SLIM software: a simple light interception model for multi-species, multi-strata forests

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Figure 1.
Crown "porosity" to light is defined as the percentage of sky visible from below the crown, and is simply assessed with sub-vertical photographs towards the sky. A: *Pterospermum javanicum*; B: *Shorea javanica* Koord. and Valeton; C: *Parkia speciosa* Hassk.; D: *Lansium domesticum* Correa.

The SLIM software computes canopy openness (a long-term index of light availability) in a forest stand based on simple tree geometry characteristics. The model also provides 3D visualization of the stand and simulated hemispherical photograph outputs to allow users to check the quality of input data and model predictions. This paper provides an overview of the model by describing the input data required, the main assumptions and algorithms and the outputs.

Introduction

Temporal and spatial distribution of light is a major factor influencing germination, survival and growth of individual trees in forests. Thus, capturing this information is critical for plant ecologists interested in the dynamics of forest stands. The complex structure and dynamics of multi-species, multi-strata forests makes it impractical to develop a detailed model of light interception taking into account detailed structural characteristics of each species (foliage lay-out, distribution of leaf orientation, optical characteristics of leaves, etc.) as it has been attempted in some other cases (CESCATTI, 1997;

CESCATTI, 1997; BARTELINK, 1998). The rationale in SLIM is to use a simple enough 3D description of trees so that individual characteristics of trees can be collected in the field quickly and easily.

SLIM essentially makes use of this 3D scene to compute canopy openness (an index of long term light availability) in very much the same way as hemispherical photographs are used. Hemispherical photographs have been widely used in ecology to characterize light environments (BECKER et al., 1989; WHITMORE et al., 1993; BELLINGHAM et al., 1996) and they may be considered to give characterizations that are rough but robust. With additional information on direct and diffuse light partitioning at the site during the period of interest, as well as longitude and latitude, hemispherical photographs can be used to compute the amount of photosynthetically active radiation received at the photograph position. The same applies to the model presented here. Even though computations are restricted to canopy openness this capability could easily be added. It would be particularly relevant in order to study seasonal or diurnal change in light levels. SLIM can be used to compute light indices for particular trees but it can also compute canopy openness at any point in space and thus be used to map canopy openness over the plot or to assess a vertical gradient of light etc.

Model Inputs

For a user-defined plot area, data regarding topography and geometry of individual trees need to be provided.

Topography

There are two ways of entering topography data. Either each tree base has a measured value for altitude, or a digital elevation model of the plot is available and the software will carry out a 2D linear interpolation from the x and y coordinates of each tree to get the altitude of the tree.

Tree geometry

A tree crown is represented in SLIM by a convex surface corresponding to the outer surface of a truncated revolution ellipsoid. The crown envelope is assigned a light porosity coefficient which is measured by taking photographs of the crown towards the sky, roughly perpendicularly to the envelope's tangent using a narrow angle lens, and calculating from the photograph the percentage of visible sky (Figure 1).

Each tree is thus characterized by a set of geometric features: location of tree base, location of the projection of the crown center on a horizontal plan, total height, maximum crown width, height of crown base, height of maximum crown width, trunk diameter, and porosity of crown to light. Altitude of tree base is also requested if a digital elevation model of the plot is not entered (Figure 2).

Average crown porosity varies significantly between species (TRI HARTONO, 2001) and it is recommended to estimate crown porosity per species, at least for the dominant species in the stand. This should preferably be done for a few trees per species as there is considerable variation between individuals within species. These may be related to tree environment or tree development stage but are often unpredictable. For example, the average crown porosity for *Shorea javanica*, a dipterocarp tree cultivated in Sumatra for its resin, was found to be equal to 33% and the coefficient of variation was equal to 30%. This high intra-species variability suggests that even very detailed architectural models developed at species level may miss an important source of variability in light distribution at stand level if the sampling of individual trees within species is not adequate. Fortunately, given the ease and rapidity of crown porosity measurements, this can be taken care of correctly within the SLIM framework.
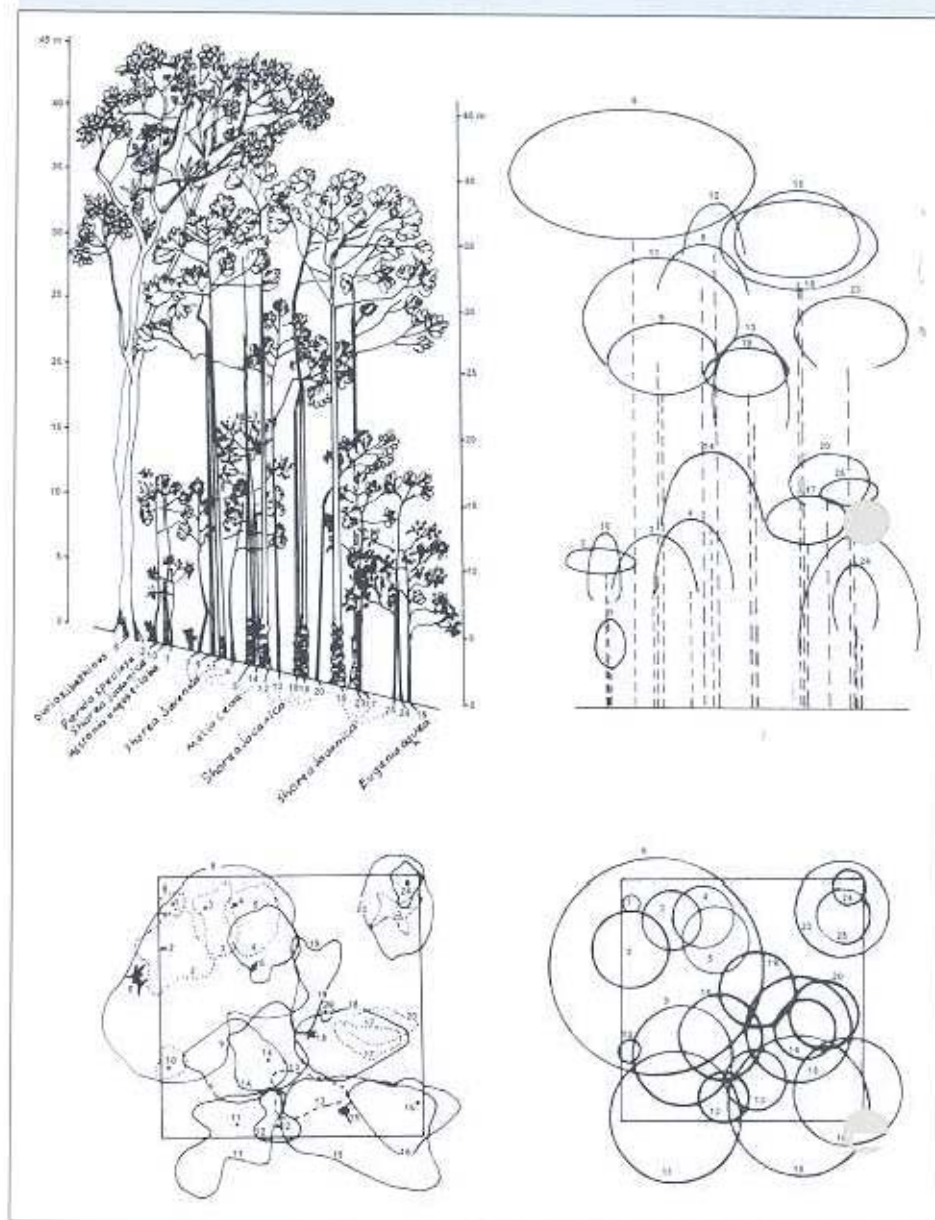

Figure 2.
SLIM's representation of a 20 m by 20 m plot of damar agroforest (original profile in MICHON, 1985). Crowns are approximated by simple truncated ellipsoids based on field measurements of the geometrical characteristics of trees.

Model calculations

A user-chosen lower limit zenith angle defines the portion of the sky vault that is explored. The default lower limit is typically 45 degrees. The portion of the vault explored is restricted to an upper portion because as zenith angle increases (or say the horizontal angle decreases), the distance at which potential intruders stand may be found also increases. Eventually, as the angle approaches the horizon, the distance of potentially shading trees tends towards infinity. At the same time the probability of having a gap near the horizon tends towards zero. In our data sets, canopy openness measured below 45 degrees was on average only 5% in damar agro-
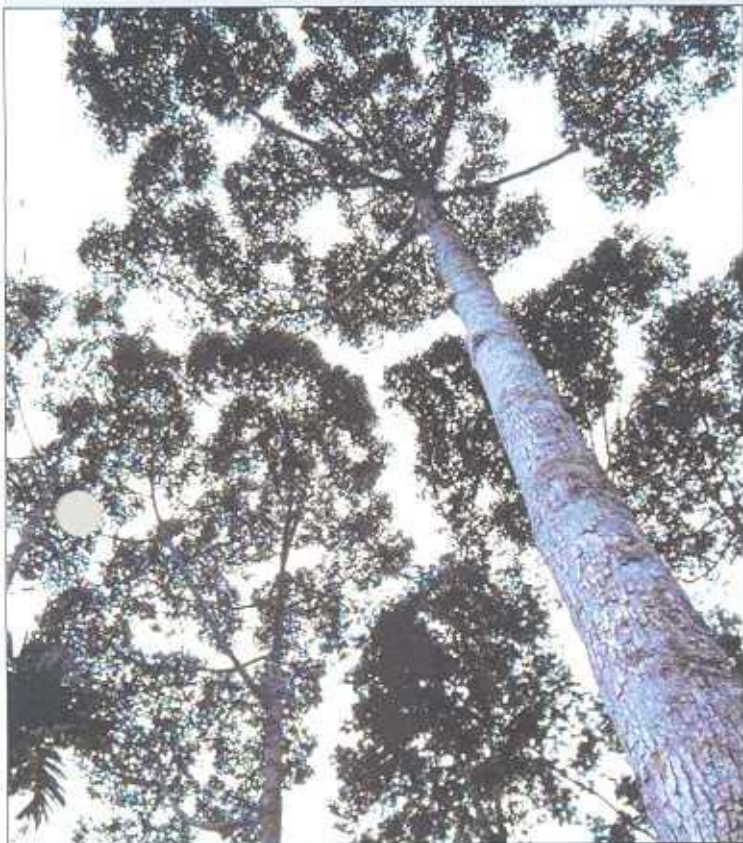
Figure 3.
Tree crowns rarely intermingle but rather occupy space in a mutually exclusive way (canopy of *Shorea javanica*, Sumatra, Indonesia).

Figure 4.
A 3D viewer allows the user to interactively explore the forest stand and perform a first level check of tree geometry data.

Figure 5.
Pseudo leaves (randomly oriented triangles) are spread over tree crown envelopes mimicking foliage. The density of those pseudo-leaves is proportional to the measured crown porosity.

forest and 6 % in rubber agroforest. Furthermore the total solar irradiance (direct and diffuse) decreases with increasing zenith angle (CAMPBELL, NORMAN, 1997). Thus if the model is to be used in combination with an illumination model, correct estimation of canopy openness at a high zenith angle will be of greater importance than at lower angles.

Canopy openness computations

The truncated hemispherical vault is further divided into segments as defined by a range of zenith and bearing angles.

Canopy openness of any point P in space is computed by summing the canopy openness of each sky vault sector weighted by its relative surface. Canopy openness of a sector of azimuth A and bearing B is simply the product of all porosity values of all the crown envelopes intersected by a beam of azimuth A and bearing B originating from point P.

Crowns of neighboring trees may overlap. Intersection between a beam and a crown may occur inside another crown. In this case no shading is considered. In other words only free parts of foliage layers (not inside the crown of another tree) effectively shed shade. This rule is equivalent to saying that any point in space will be inside one single crown at the most. This rule is important because forcing crowns into symmetric shapes leads to considerable intermingling of theoretical crowns, whereas in real world this is not the case as crowns are most often mutually exclusive (Figures 3, 4 and 5). The shading effect of trunks is also taken into account. Trunks are represented as truncated cones linking the tree base to the crown center.
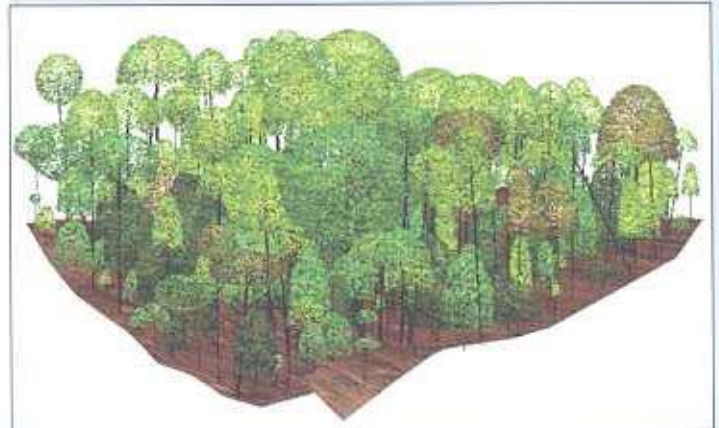
Setting a limit zenith angle for exploring space also defines a maximum distance at which the highest tree can possibly intrude in the vault fraction under consideration. A user-defined parameter sets the maximum distance at which the model will search for shading crowns. This should be set so that it is consistent with the above limit zenith angle by considering the height of the tallest tree and topography characteristics. The distance of interaction also determines which bearings will be used to compute canopy openness. If for a particular bearing, at a particular point in the stand, potential intruders are outside the stand, then this bearing is not used for computing canopy openness at this point. Similar restriction to bearing range is applied to compute pseudo hemispherical photograph views (Figure 6).
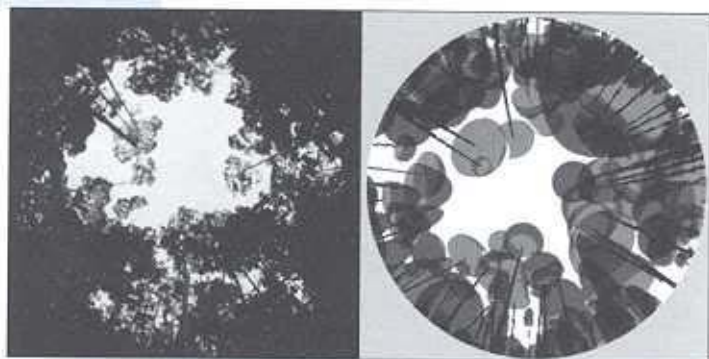
Figure 6.
A simulated hemispherical view allows thorough checking of canopy openness at a particular point by comparison with an actual hemispherical photograph taken at the same location.

Model use

The model was tested on two sets of data: a one-hectare plot of damar-based agroforest (VINCENT *et al.*, 1999) and a one-hectare plot of rubber-based agroforest (AZHIMA, 2001), providing reasonable predictions. The linear correlation coefficient between canopy openness computed from hemispherical photographs taken 1.5 m above ground and predicted by the model at the same locations were above 0.8).

Two major sources of errors were identified. Simulations proved that a relatively small inaccuracy in tree positioning could result in significant errors in canopy openness prediction (VINCENT *et al.*, 1999). The second major source of error is probably related to discrepancies between actual volume and idealized volume of individual crowns. Such discrepancies can arise from inaccurate measurements of tree geometry (height measurements and mapping of vertical crown projection) on the one hand and from forcing irregular shapes into regular ellipsoids on the other hand.

Forcing asymmetric crowns into regular shapes necessarily brings about some distortion. This constraint could be relaxed (as in CESCATTI, 1997) by using asymmetrical envelopes. Nevertheless, the problem then is obtaining a reasonable description in the field of the crown shape at a reasonable cost. Sensitivity tests suggest that crown size and crown porosity are relatively less sensitive than positioning.

Future developments

Future improvements will include enhancing crown description by adding different generic shapes to describe the crown volumes or alternatively a user-defined equation of a crown profile. An illumination model will be added to compute actual PAR during particular periods of time.

The model is freely downloadable from our web site (http://www.icraf.cgiar.org/sea/) and the authors would very much appreciate any feedback from future users.

References

AZHIMA F., 2001. Spatial and temporal distribution of light in a rubber agroforest in Jambi, Sumatra («Distribusi spasial dan temporal cahaya pada hutan karet di Muara Kuamang, Jambi»).BSc thesis, Bogor Agricultural Institute (IPB), Indonesia, 14 p.

BARTELINK H. H., 1998. Radiation interception by forest trees: a simulation study on effects of stand density and foliage clustering on absorption and transmission. Ecological Modeling 105, 213-225.

BECKER P., ERHART D. W., SMITH A. P., 1989. Analysis of forest light environments Part I. Computerized estimation of solar radiation from hemispherical canopy photographs. Agricultural and Forest Meteorology 44, 217-232.

BELLINGHAM P. J., TANNER E. V. J., RICH P. M., GOODLAND T. C. R., 1996. Changes in light below the canopy of a Jamaican montane rainforest after a hurricane. Journal of Tropical Ecology 12 (5): 699-722.

CAMPBELL G. S., NORMAN J. M., 1997. An introduction to environmental biophysics. Springer-Verlag, New-York, United States.

CESCATTI A., 1997. Modelling the radiative transfer in discontinuous canopies of asymmetric crowns. I. Model structure and algorithms. Ecological Modeling 101, 263-274.

CESCATTI A., 1997. Modelling the radiative transfer in discontinuous canopies of asymmetric crowns. II. Model testing and application in a Norway spruce stands. Ecological Modeling 101, 275-284.

TRI HARTONO T., 2001. Comparison of various methods to assess light requirement of tree species occuring in damar agroforest , Sumatra («Kajian metodologi mengenai identifikasi ekologis tingkat kebutuhan cahaya bergagai jenis tumbuhan di tingkat anakan dan pohon dewasa di damar agroforest, Krui, Sumatra»).Master of sciences thesis, Bogor Agricultural Institute, Indonesia, 73 p.

VINCENT G., AUTHAR S., DE FORESTA H., 1999. A simple model of light interception by trees in multi-species, multi-strata forests. Multistrata Agroforestry Systems with Perennial Crops, Turrialba, Costa Rica, CATIE.

WHITMORE T. C., BROWN N. D., SWAINE M. D., KENNEDY D., GOODWIN-BAILEY C. I., GONG W. K., 1993. Use of hemispherical photographs in forest ecology: measurement of gap size and radiation totals in a Bornean tropical rain forest. Journal of Tropical Ecology 9, 131-151.