SUITABLE HABITATS FOR THE ESTABLISHMENT OF *SHOREA CURTISII* SEEDLINGS IN A PRIMARY HILL FOREST IN MALAYSIA

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YAGIHASHI T, OTANI T, NAKAYA T, TANI N, SATO T, ABD RAHMAN K & NIIYAMA K. 2016. Suitable habitats for the establishment of *Shorea curtisii* seedlings in a primary hill forest in Malaysia. The availability of microsites suitable for the establishment of *Shorea curtisii* seedlings mainly depends on the topography and distance from the mother tree. Approximately 90% of seedlings are located within 30 m of the mother tree in a selectively logged forest. However, whether these results are also applicable to a primary forest remains unclear. Since some *S. curtisii* seedlings have a considerably long survival time on the forest floor, some seedlings in a selectively logged forest may be derived from the trees that have already been cut down, which may affect statistical analysis. Here, we investigated and statistically analysed the relationships between seedling density and topographic index, distance from the mother tree and angle of the slope in a primary forest. In the fitted model, distance from the mother tree and topographic index were significantly correlated with seedling density. We conclude that microsites suitable for the establishment of *S. curtisii* seedlings are limited by topography and distance from the mother tree not only in a selectively logged forest but also in a primary forest.

Keywords: Dipterocarp, dispersal limitation, natural forest, tropical rain forest, Bayesian approach

INTRODUCTION

Trees of the Dipterocarpaceae family dominate the emergent canopy of most lowland rain forests in Asia (Ashton 1988, Ashton et al. 1988) and also dominate international hardwood markets. Therefore, this family represents not only one of the most ecologically relevant tree species in South-East Asia but also one of the most important sources of timber. However, as a result of logging, the extent of dipterocarp forests has declined over the last several decades. Sustainable use of dipterocarps as a source of timber is already becoming problematic in lowland forests. Therefore, hill dipterocarp forests, which still represent a comparatively rich source of timber, are becoming increasingly important. *Shorea curtisii* is the most common tree species in the hill dipterocarp forests of Peninsular Malaysia (Symington 2004). The trees of this species are regarded as an important source of timber and a key species for the conservation and sustainable use of such forests. At present, most Malaysian hill forests are selectively logged, which involves harvesting all trees over a predetermined stem size. Subsequent timber harvests are governed by the number of trees derived from the seedlings that are already present and from future seeds produced by the residual trees (Appanah & Mohd Rasol 1994). Therefore, ensuring the survival and growth of existing seedlings of *S. curtisii* in the forest is a crucial consideration in the sustainable use of hill dipterocarp forests. We previously reported that suitable microsites for the establishment of *S. curtisii* seedlings in the selectively logged forest were mostly determined by topography and distance from the mother tree and that approximately 90% of the seedlings were located within 30 m of the mother tree (Yagihashi et al. 2010). However, whether these results are also applicable to primary forest remains unknown.

The aim of the present study is to identify suitable habitats for *S. curtisii* seedlings in primary forest by examining a study plot with wide environmental variation including a topography ranging from ridge to valley and various distances from the mother trees.

MATERIALS AND METHODS

Study plot and measurement of trees

The study was conducted at Semangkok Forest Reserve, Selangor, Peninsular Malaysia. The reserve is located approximately 60 km north of Kuala Lumpur and approximately 10 km south of Fraser's Hill. A typical hill dipterocarp forest covers the ridge and a steep slope around Semangkok (Putz 1978). A 6-ha (200 m × 300 m) study plot (3° 37' N, 101° 44' E) was established in an undisturbed area of the forest in 1992 (Niiyama et al. 1999). In 2008 and 2009, we recorded the spatial distribution of all *S. curtisii* trees taller than 30 cm in 5 m × 5 m quadrats within the 6-ha plot. For these trees, diameter at breast height (dbh) was recorded if greater than 5 cm, while counts were obtained if smaller than 5 cm. We assumed that the mother tree of each seedling was the nearest individual with a dbh greater than 30 cm. We used 30 cm dbh as the minimum size in recording mother trees because smaller *S. curtisii* trees in the reserve rarely fruit (R Azizi & K Niiyama, unpublished data) while fruiting has been observed in dipterocarps with a dbh > 25 cm (Appanah & Mohd. Rasol 1990). Mean annual rainfall recorded at the meteorological station nearest to the study plot (Kuala Kubu Bharu, 15 km south-west of the plot) was 2414 mm and the mean annual minimum and maximum temperatures were 21.9 and 33 °C respectively (Saifuddin et al. 1991). The altitude of the study plot ranged from 400–515 m above sea level (asl).

Statistics

We used a Bayesian approach for the analysis. A random-effect Poisson regression model was fitted using the Markov Chain Monte Carlo (MCMC) procedure in the OpenBUGS software (Thomas et al. 2006). Spatial autocorrelation of unknown factors was considered in the model using a spatially structured error based on Conditional Autoregressive formulation as follows:

$$Y_i \mid R_i \sim \text{Poisson}\ (E_i\ R_i)$$
$$\log(R_i) \mid \alpha, \beta, \rho_i = \alpha + \beta X_i + \rho_i$$
$$\rho_i \mid \rho_{j \neq i} \sim N\ (\Sigma_{j \in \delta i}\ \rho_j\ /\ n_i,\ 1\ /\ \tau^2\ n_i)$$

where Y_i indicates the dependent variable, R_i denotes the variable at neighbouring locations, δ_i denotes the set of labels of the neighbours of quadrat i, n_i is the number of neighbours of quadrat i, τ^2 denotes the inverse of the variance parameter of the structured random effect, ρ_i (i = 1,...,2400) models the spatially structured area-specific random effect based on the conditional autoregressive approach CAR.

The number of seedlings < 5 cm dbh was used as the dependent variable and three environmental factors served as the predictor variables: distance from the mother tree (m), topographic index and the angle of the slope (degrees). The topographic index of each quadrat was calculated using the following equation:

$$\ln\ [a/\tan\ (\beta)],$$

where a denotes the area of the hill slope per unit contour length that drains through a specific quadrat and β is the local slope angle in that quadrat. Topographic index is also known as the wetness index because the value correlates with the moisture level. Topographic index was calculated using the software package Geographic Resources Analysis Support System (GRASS) version 6.4 (2009).

Prior to model fitting, we standardised the distribution of all predictor variables by z-transformation so that the mean and the standard deviation of every predictor variable became zero and one respectively. The MCMC procedure was run for 20,000 iterations after a burn-in period of 2000 iterations. To check the convergence of MCMC we ran three chains and calculated the Gelman–Rubin convergence statistic as modified by Brooks and Gelman (1998) using the 'bgr diag' module in the Open BUGS software (2006). We considered a coefficient within the model significant at the 5% level if the 95% credible interval did not contain the value zero. The BUGS code is attached as an appendix.

RESULTS

There were 2508 seedlings and 128 mother trees (dbh > 30 cm) in the plot. Of these seedlings, 88.6% were within 20 m of the mother tree, 96.8% were within 30 m and 99.6% were within 40 m (Figures 1a and b). These percentages were higher than the 95% confidence intervals for their respective populations: 68.9 ± 1.8% within

20 m, 85.5 ± 1.4% within 30 m, and 92.0 ± 1.1% within 40 m. The slope ranged from 1.4 to 51.8° (Figure 1c). Lower topographic index values were associated with the ridge and higher values were associated with the valley (Figures 1c and e).

In the fitted model, distance from the mother tree and topographic index significantly correlated with seedling density whereas slope angle did not significantly correlate with seedling density (Table 1). Both distance from the mother tree and topographic index negatively correlated with seedling density. In other words, seedling density tended to be high close to the mother tree in locations with low topographic index values, and low in locations with high topographic index values, even when they were close to the mother tree (Figures 1a, b and f).

DISCUSSION

The negative correlation of seedling density with distance from the mother tree and topographic index indicated that the seedling density tended to be high close to the mother tree in locations with low topographic index values, i.e. ridges or comparatively drier places. These results are

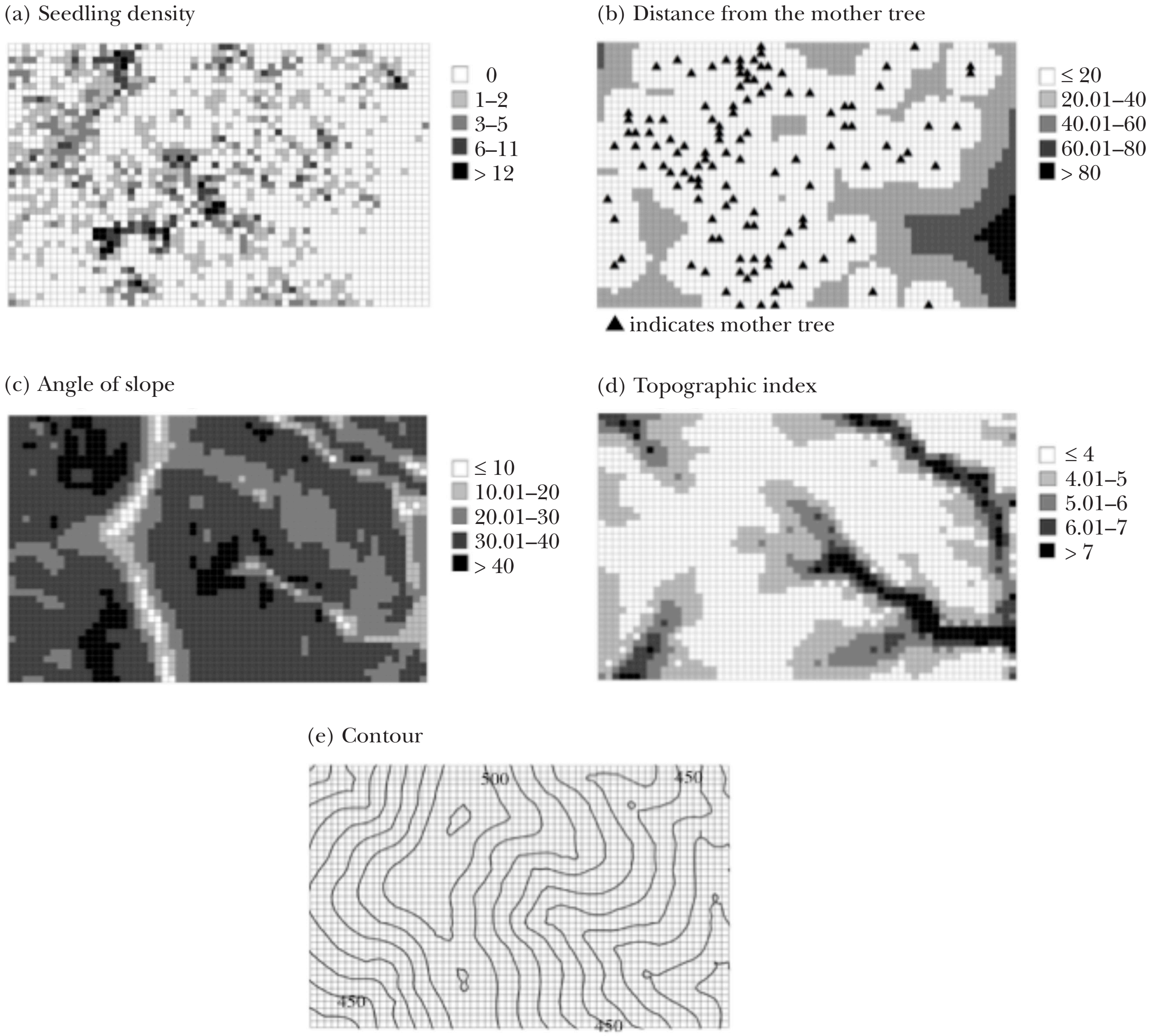

Figure 1 Spatial distribution of variables according to a random-effect Poisson regression model developed for examining *Shorea curtisii* seedling density together with a contour map of the 6-ha (200 m × 300 m) primary hill dipterocarp forest plot in Peninsular Malaysia: (a) seedling density (individuals per 25 m^2), (b) distance from and distribution of mother trees (cm), (c) topographic index, (d) angle of slope (°) and (e) contour map (m asl); the size of each grid square is 5 m × 5 m

Table 1 Summary of coefficients for the random-effect Poisson regression model for seedling density in a 6-ha primary hill dipterocarp forest plot in Peninsular Malaysia

Variable		Mean ± SD	MC error	CI2.5	Median	CI97.5	MC sample
Distance from mother tree	(-)	-0.285 ± 0.144	0.0019	-0.566	-0.286	-0.001	60000
Topographic index	(-)	-0.236 ± 0.105	0.0011	-0.442	-0.235	-0.031	60000
Angle of slope	NS	0.128 ± 0.080	0.0011	-0.029	0.128	0.285	60000

Mean = posterior mean, SD = standard deviation, MC error = the error introduced by the random sampling procedure, CI2.5 = lower limit of 95% credible intervals, Median = posterior median, CI97.5 = upper limit of 95% credible intervals, MC sample = the total number of random sampling of three chains, NS = not statistically significant; (-) denotes negative coefficients with 95% credible intervals not overlapping, deviance of the model was 3933 ± 54 (n = 2400)

almost identical to that of our previous study in a selectively logged forest, which showed topography and distance from the mother tree to be the factors that most influenced seedling density (Yagihashi et al. 2010). Recent evidence that some seedlings of *S. curtisii* have a considerably long survival time on the forest floor (K Niiyama, unpublished data) indicated that the census of seedlings originating from residual mother trees in our previous study may have inadvertently included existing seedlings from trees that had already been harvested. However, because seedling density values from the primary (undisturbed) forest in the present study were so similar to that from the selectively logged forest in our previous study, it appears that the inclusion of existing seedlings in the seedling census for the latter study may have minimal bearing on that study's results.

In the present study, the aggregation of 96.8% of seedlings within 30 m of the mother tree might be a result of dispersal limitation. While a dispersal distance of up to 80 m has been recorded for fruit of *S. curtisii* mother trees on a (windy) ridge (Burgess 1970), most mature fruit is generally dispersed within 20 m of dipterocarp mother trees (Chan 1980). Our findings are similar to that of a previous study on *S. curtisii* in a selectively logged hill dipterocarp forest that showed 90.7% of seedlings aggregated within 30 m of the mother tree (Yagihashi et al. 2010).

The aggregation of seedlings close to their mother trees may also have been as a result of the distribution of ectomycorrhizas being limited to a distance from the mother tree. Contact with living ectomycorrhiza roots has been shown to be crucial for early infection of *S. leprosula* seedlings (Alexander et al. 1992). In nutrient-poor soils, ectomycorrhizal infection may be crucial to the growth of *S. curtisii* seedlings (Turner et al. 1993) and survival of *S. seminis* seedlings (Turjaman et al. 2006) as ectomycorrhizas can improve plant nutrient uptake (e.g. Lee & Alexander 1994, Yazid et al. 1994).

In the present study and our previous study (Yagihashi et al. 2010), we assumed that the mother tree of each seedling was the nearest individual with a dbh > 30 cm. This assumption may underestimate distance from the mother tree in our model because the actual mother tree may not always be the tree (dbh > 30 cm) closest to the enumerated seedling. Genetic analysis that matches mother trees with their seedlings would be a useful subject for further research that would allow comparison against the observational data obtained in the present study. However, their effect in this study was likely insignificant because the dispersal distance of *S. curtisii* was comparatively short (Burgess 1975, Symington 2004).

We conclude that microsites suitable for the establishment of *S. curtisii* seedlings are limited by topography and distance from the mother tree not only in a selectively logged forest but also in a primary forest. Seedling density was comparatively high at locations within 20 m of the mother tree on the ridge. Hence, when selectively logging for *S. curtisii* in hill forests, seed trees should be retained at 40 m intervals or less.

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Appendix

```
model
{
  for (i in 1:2400) {
    y[i] ~ dpois(p[i])  #observed data drawn from Poisson distribution
    log(p[i]) <- rho[i] + xbeta[i] + α
    xbeta[i] <- beta[1] * zDistMT[i] + beta[2] * zTopoIndex[i] +
      beta[3] * zSlope[i]
  }
  rho[1:2400] ~ car.normal(adj[], weights[], num[], tau) # CAR prior distribution for spatial random effects
  α ~ dnorm(0, 1.0E-06) #uninformative prior for intercept
  for (i in 1:3) {
    beta[i] ~ dnorm(0, 1.0E-06) #uninformative priors for predictor variables
  }
  tau ~ dgamma(1.0E-06, 1.0E-06) #uninformative priors
  vrho <- 1/tau
}
```

