLEAR BOLE LENGTHS AND CROWN CHARACTERISTICS OF LINE-PLANTED AND NATURALLY-REGENERATED *SHOREA LEPROSULA* TREES: A CASE STUDY FROM KALIMANTAN, INDONESIA

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HARDIANSYAH G, RUSLANDI, HIDAYAT D, NUGRAHA A, MAHARDI M & PUTZ FE .2015. Clear bole lengths and crown characteristics of line-planted and naturally-regenerated *Shorea leprosula* trees: a case study from Kalimantan, Indonesia. *Shorea leprosula* seedlings planted at 5-m intervals along 3-m wide cleared lines at 20-m intervals through twice-logged forests in Kalimantan grew rapidly in dbh (diameter at 1.3 m) but at age 14–15 years, had branch-free stems that averaged 11% shorter than those of naturally-regenerated trees of the same dbh (20–40 cm). There was no relationship between clear bole length and terrain slope or current crown exposure. If low branches continue to be maintained until the harvest (planned at 25 years), commercial timber yields will be lower than predicted from allometrical relationships calculated using data from naturally-regenerated trees. Even if low branches on the planted trees are shed before harvest, log values will be reduced due to the presence of large knots. Pruning and manipulation of light exposure are possible ways to avoid long-term branch retention.

Keywords: Branch retention, enrichment planting, pruning, silvicultural intensification, stem quality

INTRODUCTION

Branch-free stem lengths (hereafter clear-bole heights), which are correlated with yields and qualities of commercial timber, result from branch shedding, a process influenced by numerous environmental factors especially crowding (Saha et al. 2012, 2014, Kuehne et al. 2013) and also by genetics (Lowell et al. 2014). Although tree growth rates are often expressed in terms of stem diameter increments, this metric is insufficient for industrial purposes if trees with high rates of stem diameter growth have short clear boles, especially if only branch-free portions of stems are harvested. Retention of branches low on the bole could be favoured by the same high light conditions that favour rapid stem diameter increments. Alternatively, if branch shedding is a slow process, comparisons of fast- and slow-growing trees of the same stem diameter might show longer clear boles on the latter. In support of this prediction, branches are reportedly retained at lower light levels and lower on the boles of *Abies anabilis* trees that are uniformly light-suppressed than on those with their upper crown well illuminated (Sprugel 2002). Similarly, if leaf retention times are longer on shaded than well illuminated branches, as found for *Shorea* spp. and other species in Malaysia (Tong & Ng 2008), then shaded branches might also be retained longer (von Lüpke 1998).

We tested the linked hypotheses that clear-bole heights vary with rates of stem diameter increment and increase with tree age by comparing fast- and slow-growing trees of the same stem diameter. This comparison was possible because 14–15 years prior to our study in a forest concession in Kalimantan, Indonesia, *Shorea leprosula* seedlings were planted and tended along cleared lines through logged forest while natural regeneration of conspecifics was allowed

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to develop slowly in strips of forest retained between the planted lines. To explore crown characteristics further, we examined the effects on clear-bole heights of current crown exposure and slope by treating them as covariates with the apparent age/growth rate effect. Finally, we evaluated how crown characteristics (crown area, crown eccentricity and crown exposure) vary between planted and naturally-regenerated trees. Our principal motivation for this study was to improve projections of future timber volume yields calculated on the basis of rates of stem diameter increment.

MATERIALS AND 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 mid-day and 22–28 °C at night (Suryatmojo et al. 2013). Soils are deep red-yellow clay loam (oxisols) with good internal drainage. The 147,600-ha concession implements two silvicultural systems referred to as Indonesian selective cutting (locally, *tebang pilih tanam Indonesia*—TPTI) and selective cutting and strip enrichment planting (*tebang pilih tanam jalur*—TPTJ). TPTI is a simple selective cutting with minimum diameter cutting limit of 50 cm for all commercial species and cutting cycle of 35 years. In 2009, TPTI was revised by lowering the diameter cutting limit to 40 cm and reducing the cutting cycle to 30 years. TPTI can be implemented in either primary or logged-over forests. TPTJ is implemented after the second timber harvest in areas with slopes < 25%. Following the second selective logging, strip enrichment planting was applied with spacing 20 m between the 3-m wide cleared strips and 5 m between planted trees. In addition, the planted trees were liberated annually from encroaching vines and other encroaching vegetation for 3 years. The cutting cycle was 25 years with the assumption that by that time, the planted trees would have reached the diameter cutting limit of 40 cm. Between 1999 and 2014, SBK carried out TPTJ in 49,000 ha of the 60,000 ha allocated for this purpose. This study was carried out in late 2014 in stands that were selectively logged in the 1970s and then again in the 1990s, and then line-planted with nursery-grown seedlings in 1999–2000.

Field data collection

The TPTJ area for the planting years of 1999–2000 was about 3600 ha, which was divided into 100-ha compartments. Three of these compartments were selected randomly for sampling. Clear-bole heights were measured on 100 randomly selected *S. leprosula* trees 20–40 cm dbh (diameter at 1.3 m), half of which were planted and half, naturally regenerated in the inter-line strips of logged-over forest. This dbh range included the largest of the planted trees, which grew in dbh at annual rates of 1.4–2.7 cm. For each sampled tree we measured the steepest slope 5 m above and below the bole with a clinometer (%), clear-bole height with a laser range finder and dbh and crown length in four directions (along steepest slope and its perpendicular). We assigned each tree a crown exposure index (1 = suppressed, 2 = substantial lateral and diffuse overhead light, 3 = codominant, 4 = dominant) (Dawkins & Field 1958). Trees with broken or forked trunks were excluded.

Data analysis

To assess the main effect on clear-bole heights of planted or naturally-regenerated trees, we used generalised linear model (GLM) analysis in R (R Core Development Team 2013) and treated dbh, slope and crown exposure index as covariates. The same method was used to assess the effect of those variables on crown characteristics (crown area, crown eccentricity and crown exposure index). Crown area and eccentricity were calculated by assuming that crown area was the sum of four quarters of an ellipse while crown eccentricity was the ratio between the longest and shortest crown radii. A GLM approach was used because it permitted fitting of linear models to any distribution function included in the exponential family (e.g. Gaussian, Poisson, binomial, gamma) and directly fit the expected mean of the dependent variable, thereby avoiding the biases of transformed linear models (McCullagh & Nelder 1989, Saha et al. 2014). The parameter estimates of model and their confidence intervals are presented in the graphs. 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). Raw data from this study will be available in September 2015 from the Dryad Data Repository (http://datadryad.org/).

The assumption that naturally-regenerated trees were growing more slowly and were therefore older than the line-planted and tended trees of the same size (20–40 cm dbh) was supported by data from permanent plots in the same area where we worked (Pamoengkas et al. 2014). Diameter growth of *S. leprosula* in logged-over forest averaged 0.5–0.7 cm year^{-1} which meant that naturally-regenerated trees 20–40 cm were expected to be 28–80 years old.

RESULTS AND DISCUSSION

Clear-bole height

Clear boles of 20–40 cm dbh planted trees were on average 1.5 m (11%) shorter than those of naturally-regenerated trees of the same diameter (11.8 ± 4.1 vs 13.3 ± 3.7 m, independent sample, $t = 1.99$, $p < 0.05$, $n = 50$, Figure 1). None of the other variables (dbh, crown exposure, slope) effected clear-bole height ($p = 0.409$, 0.176, 0.592 respectively). Nevertheless, clear bole heights of planted trees tended to increase slightly with dbh, slope and crown exposure (Figure 2). When the regressions were run for planted trees only, slope was the only significant parameter ($p < 0.05$).

Given that seeds and wildlings that provided the planted nursery stock were collected from the same area where the strips were later planted, we saw no reason to expect genetic

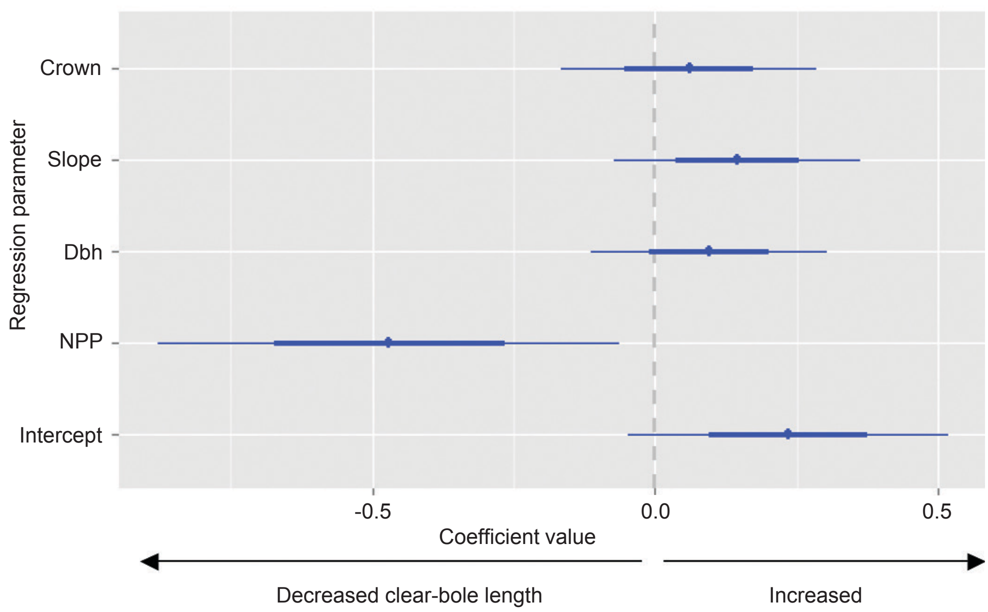

Figure 1 Coefficients for the model of clear-bole length as a function of naturally-regenerated or planted trees (NPP), dbh (diameter at 1.3 m), slope and crown exposure index; NPP is significant predictor and slope is marginally-significant; positive estimate indicates that higher values of that predictor correspond to higher first branch (i.e. longer clear bole)

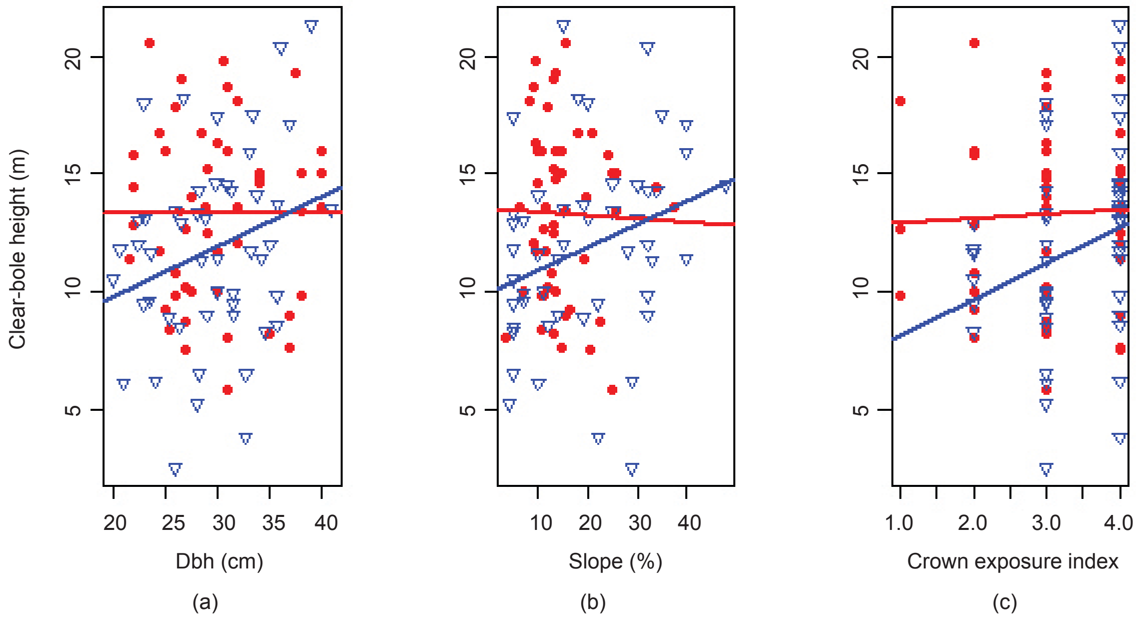

Figure 2 Clear-bole height of naturally-regenerated (dots) and planted trees (triangles) plotted against the covariates of dbh (diameter at 1.3 m), slope and crown exposure index

differences between the planted and naturally-regenerated trees. We therefore assumed that the observed difference in clear-bole length was due to environmental factors. Although the crown exposure effect was not significant, current exposure status might not reflect historical conditions. In particular, the sampled trees might have attained upper canopy status only recently. Furthermore, it was important to note that planted trees were exposed to at least some direct overhead and probably substantial diffuse light, especially during the first 3 years after planting when the 3-m wide cleared lines were kept clear (Inada et al. 2013). In contrast, the naturally-regenerated trees in the strips of twice-logged forest between the planting lines were not so consistently favoured.

The distinctive crown architecture of trees in the Dipterocarpaceae described by Halle and Ng (1981) might also help explain these results and suggest a follow-up study. Basically, branches on *S. leprosula* trees emerge at 45° angle to the stem. Until the trees reach at least mid-canopy positions, the branches gradually lean over under their own weight until they are horizontal, die and are shed. Branches produced by taller and perhaps better illuminated trees retain their upward angles as examples of adaptive apical reiteration. Basically, each upwardly-angled branch becomes a separate leaf bearing trunk. In other words, and using the terminology of Halle and Ng (1981), we predicted that the height at which adaptive reiteration of orthotropic branches commenced decreased with increasing crown exposure. This pattern of growth was evident on many large canopy dipterocarps that had crowns composed of seemly separate 'crownlets' that resembled small heads of cabbage. Our data suggested that height of the transition from branches that became horizontal and were shed to branches that remained closer to vertical and were retained varied with crown exposure to light. In other words, the height at which adaptive reiteration of orthotropic branches commenced decreased with increasing crown exposure.

Even if the lower branches on the boles of planted trees were shed before the trees were harvested, there could nevertheless be negative consequences for wood quality. As the general height of the canopy increased as these stands recovered from two episodes of logging, we expected that more of the low branches on the boles of planted trees would be shed and clear-bole heights would consequently increase. Unfortunately, even if these low branches are shed they will leave large knots, which reduce wood strength and other qualities (Lowell et al. 2014). When large branches are shed, the wounds they leave on the trunk serve as excellent entry ways for wood-rotting organisms, which have access to heartwood of the stem via the heartwood in the fallen branch (Shigo 1985).

Crown characteristics

Crown areas of planted trees were on average slightly larger than those on naturally-regenerated trees (44.6 ± 3.6 vs. 41.4 ± 4.0 m^2, Kruskal–Wallis $X^2 = 1.73$, $p = 0.18$, $n = 50$). Crown areas increased with dbh ($p < 0.001$, Figure 3). There was strong interaction between main effect of whether trees were planted or naturally regenerated and dbh (Figure 5a). Crown exposure increased with dbh and slope ($p < 0.05$ and $p < 0.001$ respectively, Figure 4) but did not differ between planted and naturally-regenerated trees (Figures 4, 5 and 6). Crown eccentricity (crown length ratio) was not affected by any of those factors (Figures 5b and 6b). These results indicated that the observed rapid dbh growth of planted trees was related to their large and well-exposed crowns. Although crown eccentricity did not affect growth rates, it might influence bole shape and hence timber quality.

CONCLUSIONS

Mean branch-free bole heights of planted *S. leprosula* trees were 11% shorter than those on naturally-regenerated trees. This suggested that projections of harvestable timber yields from planted trees should be adjusted downwards by about that amount. We suggest that the process of branch shedding continue to be monitored for the entire rotation in case the pattern changes. Experimental studies on this topic might also prove useful (e.g. thinning and pruning), but of course any additional costs should be documented. Finally, this study should be repeated with other planted species grown under different stand conditions, different spacing and different planting methods such as cluster plantings.

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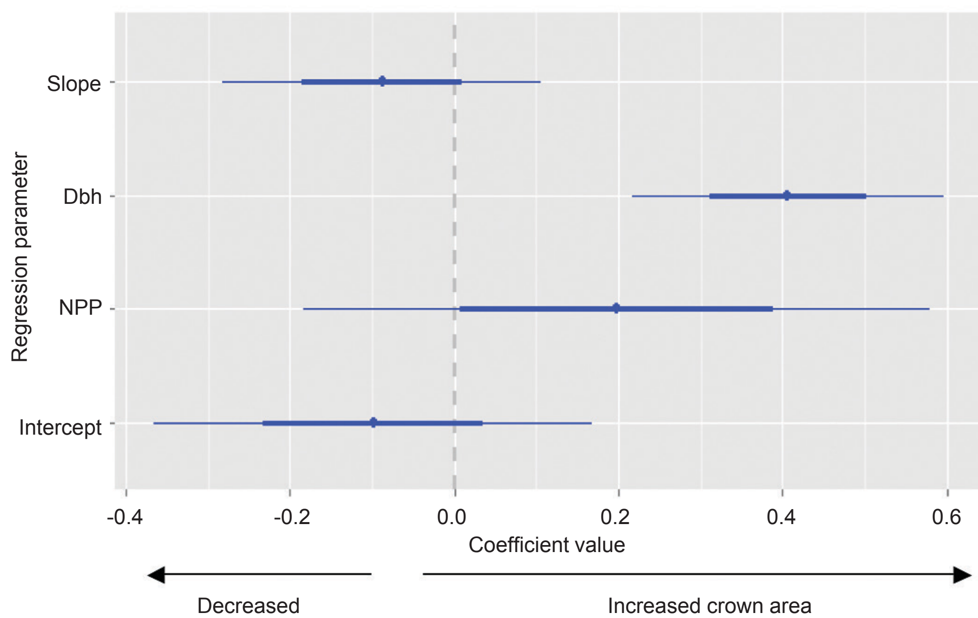

Figure 3 Coefficients for the model of crown area as function of naturally-regenerated or planted trees (NPP), dbh (diameter at 1.3 m), slope; dbh is the only significant predictor while the effect of being planted (NPP) is marginal

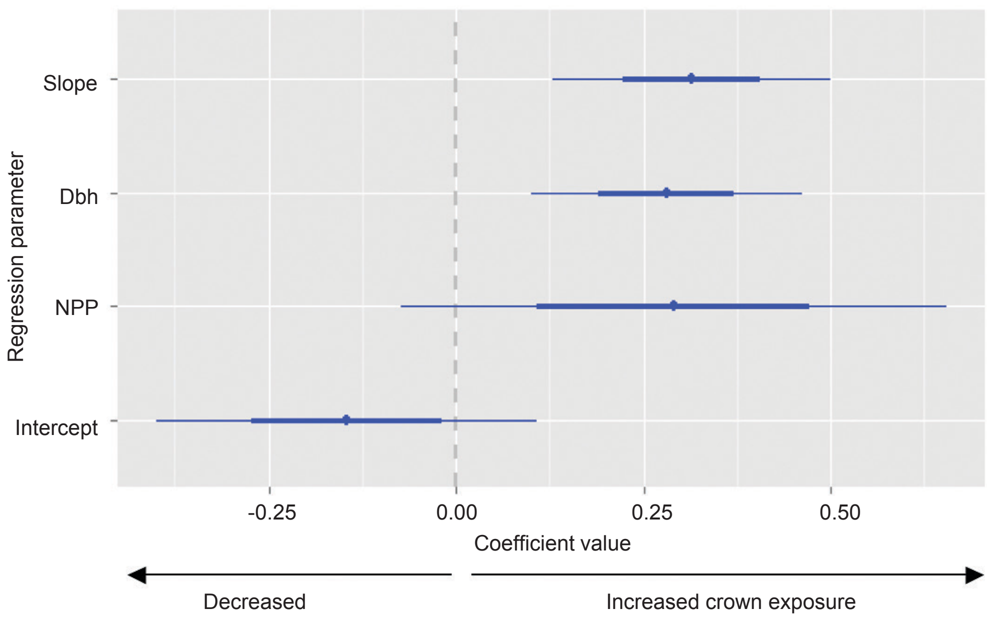

Figure 4 Coefficients for the model of crown exposure as a function of naturally-regenerated or planted trees (NPP), dbh (diameter at 1.3m) and slope; slope and dbh are significant predictors

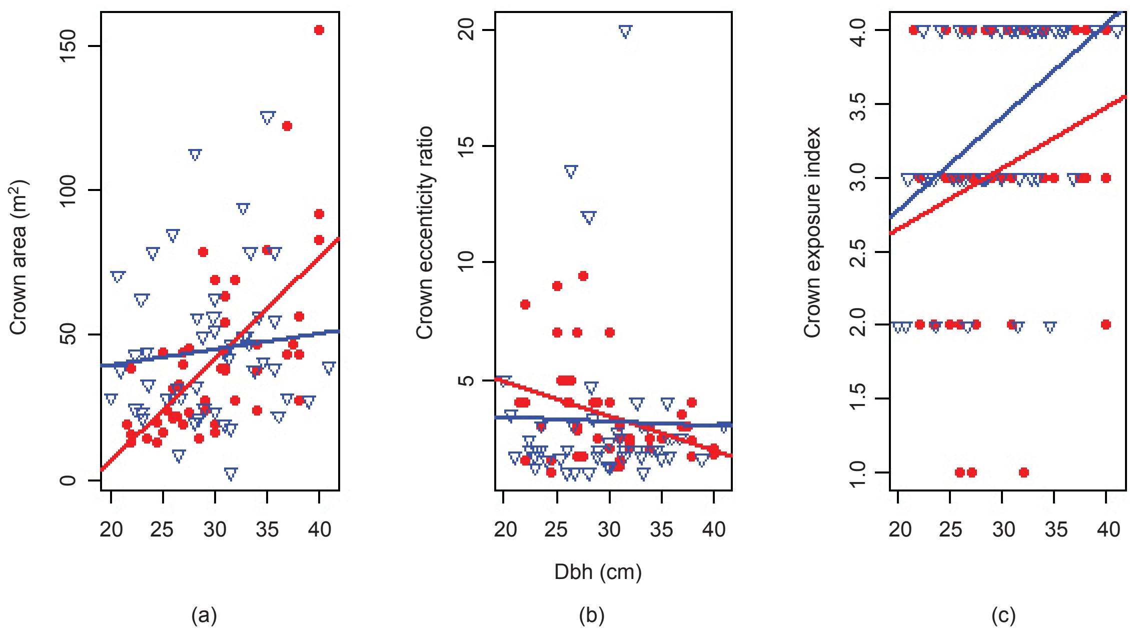

Figure 5 Crown area, crown eccentricity ratio and crown exposure index of naturally-regenerated (dots) and planted trees (triangles) plotted against the covariate of dbh (diameter at 1.3 m)

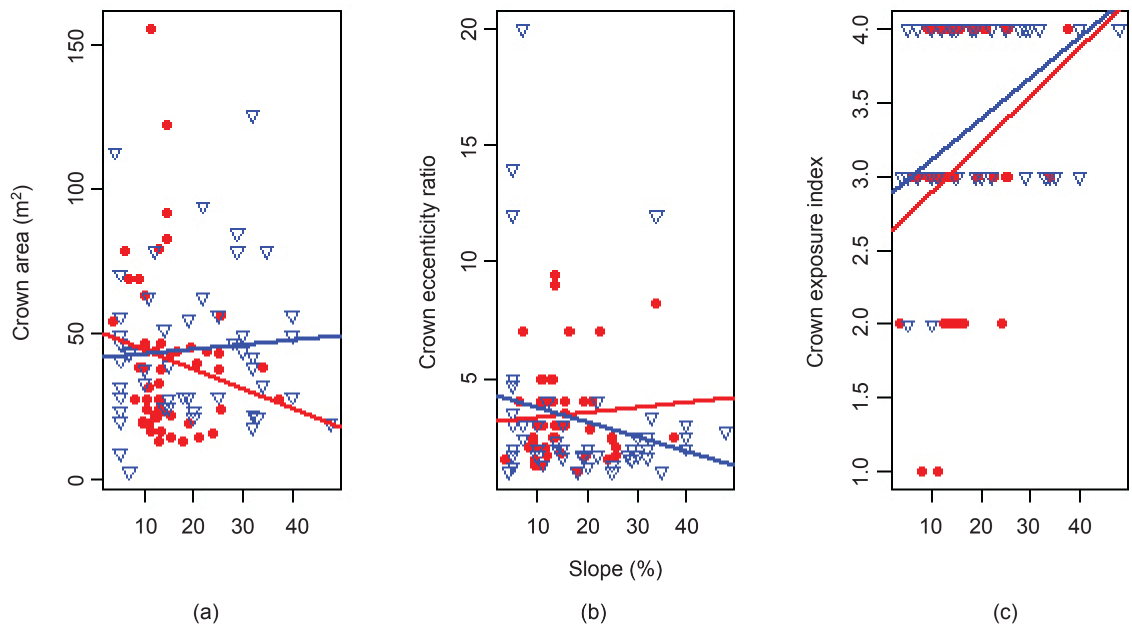

Figure 6 Crown area, crown eccentricity ratio and crown exposure index of naturally-regenerated (dots) and planted trees (triangles) plotted against the covariate of slope

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