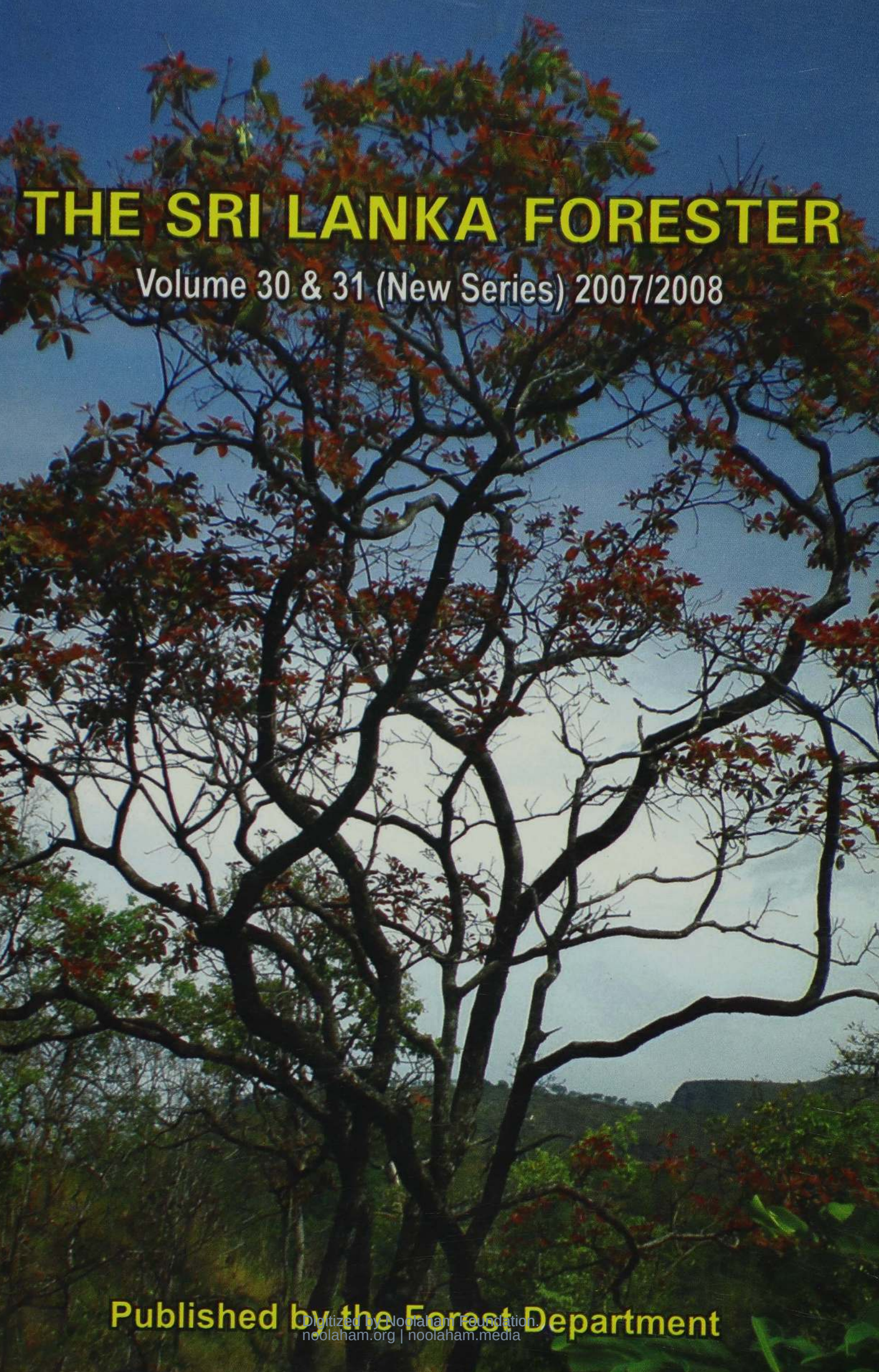


THE SRI LANKA FORESTER

Volume 30 & 31 (New Series) 2007/2008

Published by the Forest Department

THE
SRI LANKA FORESTER

Volume 30 & 31 (New Series) 2007/2008

FOREST DEPARTMENT

THE SRI LANKA FORESTER

Volume 30 & 31 (New Series) 2007/2008

JOURNAL OF
THE SRI LANKA FOREST DEPARTMENT

Editorial Office
Forest Information Service
FOREST DEPARTMENT
Rajamalwatta Road
Battaramulla
Sri Lanka.

Cover Photographs
Savannah Forest in Koslanda by S. H. Bandumala

Subscriptions to the Sri Lanka Forester

All correspondence about subscriptions, including exchange agreements should be addressed to :

The Librarian
Forest Department
Rajamalwatta Road
Battaramulla
Sri Lanka.
Email: forest_libary@yahoo.com

The present subscription rate is Rs, 200.00(Local) / US$ 10.00 (overseas) per issue.

Money orders, postal orders or cheques should be drawn in favour of 'Conservator General of Forests', and crossed " A/c payee only"

THE SRI LANKA FORESTER

(THE CEYLON FORESTER)

Volume 30 & 31 ISSN 0258-624X Year 2007/2008

The forest is a peculiar organism of unlimited kindness and benevolence that makes no demand for its sustenance and extends generously the products of its life activity; it affords protection to all beings, offering shade even to the axeman who destroys it.

GAUTAMA BUDDHA

THE SRI LANKA FORESTER

(THE CEYLON FORESTER)

Volume 30 & 31 ISSN 0258-624X Year 2007/08

RESEARCH ARTICLE PAGE

CONSTRUCTION OF A PRECISE GROWTH MODEL TO PREDICT THE INDIVIDUAL TREE STEM VOLUME FOR MATURE *Tectona grandis* L.f. (TEAK)

S.M.C.U.P. Subasinghe[1] and W.P.K.Gunarathne[1]

Summary

Stem volume is the most important variable in commercial forestry because most of the important management decisions are taken on the volume production of trees. However, it is also the most difficult variable to measure and therefore it is necessary to have accurate volume prediction methods. For the present study, a growth model was constructed to predict the stem volume of individual Tectona grandis *L.f. (teak) trees of a 30 year old plantation (34.0 ha) in Mihintale Beat of the Anuradhapura Forest Division. In order to collect data, ten 0.02 ha circular sample plots were randomly laid out. Diameter at breast height (dbh), total height and crown height of the trees in all the sample plots were measured as the first step. Tree basal area, stand basal area and top height were calculated using those data. For the second step of data collection, each tree stem was divided into 3-5 m sections, without felling them, using a Blume-Leiss altimeter. Then the bottom, middle and top diameters of each section were measured using Spiegel relascope. The volume of each section was calculated separately using Newton's formula and the stem volume was determined by summing the section volumes together. For this reason, the final section of the tree was considered as a cone.Then a theoretical model was developed to predict the individual tree volume using the relationship of form factor with volume, basal area and total height. It was fitted to the collected data using multiple linear regressions. Three site factors and four transformations were used to enhance the quality of the models. After fitting the possible 475 models with different forms, 13 models were selected for further analysis due to their high R^2 values which were over 85% and good distribution of standard residuals. For these selected models, average model bias and modelling efficiency were tested to select the best model. The biases indicated by all the models were insignificant and the model with the highest modelling efficiency (0.982) was selected for the field use. When the final model was validated with independent data reserved at the beginning of the model construction, the results proved the ability of using the selected model in the field without producing errors.*

[1] *Department of Forestry and Environmental Science, University of Sri Jayewardenepura, Gangodawila, Nugegoda.*

INTRODUCTION

Tectona grandis L.f. (teak) belongs to family Verbenaceae is an important timber species due to its high value for the wood. Teak has a worldwide reputation as a high quality timber on account of its remarkable physical and mechanical properties particularly shape retention, durability, resistance to fungi and chemicals. The most important feature is its resistance to termites, due to the presence of sesquiterpenes. It is indigenous to Myanmar, Central and South India and Thailand. Teak was one of the main exotic species selected for plantation forestry in the tropics (Evans, 1982).

The rehabilitation of the forest cover loss in Sri Lanka due to the degradation and exploitation of natural forests was started by establishing forest plantations. These plantations mainly consisted of fast growing exotic species such as *Eucalyptus, Pinus, Acacia, Casuarina, Swietenia* and *Tectona* (Ponnamperuma, 1996). In Sri Lanka, approximately 45,300 ha of teak plantations are maintained by the Forest Department and they are mostly located in Ampara, Anuradhapura, Hambantota, Kurunegala, Moneragala, Polonnaruwa and Puttlam districts (Bandaratillake, 1999).

In 1970s researchers started to develop mathematical and computer models to simulate the development of stands and individual trees within the stands (Stage, 1973; Clutter and Allison, 1974; Johnstone, 1976). Most of the forest growth models are constructed by fitting several equations independently to data (Soares *et al.*, 1995) and these may comprise many separate but interrelated components, each of which may influence and influenced by other components and assumptions (Vanclay, 1994). These models usually describe growth rate as a regression function of variables such as site index, basal area and stem density. In most growth and yield models, site index is used to determine the growth potential or maximum growth rate (Liu and Ashton, 1995).

Construction of growth and yield models

A major step in estimation of the model parameters is to decide on the mathematical form of that model to be fitted to the data at hand (Kassab, 1987). The benefits of the mathematically presented model are that they are clearly defined and thus easily communicated, so that strengths and weaknesses may be analysed (Gilchrist, 1984).

The commonest way of model construction in natural resource modelling is to use the regression analysis. Linear models are widely used in growth and yield studies, and those contain several advantages. Most computer systems and many pocket calculators incorporate reliable algorithms to fit such equations to data. The solution to the equation is unique, easily obtained and rather robust, even when assumptions implicit in the models are violated (Vanclay, 1994). The structure of the forest growth model reflects the model objectives and different types of models are required to satisfy different purposes (Kimmins, *et al.*, 1990). The first step in model construction is to prepare an outline of the model, formulate the functional relationships required, and fit the functions into the data (Vanclay, 1994).

Model evaluation and validation

Model evaluation is an important part in model building, and at least some examination of the model should be made at all stages of model design, fitting and implementation (Vanclay and Skovsgaard, 1997). Evaluation should not merely be an afterthought or an acceptance trial. A thorough evaluation of a model involves several steps, including two which are often called qualitative and quantitative tests in forest growth modelling (Vanclay, 1994). Model evaluation should extend to all model components and assumptions, and these require a thorough understanding of the structure of the model and the interrelationships between components (Soares *et al.*, 1995).

One of the most effective ways to examine model performance is to plot residuals for all possible combinations of tree and stand variables, and to look for patterns which may indicate serial correlation, dependencies on initial conditions or on projection length, or other systemic patterns (e.g., Soares *et al.*, 1995). It is common to plot observed values (y) against predicted values ($\hat{y}$), but in many cases it is more revealing to plot residuals ($e = y - \hat{y}$) versus observed values (Vanclay, 1994).

If sufficient independent data are available, the model should be validated by comparing model predictions with data. In the absence of such validation data, errors and the uncertainly in the model structure cannot be detected. However, it is possible to quantify the uncertainties in the model inputs and often to identify the inputs that are primarily reasonable (Voet and Mohren, 1994).

METHODOLOGY

Formation of the theoretical model structure

For the construction of the volume prediction model, a theoretical structure was developed using the relationship of volume with form factor, basal area and total height (equation 1).

$$v = g \times h \times ff$$

(equation 1)

where: g = tree basal area, m^2
ff = form factor of the tree
h = total height, m
v = total volume of the tree, m^3

(Philip, 1994)

Form factor is difficult to measure due to its variability with other tree parameters and environmental and geological factors. Therefore keeping the other variables intact with the equation 1, it was decided to replace form factor using other explanatory variables which can be measured easily such as diameter at breast height (dbh), total height, height to the crown base and top height. According to Philip (1994), form factor also changes according to site factors, age and density variations and also from tree to tree in the same site and same age. Therefore other than tree's own variables, form factor is influenced by site factors, density, competition and age. However, age can be ignored because the plantation is even-aged. Competition is another difficult parameter to quantify and therefore it was replaced by the stand density and crown

parameters, because crown height is a good indicator of the competition. Top height represents the quality of the site. Therefore top height itself and related indices such as top height/stand age, top height/stand basal area were used to represent the site quality. The final theoretical equation used for this study is given in the equation 2.

volume = f (basal area, height, site factors, crown parameters, stand density)

(equation 2)

Selected plantation and data collection

A 30 year old *Tectona grandis* plantation was selected from Mihintale area in Anuradhapura Forest Division for this study (Sub-Block 29, Block 01, Mihintale Beat, Anuradhapura Range) which had the extent of 34.0 ha. Undergrowth was also present in the plantation comprised of some medicinal plants, shrubs and dry grasses. The soil type was reddish brown.

There was no geographical variation within the selected plantation. The land was flat and free of hilly areas or slopes. The growth rate of trees was visually equal for the entire population. Therefore it was decided to use random sampling with 0.02 ha circular plots. Altogether, 10 plots were used for the data collection. dbh, total height, and height to the crown base were initially measured for all the trees in the sample plots.

Measurements taken for the stem volume calculation

For the calculation of the volume of the standing trees, tree stem was visually divided into several sections which were about 3-5 m. The section length was measured using Blume-Leiss altimeter and end and mid diameters of each section were measured using Spiegel relascope. The final part of the stem was considered as a cone and only the base diameter was measured.

Calculations

Determination of total stem volume

For calculating the stem volume of standing trees, Newton's formula (equation 3) was used since it is accepted as the most accurate equation for all types of stem shapes (Avery and Burkhart, 1994; Philip, 1994).

$$v_s = \frac{\pi l(d_b^2 + 4d_m^2 + d_t^2)}{240000}$$

(equation 3)

where: d_b = diameter at the base of the log, cm
d_m = diameter at the mid-length of the log, cm
d_t = diameter at the top of the log, cm
l = log length, m
v_s = volume of the log, m^3

The final part of the stem was assumed as a cone, and the volume of the total stem was calculated by adding section volumes to the volume of the final part.

Basal area

Basal area at breast height (g, m^2) for each tree was calculated by the dbh as shown in the equation 4 and the stand basal area per hectare (G, m^2) was calculated by using the cumulative basal area in the plots used.

$$g = \frac{\pi\, dbh}{40000} \qquad \text{(equation 4)}$$

Top height and stand density

Top height is defined as the average total height of 100 thickest trees at breast height point per hectare and believed to be a good indicator of the site quality (Philip, 1994). In order to determine the top height, the two thickest trees at breast height point were selected from each plot and then the average height was calculated. The stand density (N, ha^{-1}) was calculated using the equation 5.

N = number of trees in the plot / 0.02 (equation 5)

Parameter estimation

After taking the measurements, the sample plots were divided into two groups, and for the parameter estimation 75% of the plots were used. The rest of the sample plots were reserved for the purpose of validating the resultant models. Before constructing each model, the distribution of the response variable with the explanatory variables was examined using scatter plots. Basic statistics and correlations of both response and candidate explanatory variables were also studied to identify the possible deviations from the model assumptions. Apart from the untransformed values for both response and explanatory variables used for model construction, it was decided to transform those variables into biologically accepted forms, i.e., logarithmic, square, square root and reciprocal in order to obtain the best model while meeting all the assumptions. Data were fitted to the all possible combinations of the candidate explanatory variables using GENSTAT statistical software while always keeping *tree basal area* × *total height* as the key explanatory variable.

Evaluation of the model performance

Other than R^2 and standard residual distributions, average model bias (equation 6) and modelling efficiency (equation 7) were used to examine the bias and the efficiency of the selected models.

$$\text{Ave bias} = \frac{\Sigma(\hat{y} - y)}{n} \qquad \text{(equation 6)}$$

$$Ef = \frac{\Sigma(y - \hat{y})^2}{\Sigma(y - \bar{y})^2} \qquad \text{(equation 7)}$$

where: n = number of data
y = observed variable
$\hat{y}$ = predicted value
= arithmetic mean value for the observed data

For the constructed models, the compatibility with the biological behaviours of variables was tested using the following procedure explained using the equation 8.

$$v = a + b_1 \times dbh + b_2 \times h \qquad \text{(equation 8)}$$

Equation 8 predicts the individual tree volume using dbh and total height of the same tree. a, b_1, b_2 are the estimated parameters. If the height of a particular tree is zero, dbh also does not have any value. Therefore volume should be zero (when $h = 0, b_2 \times h \rightarrow 0$ and $b_1 \times dbh \rightarrow 0$). Then the volume, $v = a$. Therefore the parameter a should not be significantly different from zero. This was tested using the equation 9.

$$t_{cal} = \frac{P_{est} - 0}{se} \qquad \text{(equation 9)}$$

where: P_{est} = estimated value of the parameter
se = standard error of the particular parameter
t_{cal} = calculated *t-value*

If the calculated *t-value* was higher than the *t-value* obtained from the student's *t* distribution table at 95% probability, the parameter was significantly different from zero and that model was removed from this study because it violated the compatibility with the biological reality.

Model validation

According to Soares *et al.* (1995) and Vanclay (1994), 25% of the sample plots was reserved for the purpose of validating the models. The reserved data were not used for the model construction and only used to test the validity of the models with the independent data. For the model validation, the finally selected models were fitted to the reserved data and normal residuals were calculated and the distributions of the normal residuals with the fitted values were examined.

RESULTS

Selected models for further tests

When the equations were fitted to the data, always the variable *basal area* × *height* was kept in tact with the model as the key ex-

Table 1: Selected models for further analysis.

No	Model	R2
01	$\sqrt{v} = 0.582\sqrt{g \times h} + 0.0070 h_{cr}$	89.6
02	$\sqrt{v} = 0.562\sqrt{g \times h} + 0.0247\sqrt{h_{cr}}$	89.7
03	$\sqrt{v} = 0.603\sqrt{g \times h} + 0.0006 h_{cr}^2$	89.5
04	$\sqrt{v} = 0.564\sqrt{g \times h} + 0.0757 \log(h_{cr})$	88.6
05	$\sqrt{v} = 0.567\sqrt{g \times h} + 0.0036 h_{top}$	87.5
06	$\sqrt{v} = 0.563\sqrt{g \times h} + 0.0152\sqrt{h_{top}}$	87.5
07	$\sqrt{v} = 0.576\sqrt{g \times h} + 0.0485\sqrt{h_{top} / age}$	88.7
08	$\sqrt{v} = 0.547\sqrt{g \times h} + 0.0741(age / h_{top})$	88.6
09	$\sqrt{v} = 0.562\sqrt{g \times h} + 0.0509 \log(h_{top})$	88.6
10	$\sqrt{v} = 0.569\sqrt{g \times h} + 0.0128\sqrt{G}$	88.5
11	$\sqrt{v} = 0.565\sqrt{g \times h} + 0.0461 \log(G)$	88.5
12	$\sqrt{v} = 0.561\sqrt{g \times h} + 0.0023(G / h_{top})$	88.5
13	$\sqrt{v} = 0.571\sqrt{g \times h} + 0.0495\sqrt{G / h_{top}}$	88.5

planatory variable. Altogether 475 combinations of the variables (including transformations) were tested with multiple linear regression analysis. With the careful observations of the standard residual distributions and R^2 values, 13 models were selected at the first phase for further analysis (table 1).

where: g = tree basal area, m^2
G = sand basal area, m^2ha^{-1}
h = total tree height, m
h_{cr} = height to the base of the crown, m
h_{top} = top height, m
v = tree volume, m^3

Evaluation of the selected models

All the selected models were compatible with the biological reality because the intercept was not significant and the signs of the estimated statistical parameters indicated the right direction. The R^2 values for all the selected models were over 87.5 indicating a good fit with the data. The distributions of the standard residuals of the first two models in the table 1 are given in the figure 1 and figure 2.

According to the figures 1 and 2, the distributions of the standard residual values with the fitted values are adequate to prove the quality of the selected models and therefore these models proved the suitability of selection for the further analysis.

The calculated model bias and modelling efficiency values are given in the table 2. The modelling efficiency values for all models were approximately similar (between 0.88-0.90) except for the 5th model which has the highest value (0.982). The least value (0.880) was recorded for the model 12. However, all these values indicated a good performance of the selected models because the modelling efficiency values are close to one.

Moreover all the models in the table 1 indicated insignificant bias. However, for the second and fourth models, over-estimations of predictions were indicated (due to the + values for the bias) and for all the other models, under-estimations were indicated.

Selected final model

Distribution of the standard residuals and the R^2 values did not show a significant difference between the selected 13 models. The 5th model (table 1) indicated the highest modelling efficiency, i.e., 0.982. Therefore taking this matter into the consideration, that model (equation 10 below) was selected as the best model for predicting the stem volume of the selected teak plantation. Distribution of the standard residuals of that model is given in the figure 3.

$$\sqrt{v} = 0.567\sqrt{g \times h} + 0.0036h_{top}$$

(equation 10)

Validation of the final model

For the validation purpose, the finally

Table 2: Calculated values for average model bias and modelling efficiency for the selected models.

Model No.	Model Bias	Modelling Efficiency
01	-0.0003	0.896
02	0.0004	0.896
03	-0.0012	0.892
04	0.0002	0.897
05	-0.0005	0.982
06	-0.0002	0.883
07	-0.0003	0.883
08	-0.0004	0.884
09	-0.0001	0.884
10	-0.0004	0.882
11	-0.0002	0.883
12	-0.0011	0.880
13	-0.0004	0.883

selected model (equation 10) was fitted to the reserved data at the beginning without changing the parameters. Then the normal residuals were calculated and the distribution of these residuals was tested with the actual values (figure 4).

DISCUSSION

When graphically tested, the individual tree volumes indicated good relationships with dbh, basal area and total height. However, the distribution of the volume did not show a good relationship with crown height. The reason could be due to the lack of pruning and other poor management practices in the selected plantation. Moreover, when tested, crown height became insignificant in regression equations.

A basic structure was theoretically developed for this study for the estimation of parameters. For this reason, the relationship developed for the prediction of artificial form factor (Philip, 1994) was selected. Selection of the

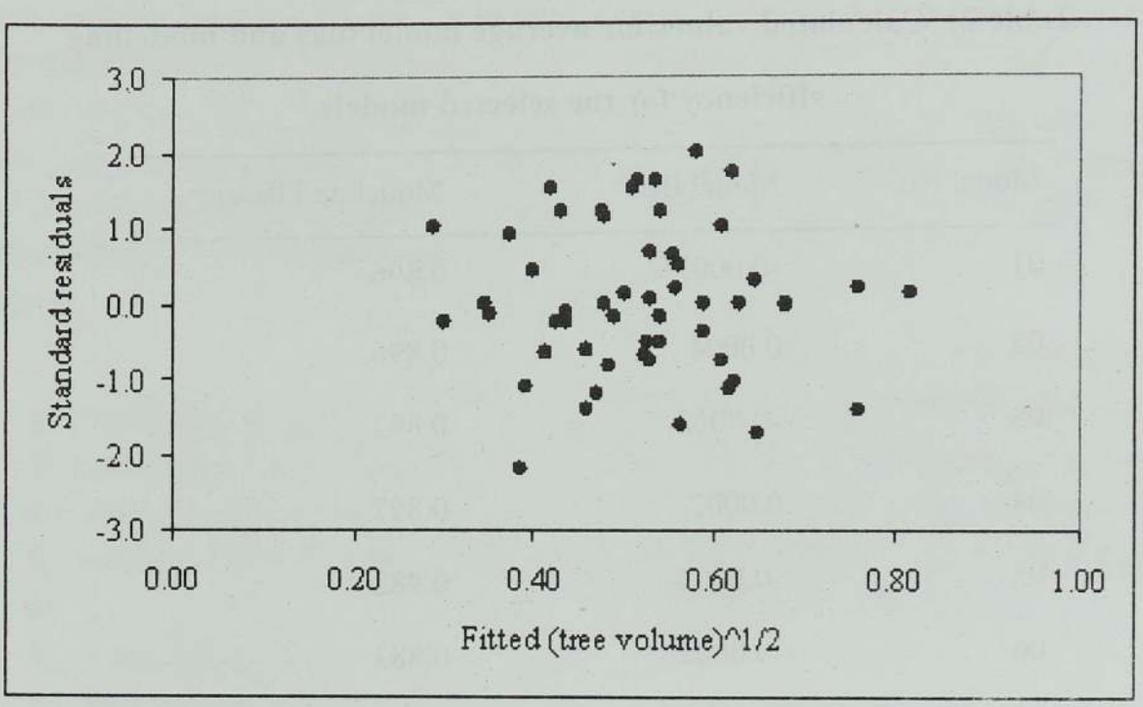


Figure 1: Distribution of the standard residuals of the *model 1* in the table 1.

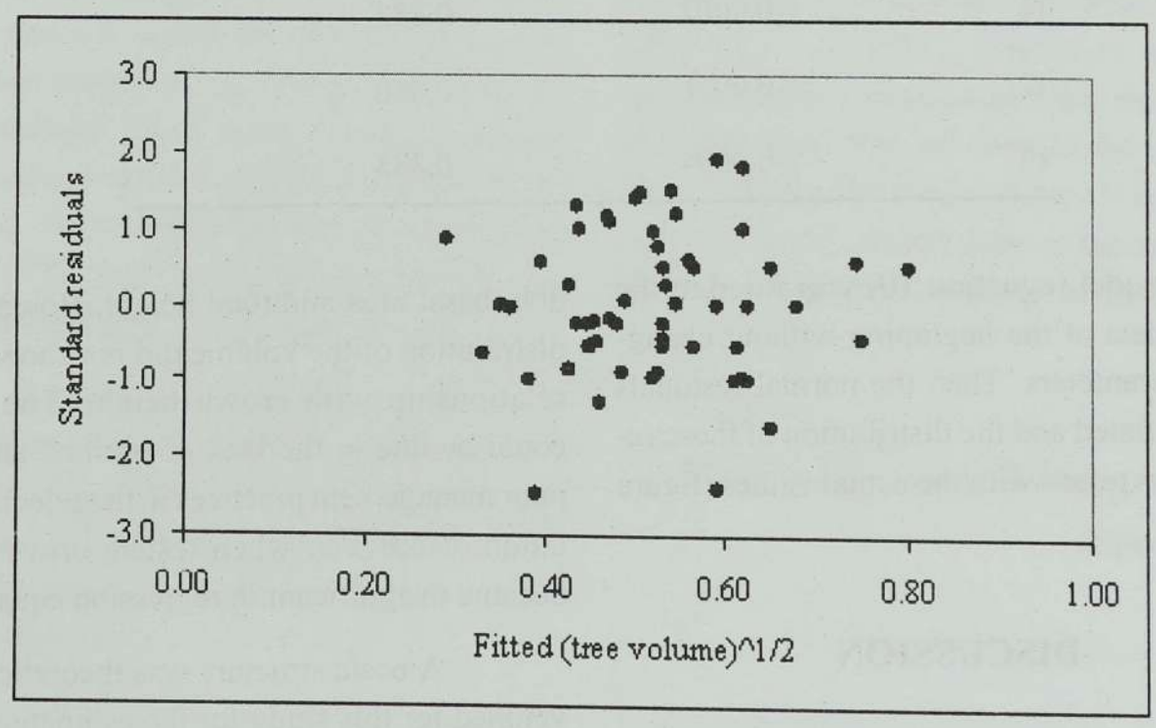


Figure 2: Distribution of the standard residuals of the *model 2* in the table 1.

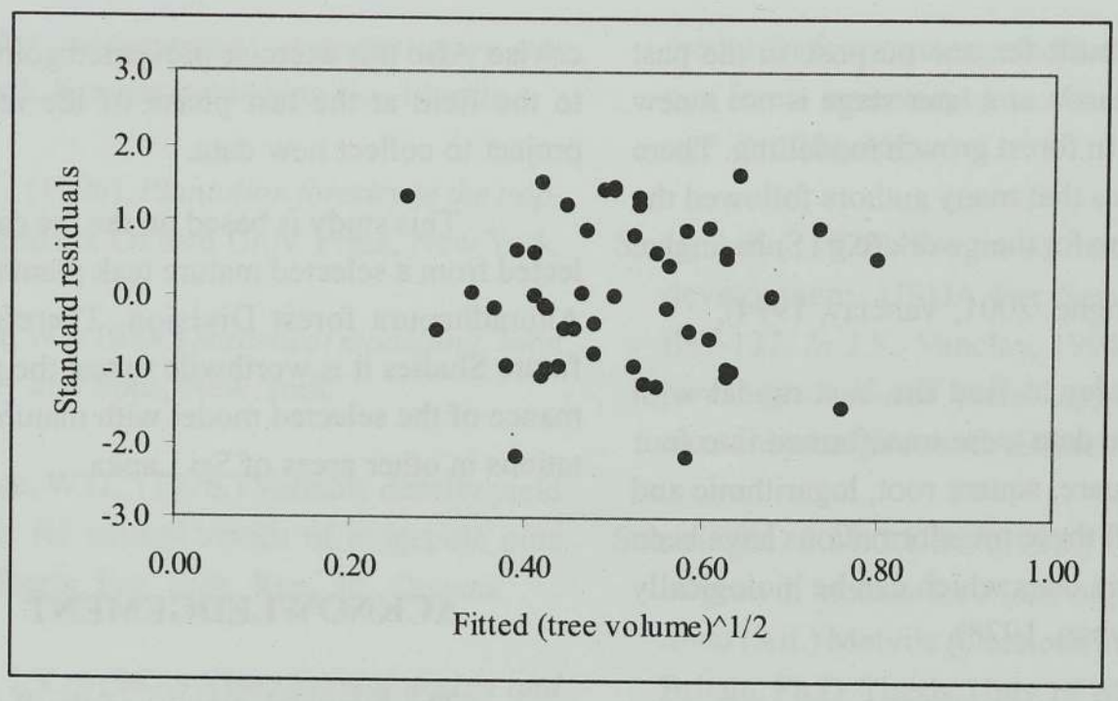


Figure 3: Distribution of the standard residuals of the finally selected model.

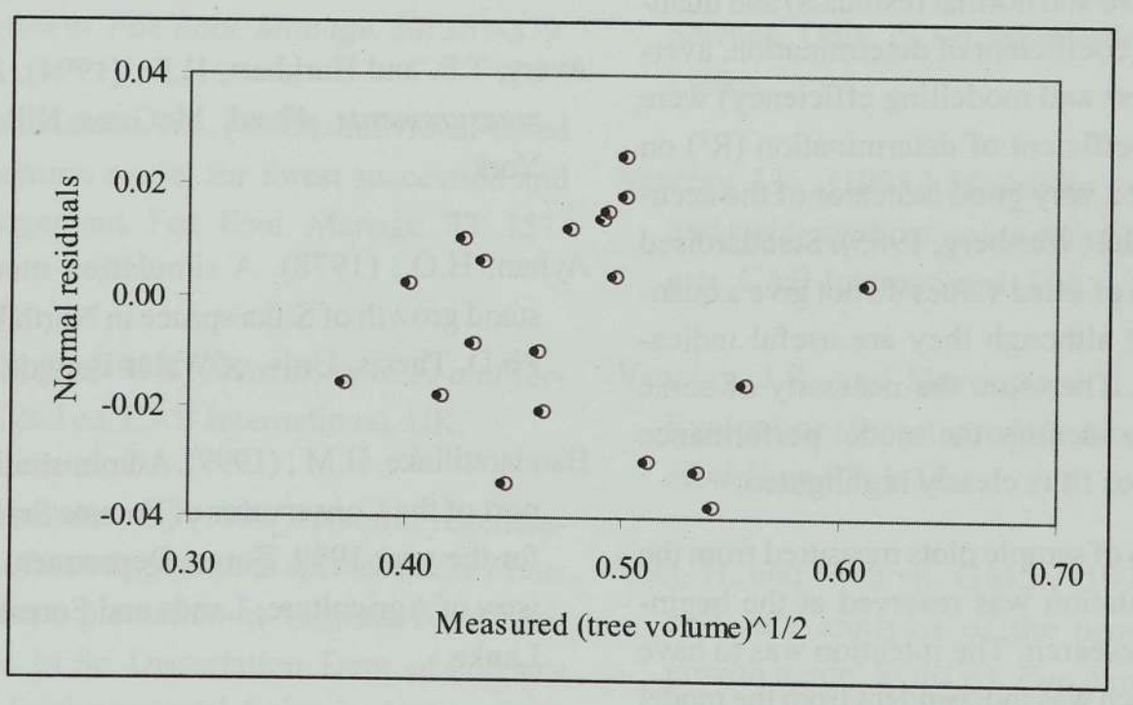


Figure 4: Distribution of normal residuals after fitting the final model into the reserved data at the beginning of the study.

relationships built for one purpose in the past for another reason at a later stage is not a new methodology in forest growth modelling. There were evidences that many authors followed the same procedure for their work (e.g., Subasinghe, 1998, Subasinghe, 2001, Vanclay, 1994).

In order to find the best model with least error, the data were transformed into four types, i.e., square, square root, logarithmic and reciprocal. All these transformations have been accepted as the ones which can be biologically explained (Ayhan, 1978).

Evaluation and validation of the selected models

For the purpose of testing the constructed models, both qualitative tests (distribution of standard and normal residuals) and quantitative tests (coefficient of determination, average model bias and modelling efficiency) were used. The coefficient of determination (R^2) on its own is not a very good indicator of the accuracy of a model (Weisberg, 1985). Standardised residual plots of fitted values do not give a quantitative result although they are useful indicators for bias. Therefore the necessity of some other tests to identify the model performance such as lack of fit is clearly highlighted.

25% of sample plots measured from the selected plantation was reserved at the beginning of this research. The intention was to have a data set which was independent from the model construction to test the behaviour of the model with new data. This is a necessary step of model building because, although the model indicates a high accuracy at the construction phase, its quality at the field use cannot be predicted otherwise. Also this exercise prevented going back to the field at the last phase of the research project to collect new data.

This study is based on the the data collected from a selected mature teak plantation in Anuradhapura forest Division. Therefore, in future Studies it is worthwile to test the performance of the selected model with mature plantations in other areas of Sri Lanka.

ACKNOWLEDGEMENT

The financial support of the Research and Publication Branch of the University of Sri Jayewardenepura and the assistance of the Sri Lanka Forest Department in data collection is acknowledged.

REFERENCES

Avery, T.E. and Burkhart, H.E., (1994). *Forest measurements*, 4th ed. McGraw Hill, New York.

Ayhan, H.O., (1978). A simulation model of stand growth of Sitka spruce in North Wales. Ph.D. Thesis, Univ. of Wales Bangor, UK.

Bandaratillake, H.M., (1999). Administration report of the Conservator of Forests Sri Lanka for the year 1999. Forest Department, Ministry of Agriculture, Lands and Forestry, Sri Lanka.

Clutter, J.L. and Allison, B.J., (1974.) Growth and yield models for *Pinus radiata* in New Zealand. In J.L. Clutter, J.C. Fortson, L.V. Pienaar, G.H. Brister and R.L. Baily, 1992.

Timber management: a quantitative approach. Kreiger Publishing Co., Florida.

Evans, J., (1996). *Plantation forestry in the tropics*. 2nd ed. Oxford Univ. Press, New York.

Gilchrist, W., (1984.) *Statistical modelling*. John Wiley and Sons, New York.

Johnstone, W.D., (1976.) Variable density yield tables for natural stands of lodgepole pine in Alberta. For. Tech. Rep. 20., Ottawa.

Kassab, J.Y., (1987.) *Experimental design and statistical analysis*. Statistical Advisory Unit, Univ. of Wales Bangor, UK.

Kimmins, J.P., Comeau, P.G. and Kurz, W., (1990.) Modelling the interactions between moisture and nutrients in the control of forest growth. *For. Ecol. Manage*. 30: 361-379.

Liu, J. and Ashton, P.S., (1995). Individual-based simulation model for forest succession and management. For. Ecol. Manage. 73: 157-175.

Philip, M.S., (1994.) *Measuring trees and forests*. 2nd ed. CAB International, UK.

Ponnamperuma, S., (1996_. Natural regeneration of woody perennial species under *Pinus caribaea* plantation at Yagirala Forest Reserve. M.Sc. Dissertation, Dept. of Forestry and Environmental Science, Univ. of Sri Jayewardenepura, Sri Lanka.

Soares, P., Tome, M., Skovsgaard, J.P. and Vanclay, J.K., (1995). Evaluating a growth model for forest management using continuous forest inventory data. *For. Ecol. Manage*. 71: 251-266.

Stage, A.R., (1973). Prognosis model for stand development. USDA For Serv. Res. Pap. INT-137. *In* J.K. Vanclay, 1994. Modelling *forest growth and yield: applications to mixed tropical forests*. CAB International, UK.

Subasinghe, S.M.C.U.P., (1998.) Construction of growth models for *Pinus nigra* var. *maritima* (Ait.) Melvile (Corsican pine) in Great Britain. Ph.D. Thesis, Univ. of Wales Bangor, UK.

Subasinghe, S.M.C.U.P., (2001.) Construction of an individual tree volume prediction model for *Eucalyptus grandis* in Sri Lanka. Res. Rep., Dept. of Forestry and Environmental Science, Univ. of Sri Jayewardenepura, Sri Lanka.

Vanclay, J.K., (1994.) *Modelling forest growth and yield: applications to mixed tropical forests*. CAB International, UK.

Vanclay, J.K. and Skovsgaard, J.P., (1997.) Evaluating forest growth models. *Ecol. Modelling* 98: 1-12.

Voet, H. and Mohren, G.M.J., (1994). An uncertainty analysis of the process-based growth model FORGO. *For. Ecol. Manage*. 69: 157-166.

Weisberg, S., (1985). *Applied regression analysis*, 2nd ed. John Wiley and Sons Inc., USA.

PREDICTION OF ERROR GENERATED BY HUBER'S AND SMALIAN'S FORMULAE IN VOLUME MEASUREMENTS OF *Pinus caribaea* (MORELET).

S. Hewage and S.M.C.U.P Subasinghe

Summary

Hubers's and Smalian's formulae are widely used by the foresters for standing tree volume estimations. However, volume estimation using those two equations can generate errors with increasing log length (Philip, 1994). Although Newton's formula predicts log volume precisely, it is not used for the standing trees because comparatively significant time is taken for obtaining the necessary measurements. Therefore this study was conducted to identify the errors associated in tree volume estimations using the Huber's and Smalian's formulae with the increasing log length in 26 year old Pinus caribaea *(Morelet) plantation at the Yagirala Forest Reserve. Three 0.05 ha sample plots were used for the data collection. Each tree was divided in to 1 m sections using a graduated stick and end diameters and mid diameters were measured for each section separately up to 12 m. Volume was calculated for each section using Huber's, Smalian's and Newton's formulae separately. The results were compared using one-way ANOVA, taking the volume estimated using Newton's formula as the actual volume. Results indicated that Huber's formula under estimates the tree volume while Smalian's formula over estimates. Results further indicated that Huber's formula predicts the tree volume without significant errors up to 6 m in length. However, volume calculated using Smalian's formula did not indicate a significant difference from the volume calculated using Newton's formula up to 12 m. There was a relationship between the errors generated by both formulae, i.e., Smalian's error was twice larger than the Huber's error. Finally considering the possibility of creating problems by over estimating the volume in commercial forestry, it is recommended to use the Huber's formula for tree volume estimations keeping the log length lower than 6 m.*

Department of Forestry and Environmental Science, University of Sri Jayewardenepura, Gangodawila, Nugegoda.

INTRODUCTION

Foresters use different methods to estimate the individual tree volume since it is the most important parameter in commercial forestry especially at the mature stage. One of the common methods of volume estimation is the use of mathematical equations. Among such equations, Huber's, Smalian's and Newton's formulae are commonly used and it is believed that Newton's formula which uses bottom, mid and top diameter of the log and log length gives most precise volume estimations. However, the use of Newton's formula is limited to research and serving as a check on volumes derived by other methods. (Hush *et al.*, 1982; Schreuder, 1993) due to its complexity and time consumed for measurements Smalian's formula uses log length and only end diameters of the log while Huber's formula uses log length and mid diameter for log volume calculations. Due to the low number of measurements involved, Huber's formula is more popular among the foresters. However, both Smalian's and Huber's formulae can introduce errors because they use fewer measurements compared to the Newton's formula. Moreover, reliability of estimate of stem volume estimation using formulae depends on the validity of the assumptions, the representativeness of the points of measurement and the accuracy of measurement according to Shreuder *et al.*, (1993), and Avery and Burkhart (1994).

Several studies were carried out to identify the error associate with different volume calculation equations (Wood and Wiant, 1990; Wiant., 1991; Patterson *et al.*, 1993; Fonweban., 1997). However, no information was available for this kind of research in Sri Lanka. None of these studies compared Huber's, Smalian's, and Newton's formulae for log volume estimation. Volume estimation methods compared in these studies were also not popular in Sri Lanka. Therefore, comparison of the most common equations which are used in Sri Lanka for log volume calculation has become important since it allows identifying the accuracy and errors.

The main objective of this study was to identify the error generated by Huber's and Smalian's formulae with log of *Pinus caribaea* (Morolet) (Caribbean pine) trees and to determine the maximum log length for the use of Huber's and Smalian's formulae without significant errors.

MATERIALS AND METHODS

Selected study site for the present study was the 26 year old *Pinus caribaea* plantation of the Yagirala Forest Reserve situated in Kalutara District. The selected area was not geographically homogeneous and therefore stratified random sampling method was used based on the geographical variations of the plantation for the data collection. Three 0.05 ha circular plots were therefore used representing valley, mid slope, and ridge top.

The main stem of each tree was divided into one meter sections using a graduated ranging staff. Three diameter measurements were taken using the Spiegal Relascope for each one meter section, i.e., bottom diameter, mid diameter and top diameter. These diameters were measured up to 12 m along the main stem or up to 10 cm over bark diameter. Other than these

three diameters base diameter, diameter at breast height and total height of each tree were measured.

The objective of this study was to identify the error generated in volume calculations using Huber's and Smalian's formulae (equation 1 and 2). Therefore it was assumed that Newton's formula (equation 3) predicts log volumes without errors. This was confirmed by previous publications such as Philips (1994) and Jenkins (1996, cited in Subasinghe 1998). However, in order to identify whether Newton's formula produces errors with increasing log length, log volume was calculated using the following methods.

i. Volume was calculated separately for each 1 m long section using Newton's formula

ii. Cumulative volumes was separately calculated from 1 m up to 12 m (i.e, 1 m, 2 m, 3 m, ...12 m) using Newton's formula

For volume calculations using Smalian's and Huber's formulae, cumulative log lengths were considered separately for each section 1 m to 12 m (as in (ii) in above).

Smalian's formula

$$v_i = \frac{\pi\, l\left(d_1^2 + d_2^2\right)}{80000} \qquad (1)$$

Huber's formula

$$v_i = \frac{\pi\, l\, d_m^2}{40000} \qquad (2)$$

Newton's formula

$$v_i = \frac{\pi\, l\left(d_1^2 + 4d_m^2 + d_2^2\right)}{240000} \qquad (3)$$

where:

d_1 =diameter at the base of the section, cm

d_2 =diameter at the top end of the section, cm

d_m =diameter at the mid point of the section, cm

l =length of the section, m

v_i =volume of the section, m^3

Effect of log length for Newton's formula

In order to identify whether there is a significant difference of volume with increasing log length, two types of volumes calculated using the Newton's formula were compared using one way ANOVA, for each section length and *p - values* were observed. According to the results, it was observed that there is no significant difference between log volumes calculated in above methods. Therefore it was concluded that Newton's formula does not produce signifi-

cant errors in volume calculations for any length up to 12 m.

Volumes calculated with different section lengths (i.e, 1 m, 2 m, 3 m,...12 m) were separately used for this test. For each section length, volumes calculated using three formulae were compared using one way ANOVA and Tukey's pairwise comparison tests. In this test volume calculated using Newton's formula for each section length was considered as the actual log volume for comparison after confirming its accuracy with the earlier test.

RESULTS

Fonweban (1997) strongly recommended to use Newton's formula for logs shorter than 6 m for *Triplochiton scleroxylon, Mansonia altissima,* and *Entandrophragma cylindricum.* However for the present study, it was proved that Newton's formula produces insignificant errors with increasing log length up to 12 m (figure 1). It was not possible to test

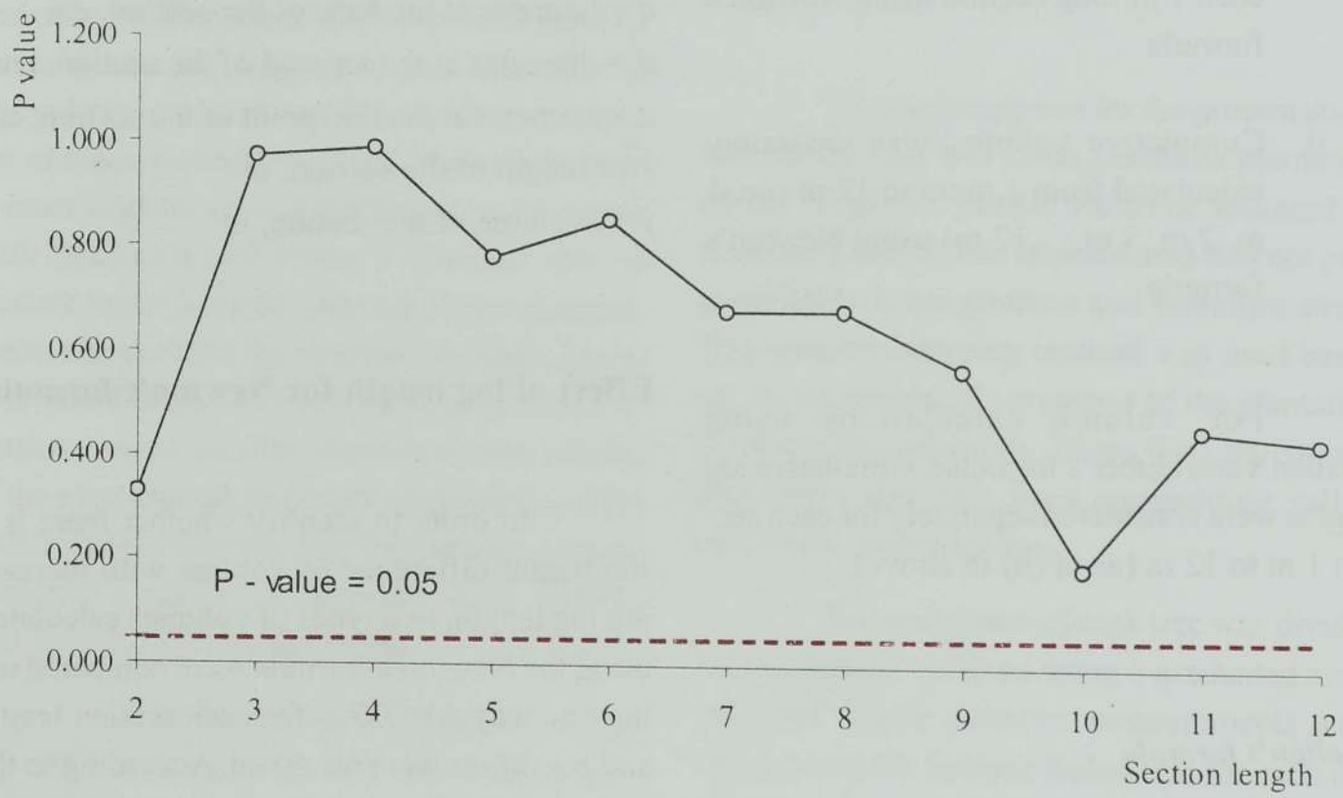


Figure 1: Section lengths vs. *p value* for cumulative and non-cumulative Newton's volume comparison

over 12 m in the selected plantation because the over bark diameter became less than 10 cm for most of the trees above that length. This 10 cm was selected as the minimum point with the merchantable value for the selected species (Subasinghe 1999).

Comparison of Huber's and Smalian's formulae.

In order to identify the maximum length which gives the accurate volume measurements for Huber's and Smalian's formulae, one way ANOVA (with Tukey's pairwise comparison) was conducted against the Newton's formula. For this purpose, Newton's formula was considered as the one which produces the precise volumes. Results obtained from this test are given in table 1.

According to the results obtained, three volumes were significantly different after 6 m log length (table 1). According to the Tukey's test, volumes calculated using both Huber's and Smalian's formulae were significantly different form that of Newton's formula after 6 m of log length (i.e., from 7 m). The graphical illustrations are

Table 1: Resultant *P – values* for the comparison of log volumes calculated using selected three formulae.

Section length, m	P - value
1	0.905
2	0.781
3	0.374
4	0.229
5	0.374
6	0.088
7	0.043
8	0.028
9	0.016
10	0.009
11	0.009
12	0.010

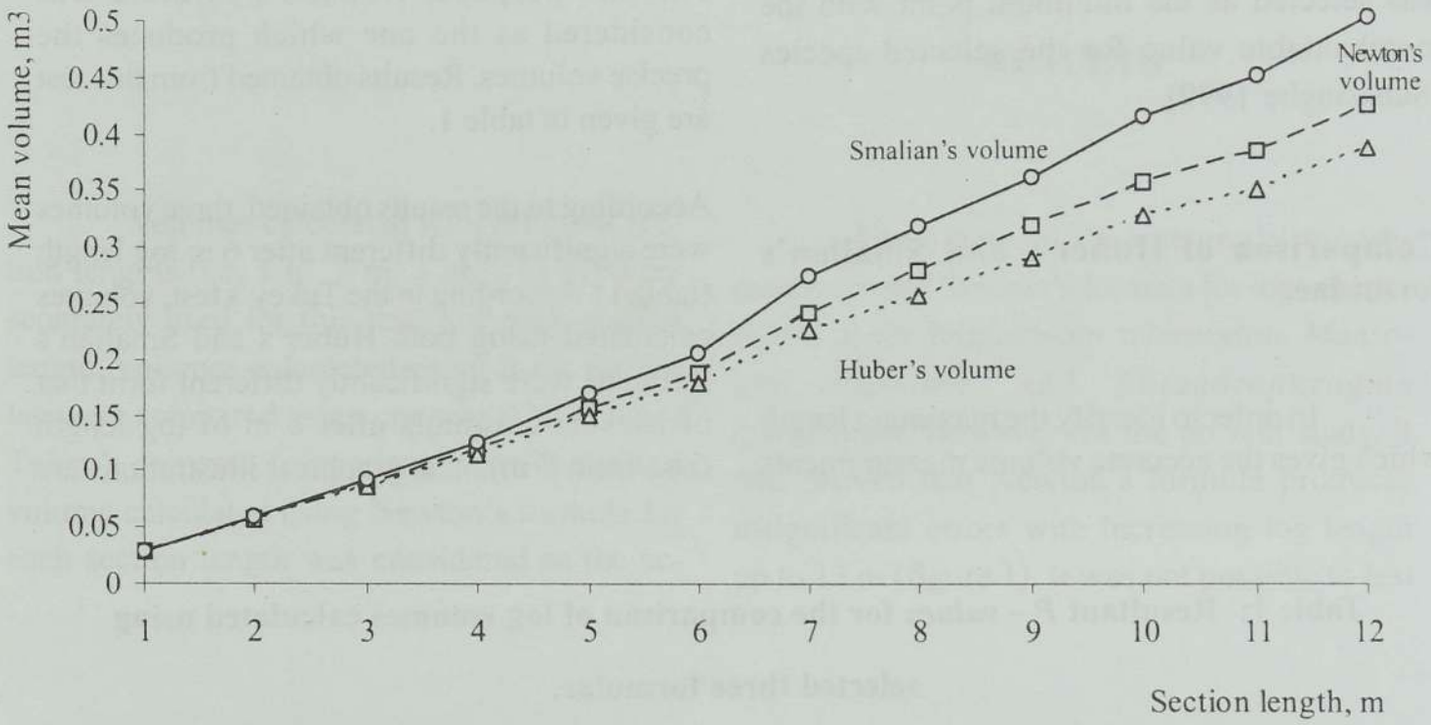


Figure 2: Mean volumes calculated using three formulae with increasing log length.

given in figure 2. Therefore it was concluded that after 6 m log length, Huber's and Smalian's formulae produce errors in log volume calculations for *P. caribaea*.

For further analysis, errors associated with volumes calculated using Huber's and Smalian's formulae were compared. Figure 3 shows the mean error produced by both formulae with increasing log length.

It was important to identify the relationship of errors between Huber's and Smalian's formulae. Figure 3 indicates that error generated by Smalian's formulae is as much as double the error generated by Huber's formula.

In order to correct the error with measurements, error percentage was also calculated for Huber's and Smalian's formulae. For the calculation of error percentage for each formula mean error and mean volume for each section length were used, table 2 gives the variation of the error percentage for different log lengths.

DISCUSSION

Patterson *et al.*, (1993) found that Newton's formula estimates the log volume most

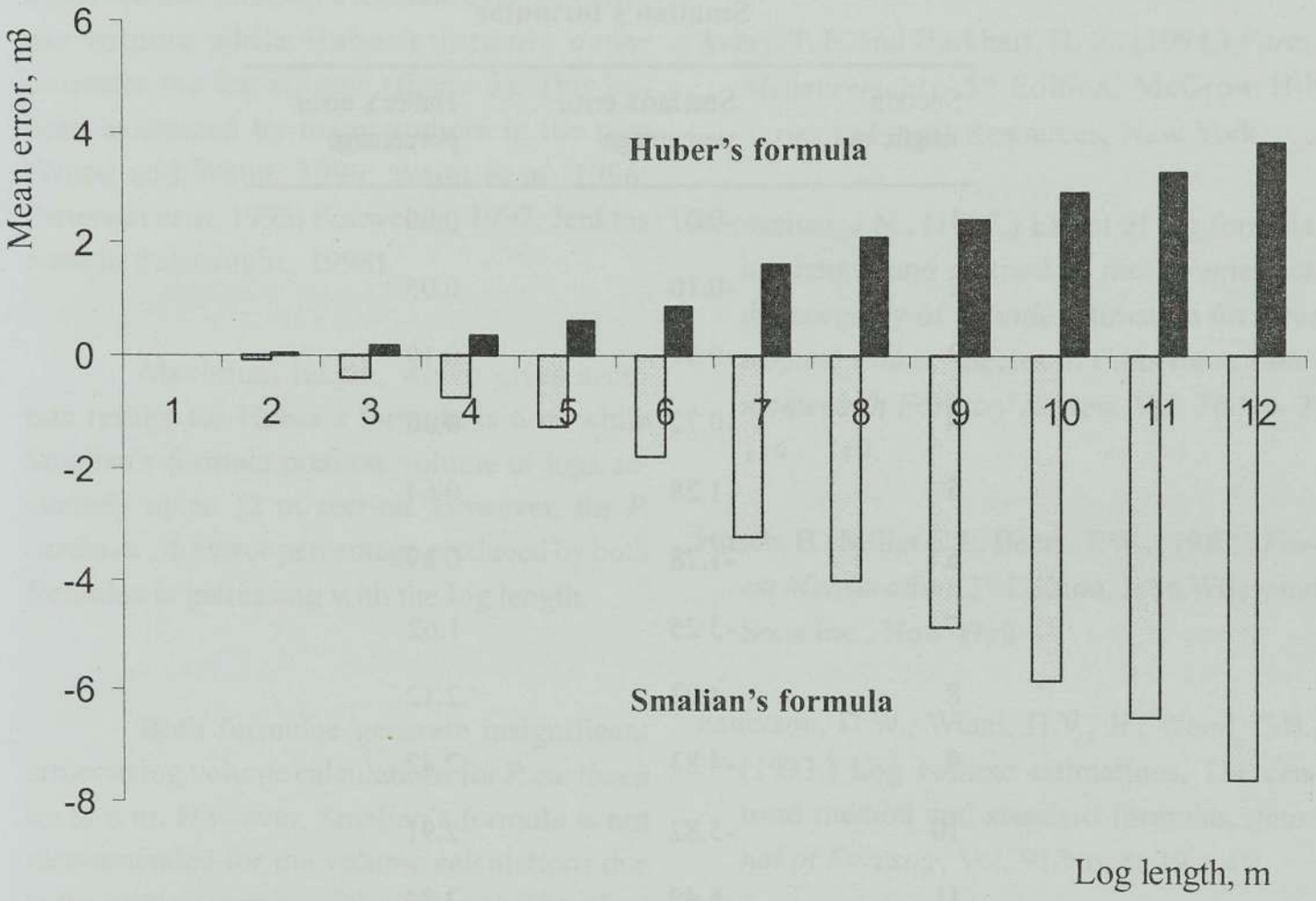


Figure 3: Mean error produced by Huber's and Smalian's formulae with increasing log length

accurately up to 6 m for *Quercus rubra*, *Liriodendron tulipifers* and *Pinus resinosa*. However, application of the Newton's formula is more costly than Huber's and Smalian's formula because it requires three diameter measurements, from one log which is more expensive with standing trees. For stacked logs Smalian's formula is the only log volume estimating formula which is applicable. However according to Patterson *et al.*, (1993) most of the studies illustrate that the poor results of estimating butt log volumes with Smalian's formula.

In 1990, Wood and Wiant found that Huber's formula under estimates log volume when studied for *Eucalyptus diversicolor, E. maculate, E. regnans, E. sieberi* and *Flindersia brayleyana.* For the application of the Huber's formula, solid shape of the main stem should be a frustum of a second degree paraboloid. For shapes less than second degree paraboloid negative bias would be expected. Present study also

Table 2: Error percentage for log length for Huber's and Smalian's formulae

Section length, m	Smalian's error percentage	Huber's error percentage
1	-0.01	0.00
2	-0.10	0.05
3	-0.37	0.19
4	-0.72	0.36
5	-1.28	0.64
6	-1.78	0.89
7	-3.25	1.62
8	-4.03	2.12
9	-4.83	2.42
10	-5.82	2.91
11	-6.49	3.24
12	-7.55	3.78

shows that Huber's formula under estimates log volume for *P. caribaea* volume measurements.

Fonweban (1997) emphasized the use of small log lengths for *Triplochiton seleroxylon, Mansona altissima* and *Entandophragma cylindricum* in his study for all log volume calculation equations, According to this study it will minimize the errors for all formulae and that accuracy deteriorates rapidly as log length increases and as log shape departs from cylindrical parabolic forms. It also showed that errors obtained with Huber's formula are approximately half (for 4 m and 6 m intervals) or are systematically lower than for Smalian's formula. This observation is confirmed by the present study when the error difference of both formulae were compared.

CONCLUSIONS AND RECOMMENDATIONS

According to the results obtained from the present study, it showed that both Huber's and Smalian's formulae produce significantly

different volumes from Newton's formula after 6 m of log length for *P. caribaea*. It was also identified that Smalian's formula over estimates the volume while Huber's formula under estimates the log volume (figure 3). This has been evidenced by many authors in the past (Wood and Waint, 1990; Waint *et al*, 1996; Patterson *et al*, 1993; Fonweban, 1997; Jenkins cited in Subasinghe, 1998).

Maximum length, which gives accurate results for Huber's formula is 6 m while Smalian's formula predicts volume of logs accurately up to 12 m section. However, for *P. caribaea* , the error percentage produced by both formulae is increasing with the log length.

Both formulae generate insignificant errors in log volume calculations for *P. caribaea* up to 6 m. However, Smalian's formula is not recommended for the volume calculations due to the over estimation of the volumes. Therefore it is recommended to use Huber's formula for log volume calculations due to the less involvement of measurements (length and mid-diameter of the log) while keeping the log length is equal to or shorter than 6 m.

If it is a must to use longer section lengths in volume calculations than 6 m, It is recommended to use error percentage table (table 2), so that the under or over estimation occurred by Huber's and Smalian's formulae respectivly can be adjusted up to 12 m section length.

REFERENCES

Avery, T. E. and Burkhart, H. E., (1994,) *Forest Measurements,* 3rd Edition, McGrow Hill Series in Forest Resources, New York.

Fonweban, J.N., (1997,) Effect of log formula, log length and method of measurement on the accuracy of volume estimation for three tropical timber species in Cameroon, *Commonwealth Forestry Review,* Vol. 76 No. 2: 114 – 119.

Husch, B., Miller C.I., Beers, T.W., (1982,) *Forest Mensuration,* 3rd Edition, John Wiley and Sons Inc., New York

Patterson, D.W., Wiant, H.V., Jr., Wood, G.B., (1993,) Log volume estimations, The centroid method and standard formulas, *Journal of Forestry*, Vol. 91 No. 8: 39 – 41

Philip M.S., (1994) *Measuring trees and Forests.* 2nd Edition, University Press, Cambridge, UK.

Schreuder, H.T., Gregoire, T.G., Wood, G.B., (1993,) *Sampling Methods for Multiresource Forest Inventory,* John Wiley and Sons Inc., New York.

Subasinghe, S.M.C.U.P., (1998,) Construction of growth models for *Pinus nigra* var. *mairitima* Ait. Melville (Corsican pine) in Great Britain, Ph.D. Thesis, University of Wales Bangor, U.K.

Subasinghe, S.M.C.U.P, (1999,) Lecture notes on Forest Mensuration and Inventory, Department of Forestry and Environmental Science, University of Sri Jayewardenepura, Sri Lanka.

Wiant, H.V., Jr., Patterson, D.W., Hassler, C.C., Wood, G.B., Rennie J.C., (1996,) Comparison of formulas for estimating volumes of butt logs of Appalachian hardwoods, *Northern Journal of Applied Forestry* Vol. 13 No. 1: 5 – 7.

Wood, G.B., Wiant H.V., Jr., (1990,) Estimating the volume of Australian hardwoods using centroid sampling, *Australian Forestry,* Vol. 53 No. 4: 271 – 274.

VARIATION OF SEED AND GERMINATION CHARACTERISTICS OF TEAK (*Tectona grandis* L.) SEEDS FROM DIFFERENT CLIMATIC LOCATIONS OF SRI LANKA

K. M. A. Bandara[1]

Summary

Seed and germination characteristics of teak seeds of 381 trees from 24 locations were studied. The overall germination percentage of the seeds is 19.5% and varies between 0 and 85% among individual trees. Average number of seeds per kg is 1857 and it varies between 726 and 4896 among trees. There is no clear pattern of variation of seed weight between populations as well as within populations. Further, no significant relationship between seed weight and the germination percentage is noticed. The germination percentage distinctly differed between climatic locations. The intermediate rainfall sites showed greater germination percentages than the drier sites, indicating the importance of careful site selection in establishment of seed production areas and seed orchards for teak in Sri Lanka.

[1] *Forest Research Station, Passara Road, Badulla*

INTRODUCTION

Teak is the main plantation tree species grown in dry and intermediate rainfall areas of Sri Lanka. The current extent of the teak plantations belongs to the Forest Department is around 30000 hectares (Bandarathilake, 1999). However, there are more teak trees planted in home gardens and private timber farms. The annual teak seed requirement of the Forest Department is about 3000 kg, and the seeds are mainly supplied by the clonal seed orchards and the seed production areas owned by the Forest Department (Forest Department, 2007).

It is reported that teak has been introduced to Sri Lanka by Dutch in the seventeenth century, and establishment of teak as a plantation tree was started in 1870s (Koelmeyer, 1957). Later it has been reported introductions of teak germplasm from Burma, Southern India, Thailand and Laos (Koelmeyer, 1957; Vivekanandan, 1975). Therefore, it can be predicted that the genetic variation of the teak plantations in Sri Lanka may be noticeably high.

Systematic teak improvement program within the Forest Department was started in 1970s by establishing three clonal seed orchards using 80 clones (Vivekanandan, 1975). However, this program had not been continued, since other exotic tree species (i.e. *Eucalyptus camaldulensis* and *Acacia auriculiformis*) were dominated in dry zone planting in 1980s. However, *E. camaldulensis* and *A. auriculiformis* plantations in the dry zone were not successful. Meantime, the first rotation teak plantation felling was started in 1990s; as a result, there was a great demand for the teak seeds. The large seed demand was mainly accomplished by the clonal seed orchards established in 1970s, and newly established seed production areas. In Year 2006, a long term breeding plan was developed for teak (Bandara, 2006).

Expansion of the extent of seed production areas is one of the immediate remedy to increase the teak seed production of the country. Further, the genetically improved seeds can only be achieved through establishment of seedling seed orchards and clonal seed orchards. However, these seed producing orchards/seed production areas have to be established in the appropriate climatic zones to obtain maximum viable seed yield (Kaosa-ard, 1999). In order to accomplish these information at local situation, investigation of the current seed production pattern and the seed viability at teak growing plantations is vital. Seeds from 381 selected plus-trees were collected across the teak plantations in Sri Lanka to establish a progeny trial in 2007. This study discusses the seeds and germination characteristics of seed sources which included in the progeny trial in 2007.

MATERIALS AND METHODS

Plus tree selection and seed collection

Teak seeds for the progeny trial were collected from 381 plus trees from 24 teak plantations from 9 forest divisions from January to March 2007. The plus trees were selected from the plantations where the age was more than ten years. Seed collected locations and the number of trees included from each site (families) are given in the Table 1.

Table 1: Description of the seed sources and number of trees per seed source

No	District	Seed source	No. of families
1	Hambantota	Middeniya	15
2	Ratnapura	Timbolkettiya	21
3	Kurunegala	Kumbalpola	1
4	Kurunegala	Sundarapola	16
5	Kurunegala	Aveniyawa	17
6	Kurunegala	Progeny trial	25
7	Kurunegala	Nikavehera	20
8	Kurunegala	Gomadiyagala	24
9	Kurunegala	Moragolla	16
10	Ampara	Karabana	8
11	Anuradapura	Batuwatta	20
12	Anuradapura	Kahalla	13
13	Anuradapura	Mihintale	20
14	Polonnaruwa	Ratmale	30
15	Polonnaruwa	habarana	45
16	Matale	Inamaluwa-1	15
17	Matale	Inamaluwa-2	15
18	Monaragala	Ice peella	14
19	Monaragala	Anapallama	16
20	Monaragala	Daragala-1	9
21	Monaragala	Daragala-2	9
22	Monaragala	Daragala-3	11
23	Monaragala	Daragala-4	5
24	Badulla	Mahiyangane	1

Notes: Number of families denotes the number of individual trees

The thin outer exocarps of the seeds were removed, cleaned and sundried. A sub sample of 100 grams from each seed sample was separated to calculate number of seeds per kilogram. Then, the individual tree seed collections were separately placed in the linen bags for seed treatment.

Seed treatment

Alternative wetting and drying treatment was applied for all seed samples (Weerawardane and Weerasighe, 2005; Wijesinghe, 1963). In the first cycle of the treatment, the seeds were soaked for 3 days in water and followed by drying for 3 days in the sun. After the third day of drying in the first cycle, the second cycle – two days soaking and two days drying- was started. Finally, the seeds were soaked for one day and piled all samples and covered with paddy straw and kept the seedlots moist for five days.

Treated seeds were sown at the spacing of 8 cm× 8 cm in the sunken beds (1 m × 10 m) maintaining seed sample identity. The seeds which were sown in the beds were pressed into the soil by using a wooden plank and then, the beds were covered with thin layer of soil and covered with paddy straw. The beds were watered daily. Number of seedlings of each seed sample was counted three weeks after sowing, and then germination percentage was calculated. Seed and germination characteristics across the sites were analyzed using the Genstat 5 statistical program (Hardings *et al.*, 2000).

RESULTS AND DISCUSSION

Seed weight variation at different climatic locations

Table 2 shows the average number of seeds per kilogram of each seed source. The overall average number of seeds per kg is 1857 and the number is varying among trees from 726 to 4896 seeds per kg. The higher standard deviations of the mean values indicate that the higher variation of seed weight among trees within the populations (Table 2).

However, the results (Table 2) indicate that there is no regular pattern of variation of the seed weight within the same climatic zones as well as between climatic zones.

Variability of seed germination

Table 3, Figure 1and Figure 2 demonstrate the germination results of 24 seed sources. Overall germination percentage is 19.6%. The highest average germination percentage (51%) is reported from Ice Peella site while the lowest germination was recorded by the seed samples of Kahalla, Daragalla site -3, and Mahiyangane. The average germination percentage values of intermediate rainfall sites (i.e. Middeniya, Kumbalpola, Nikavehera, Progeny trial seeds at Horakelle, Moragolla, Ice paella, Anapallama, Innamaluwa sites) is over 20%. In general, the drier sites showed lower germination values than the higher rainfall sites (i.e. Kahalla, Mihintale and Habarana) The current functional clonal seed orchards and seed production areas of teak

Table 2: Number of seeds per kilogram of teak seeds- seed source mean, minimum and maximum for 24 seed sources.

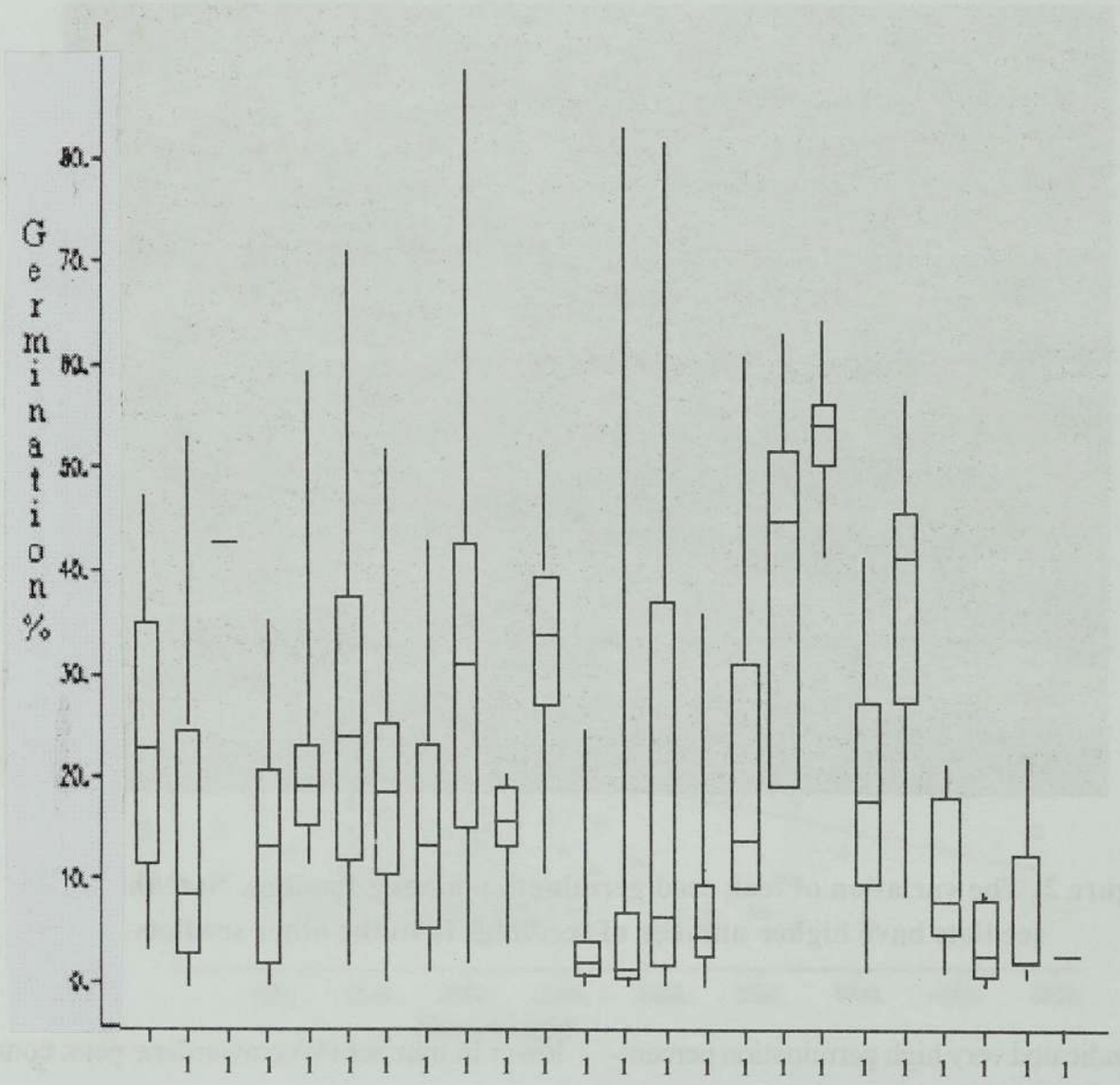
No	District	Seed source	No families	Mean	Minnimum	Maximum	SD(mean)
1	Hambantota	Middeniya	15	1378	1067	1766	214
2	Ratnapura	Timbolkettiya	21	1985	1333	2647	431
3	Kurunegala	Kumbalpola	1	1918	1918	1918	0
4	Kurunegala	Sundarapola	16	2681	1579	4896	247
5	Kurunegala	Aveniyawa	17	2316	1680	2703	301
6	Kurunegala	Progeny trial	25	2105	1457	3609	84
7	Kurunegala	Nikavehera	20	1959	1046	3900	754
8	Kurunegala	Gomadiyagala	24	1564	726	2053	329
9	Kurunegala	Moragolla	16	1786	1100	2600	397
10	Ampara	Karabana	8	1968	1650	2500	263
11	Anuradapura	Batuwatta	20	1846	1633	2133	153
12	Anuradapura	Kahalla	13	1657	941	2500	426
13	Anuradapura	Mihintale	20	1666	1077	3000	456
14	Polonnaruwa	Ratmale	30	1820	1063	2609	343
15	Polonnaruwa	Habarana	45	1836	1000	2522	378
16	Matale	Inamaluwa-1	15	1663	800	2292	443
17	Matale	Inamaluwa-2	15	1672	890	2240	342
18	Monaragala	Ice peella	14	1797	1419	2280	213
19	Monaragala	Anapallama	16	1639	1010	3920	679
20	Monaragala	Daragala-1	9	1654	1163	2000	276
21	Monaragala	Daragala-2	9	2025	1412	2868	472
22	Monaragala	Daragala-3	11	1816	1264	3223	545
23	Monaragala	Daragala-4	5	2444	1398	3529	1007
24	Badulla	Mahiyangane	1	1371	1371	1371	0
		mean		1857			

Note: SD = Standard deviation of the mean value

Table 3 : Seed source average germination percentages values

No	District	Seed source	No families	Mean	Min	Max	SD
1	Hambantota	Middeniya	15	23	3	45	13.6
2	Ratnapura	Timbolkettiya	21	13	0	51	14
3	Kurunegala	Kumbalpola	1	41	41	41	0
4	Kurunegala	Sundarapola	16	13	0	34	10.2
5	Kurunegala	Aveniyawa	17	20	11	57	10.4
6	Kurunegala	Progeny trial	25	27	2	69	18
7	Kurunegala	Nikavehera	20	19	0	49	12.6
8	Kurunegala	Gomadiyagala	24	16	1	41	11.7
9	Kurunegala	Moragolla	16	31	2	85	22.7
10	Ampara	Karabana	8	14	4	19	5.3
11	Anuradapura	Batuwatta	20	31	10	50	9.2
12	Anuradapura	Kahalla	13	4	0	23	6.3
13	Anuradapura	Mihintale	20	9	0	80	18
14	Polonnaruwa	Ratmale	30	17	0	78	20.4
15	Polonnaruwa	Habarana	45	7	0	34	6.3
16	Matale	Inamaluwa-1	15	20	2	58	15.5
17	Matale	Inamaluwa-2	15	38	5	60	19
18	Monaragala	Ice peella	14	51	40	62	57
19	Monaragala	Anapallama	16	18	1	40	11
20	Monaragala	Daragala-1	9	35	8	55	14
21	Monaragala	Daragala-2	9	10	1	20	7.2
22	Monaragala	Daragala-3	11	4	0	8	3.6
23	Monaragala	Daragala-4	5	7	0	22	8.7
24	Badulla	Mahiyangane	1	3	2	2	0
	Overall mean			**19.6**	**5.5**	**45.1**	**13.1**

Notes: Min = within site individual minimum germination percentage value; Max = within site individual maximum germination percentage value; SD = standard deviation of the seed source average value.



Notes: Numbers 1-24 in X axis represents the seed sources listed in Table 1

Figure 1: Box plots graphs for seed germination results

are located in the intermediate rainfall sites in Kurunegala District and the average germination percentage of Kurunegala sites were 24%

Within site variation of germination is higher than that of between sites (Table 3; Figure 1). The minimum germination percentage, zero was showed for some individual tree seed collections while some individual trees showed very high germination percentage (85%). Similar, large variation of germination among trees within population is observed by Abdullah *et al* (2002). Even though some seed sources showed very low average germination percentage values, some individual trees within the same seed

Figure 2: The variation of teak seed germination among families. Note that some seedlots have higher number of seedlings than the other seedlots

sources indicated very high germination percentage values (i.e. Mihintale and Ratmale sites; Table 3 and Figure 1). This may be due to some favorable environmental conditions (i.e high soil moisture level) surrounding those individual trees or may be due purely to inheritance. Further, the very low germination percentage values (0%) of some trees may be due to the damage by fruit borer (*Conogethes punctiferalis*) as reported by Mannakkara (2004) in the intermediate rainfall sites in Kurunegalla district or may be due to genetic factors. The very high germination percentage of few trees (80%) may be contributed by multiple seeded fruits; however, the numbers of multiple viable seeded fruits are lower in number (Weerawardane pers. comm.).

Interestingly, the germination percentage of Batuwatta (a drier site in Anuradapura) showed higher germination percentage and further it showed lower variation among trees within site. An irrigation water canal is situated near the boundary of Batuwatta site, and this plantation is surrounded by agricultural fields which indicate that there is higher moisture level of this site in the dry seasons. Therefore, the higher germination percentage of the seeds of this site may be due to higher moisture content of the soil in the flowering and fruit setting periods.

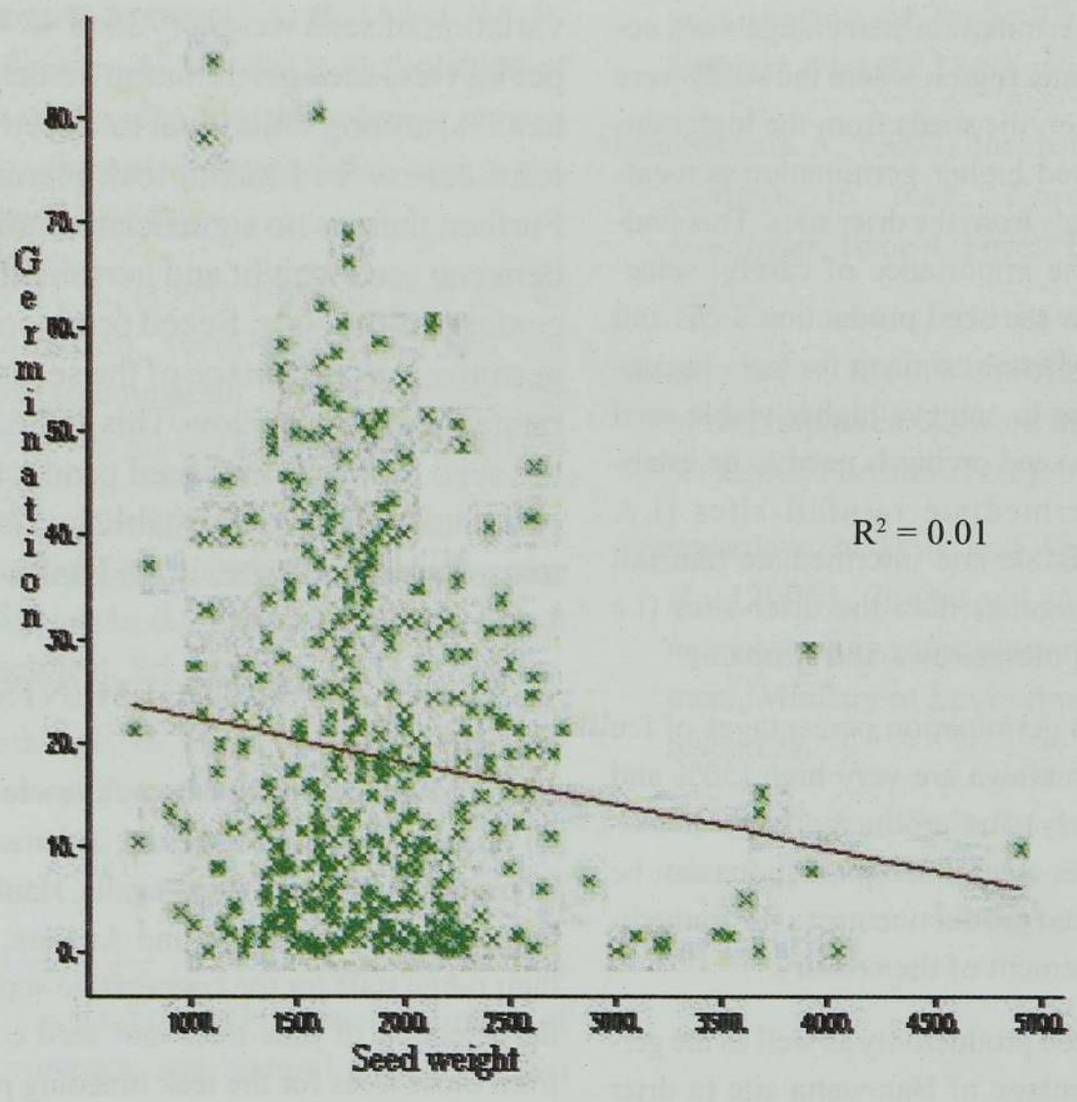


Figure 3: The relationship between seed weight and germination percentage

Relationship between fruit weight and the germination percentage

Figure 3 demonstrate the relationship between fruit weight and the germination percentage. The low coefficient of determination (0.01) indicates that the variation in seed germination percentage is not explained by the variation of fruit weight. This indicates that the weight may not be a good indicator in predicting of the viability of the teak seeds. The neutral relationship between fruit size and the germination is comparable with other published data (i.e Kumar, 1979; Indra *et al* 2000; Agboola, 1993). However the larger viable fruits might produce vigorous seedlings than the small fruits as indicated by Agboola (1993).

GENERAL DISCUSSION

The results of this study indicate that the teak seed germination percentage vary according to climatic region where the seeds were obtained. Further, the seeds from the high rainfall areas showed higher germination percentage than the seeds from the drier sites. This finding indicates the importance of careful selection of lands for the seed production areas and the seed orchard establishment for teak. In conclusion, in order to achieve higher viable seed production, the seed orchards need to be established in intermediate rainfall sites (i.e. Kurunegala, Matale and intermediate rain fall sites at Monaragalla) than the drier sites (i.e Anuradapura, Polonnaruwa and Ampara).

As the germination percentages of Ice peella and Inamaluwa are very high (50% and 29% respectively) and producing large quantities of seeds per tree, those plantations can be converted to seed production areas for immediate seed requirement of the country.

The seed productivity as well as the germination percentage of Batuwatta site (a drier site but surrounded by agricultural fields) reveals that seed productivity as well as the germination percentage of the teak seeds can be improved by means of environmental improvement such as irrigation and nutrient management.

The greater variation of germination percentages of individual tree seeds within sites may be due to inheritance or environmental causes such as moisture level of the soil, pest damages to the seeds and flowers.

CONCLUSION

The results indicate higher phenotypic variation of seed weight (726 to 4896 seeds per kg) and seed germination percentage (0 to 85%) among individual tree seed collections across Sri Lankan teak plantations . Further, there is no significant relationship between seed weight and germination percentage of the seds. Seeed production and germination percentage of the seeds of low rainfall sites are very low. This indicates that the seed orchards and seed production areas of teak needs to be established in the intermediate rainfall sites in Sri Lanka.

ACKNOWLEDGEMENTS

Author wishes to acknowledge the Divisional Forest Officers, Anuradapura, Kurunegalla, Matale, Monaragalla, Hambantota, Polonnaruwa, Ratnapura and Ampara, and for their range staff for the cooperative support for the selection of plus trees and seed collection from those trees for the teak breeding program. Special thanks are due to the Range Forest Officer Wellawaya Mr. Yogarathnam and his staff for the nursery activities. Further, I would like to thank Mr. Karunaratna, Beat Forest Officer (research), Mr. Sanjeewa, Forest Field Assistant (research) and to Mr.Yapa, Forest Field Assistant (research) for their valuable contribution in tree selection, seed collection and nursery activities.

REFERENCES

Abdullah, M. Z, Ghani., A. R, Mahat., M. R. and Kassim, A. S., (2002). Germination of *Tectona grandis* progenies during nursery stage, *Journal of tropical Forest Science*, 14(4): 552-554.

Agboola, D. A., (1993). Effect of seed size on germination, seedling growth and dry matter accumulation in some tropical tree species, *The Malaysian Forester*, 56(1): 61-71.

Bandara, K. M. A., (2006). *Teak breeding plan for Sri Lanka* (Unpublished report), Forest Department, Sri Lanka.

Bandarathilake, H. M., (1999). *Administrative Report of Conservator of Forests Sri Lanka*, Ministry of Forestry and Environment, Sri Lanka.

Forest Department, (2007). Annual records, Tree Seed Centre, Forest Department, Ministry of Environment and Natural Resources, Sri Lanka.

Harding, S., Lane, P., Murray, D. and Payne, R., (2000). *Genstat for Windows 5th edition.*

Indra, E. P., Chand Basha, S. and Chaka, K. L., (2000). Effect of seed size grading on the germination and growth of teak seedling, *Journal of Forest Science* 12(1): 21-27.

Kaosa-ard, A., (1999). *Teak (Tectona grandis Linn.f.) Domestication and Breeding*, Teaknet-Asia Pacific Region, Publication No 5/1999.

Koelmeyer, K. O., (1957). Teak plantations in Ceylon, *The Ceylon Forester*, 3(2) 178-184. Kumar, A., 1979. Effect of fruit size on germination of teak, *The Sri Lankan Forester*, 14(1/2): 58-63.

Mannakkara, A., (2004). Incidence of fruit borer damage in teak, *Forest Research Newsletter*, Issue 4, Forest Department, Sri Lanka.

Vivekanandan, K., (1975). The present status of tree improvement work in Sri Lanka, *The Sri Lanka Forester*, 12(2): 95-100.

Werawardane, N. D. R. and Weerasighe. N. N. H., (2005). *Teak seed production and nursery management manual* Forest Department, Ministry of Environment and Natural resources.

Wijesinghe, L.A., (1963). Pre sowing treatment trials on teak, *The Ceylon Forester*, 6(1/2): 4-11

EVALUATION OF NATURAL REGENERATION POTENTIAL OF A GRASS INVADED FOREST IN KOSLANDE, SRI LANKA

S.H. Bandumala [1] , N. T. P. Karunarathna [1]

Summary

Planting is the major primary means that is currently used to restore degraded areas back to forests. Retarded seedling growth and poor seedling survival are the major hindrance for success of these enrichment planting programs. However, natural regeneration or human-assisted natural regeneration may provide an alternative way to regenerate these degraded areas. To evaluate the potential of this alternative, the density and species composition of existing trees and planted tree seedlings in the same area were estimated. Fifty four circular plots were established randomly to assess the tree seedlings. All the artificially regenerated seedlings were counted. Number of seedlings, saplings and trees of naturally regenerated tree species were enumerated and their DBH measured. There were nine tree species planted and the survival was 278 seedlings per ha. Syzygium cumini *(Madan) and* Berrya cordifolia *(Halmilla) showed the highest survival percentage. The density of naturally regenerated tree species were 2050 per ha. and were well distributed in the area. We identified 51 tree species and the density of tree seedlings (4985per ha) was 5 times higher than saplings and trees, but the contribution to the species composition is mainly by* Anogeissus latifolia *(Dauw) and* Pterocarpus marsupium *(Gammalu). Diameter class distribution of all woody species showed inverted j-shaped frequency distribution. The results suggest that there are enough tree seedlings to restore the degraded area back to forest.*

Forest Research Station, Forest Department, Passara Road, Badulla

INTRODUCTION

Over the years Sri Lanka has experienced a decline in its forest cover drastically. The depletion of the forest resources is closely linked to the demand for forest products such as timber, non-wood forest products, and fuelwood (FSMP 1995). The increasing demand for forest products and the large scale degradation of forests have demanded large-scale regeneration programs.

The Sri Lankan Forest Department has made several attempts to supply the demand for forest products through planting of many exotic species especially with *Eucalyptus* sp. and Teak. Even though the exotic species have been successful, most of the native species had failed to recover in most of the planting sites. Lack of soil nutrients, unsuitable microclimatic conditions and frequent fires are some of the factors that affect the poor growth and lower survival of native species (Perera, 2001., Weerawardene NDR, pers. comm.,2006., personal observations).

However, natural regeneration or human assisted natural regeneration (ANR) may provide an alternative way to increase the extent of forested lands. Assisted natural regeneration (ANR) is a forest rehabilitation technique based on the ecological principle of secondary succession (Kathleen et.al. 1999). It utilizes natural processes and promotes the regeneration of indigenous species. Natural regeneration has been successfully applied in other countries (Weemian and Vyse 1990), as well as in Sri Lanka to regenerate forests. One of the most successful example in Sri Lanka is ANR in Dambulla arboretum (Weerawardane, 1999) According to their observations, careful weed control and continuous attention gives good results for forest natural regeneration. Experience in other countries has shown that natural regeneration is much cheaper than planting (Weetman and Vyse 1990). But natural regeneration of savanna forests in Sri Lanka is not well understood. One of the possible explanations for the poor natural regeneration is the aggressive invasion of these forests by exotic grasses but there is no information to accept or reject this hypothesis (Hawthorne, 1989, Honu and Dang, 2000)

To evaluate the potential of natural regeneration, the density and species composition of tree seedlings in a grass invaded forest were estimated. Meanwhile a survey was carried out to find out the success of enrichment planting in the same area. The findings of this study will be important for restoration and sustainable management of tropical forest.

The general objective of this study was to investigate the natural regeneration potential and the role of enrichment planting in the rehabilitation of degraded forest.

Specific objectives included investigating the survival of planted tree species, studying the diversity, *i.e.*, species richness and evenness of woody species, assessing the regeneration potential of some woody species and formulating recommendations that would assist in further development and management of degraded forest.

Study site

The study was carried out in Koslande and Haldummulla forest beats which are parts of Welanvita state forest. This is one of the

heavily grass invaded forest and the most biologically unique sananna type forest in the country. The annual rainfall is less than1000 mm and is confined to north-east monsoons, from October to December. Conditions are very dry in February to August.

This site has been enriched with 9 local tree species in 2004, 2005, and 2006. One of the main reasons that hinders the growth of these planted seedlings and natural regeneration of the area is deliberate burning of grasses by farmers for hunting and cattle farming.

Survey Procedures

Sites were surveyed for tree density, species composition and their distribution, using circular sampling plots of 12.66 m radius. For each location, six sample plots were established and altogether 54 sample plots were surveyed. Data were collected for artificially regenerated (planted) and naturally regenerated species. All the artificially regenerated seedlings were counted. For existing seedlings and trees following measurements were taken.

- For trees, diameter at breast height, and height of each tree.
- For saplings, species and number of stems
- For seedlings, species and number of plants.

The following definitions of different habits were used in this study.

Tree –A woody plant with a diameter at breast height (DBH) > 2 cm
Saplings -A woody plant with a DBH < 2 cm and height of > 1m
Seedlings - A woody plant < 1m tall. (Singhakumara, 1995)

Stand variables

From the data obtained, following stand variables were calculated.

Relative density
= (Number of individuals of the species/ total number of individuals of all species)x100

Relative basal area
= (Total basal area of a species/total basal area of all species)x100

Relative frequency
= (Total frequency of a species/ total frequency of all species)x100

Important value index
=Relative density +Relative basal area + Relative frequency
(Panwar and Bhardwaj, 2005)

RESULTS AND DISCUSSION

Survival of planted tree species

For this study nine locations in Koslanda and Haldummulla area were selected. The highest seedling survival percentage (37.5%) was found in Uva Kosgama -2004 site followed by the Uva Kosgama-2005 and Dambakotte (Table 1) The lowest seedling survival percentage (6.8%) was found in Icepeela-1 and Icepeela-2 areas.

Table 1: Survival percentage of artificially regenerated tree seedlings

Location	No. of seedlings originally planted/ha	Total No. of plants surviving/ha	Survival %
Haldummulla-1			
Badulludenne	1333	343	25.8
Haldummulla-2			
Uva Kosgama-2005-2	1333	410	30.8
Uva Kosgama-2004	1333	500	37.5
Uva Kosgama-2005	1333	117	8.8
Uva Kosgama-2006	1333	247	18.5
Koslanda			
Dambakote	1333	403	30.3
Bibilehela	1333	323	24.3
Icepeella-1	1333	90	6.8
Icepeella-2	1333	90	6.8

The total of 757 seedlings which were planted in 2004, 2005 and 2006 were recorded in this study. In each location, 9 species were planted. In six out of nine locations *Syzygium cumini* (Madan) showed the highest survival percentage. In two locations, Dambakote and Icepeella-2 , *Berrya cordifolia* (Halmilla) had performed better than other species.

Relative density, relative frequency and important value index for planted tree seedlings were calculated and recorded in the table 2. IVI indicates the dominance in a particular site. The highest value of IVI was obtained by *Syzygium cumini* compared with other planted species. The second highest IVI value was obtained by *Berrya cordifolia* followed in decreasing order by *Adenanthera pavonina* (Madatiya), *Terminalia bellirica* (Bulu), *Cassia fistula* (Ehela), *Pterocarpus marsupium* (Gammalu), and *Filicium decipiens* (Pihimbiya). *Albizia lankaensis* (Suriyamara), *Neolitsea cassia* (Kududawla) , *Pterospermum suberifolium* (Welan), *Phyllanthus emblica* (Nelli) and *Terminalia chebula* (Aralu) showed a lower IVI value.

Table 2. Relative density, relative frequency and important value index of planted tree seedlings.

Species	RD	RF	IVI
Syzygium cumini	46.63	29.93	76.56
Berrya cordifolia	12.15	10.95	23.10
Adenanthera pavonina	6.34	12.41	18.75
Terminalia bellirica	7.40	7.30	14.70
Cassia fistula	4.76	6.57	11.32
Pterocarpus marsupium	5.68	5.11	10.79
Filicium decipiens	3.43	6.57	10.00
Tamarandis indica	3.30	5.84	9.14
Tectona grandis	4.10	0.73	4.83
Albizia lankaensis	1.06	2.92	3.98
Neolitsea cassia	1.32	2.19	3.51
Pterospermum suberifolium	1.32	1.46	2.78
Phyllanthus emblica	0.40	1.46	1.86
Terminalia chebula	0.66	0.73	1.39
Bridelia retusa	0.40	0.73	1.13
	0.13	0.73	0.86

Density, Basal area, and frequency of naturally regenerated tree seedlings

In the study area 52 naturally regenerated plant species representing 21 families were recorded. In each study location more than half of the density was contributed by two species namely *Anogeissus latifolia* (Dauw) and *Pterocarpus marsupium* (Gammalu) which had also the highest frequency (Table 3). The importance value index, basal area (BA) and density are also higher for these two species in study sites. The important value index reflected first ten important dominant woody species as *Anogeissus latifolia*, *Grewia tilifolia* (Damaniya), *Pterocarpus marsupium*, Waluamba (unknown), *Phyllanthus emblica* (Nelli), *Bridelia retusa* (Ketakela), *Terminalia chebula* (Aralu), *Careya arborea* (Kahata), *Terminalia bellirica* (Bulu), and *Woodfordia*

Table 3 : Relative dominance, relative density, relative frequency and important value index of some naturally regenerated tree seedlings.

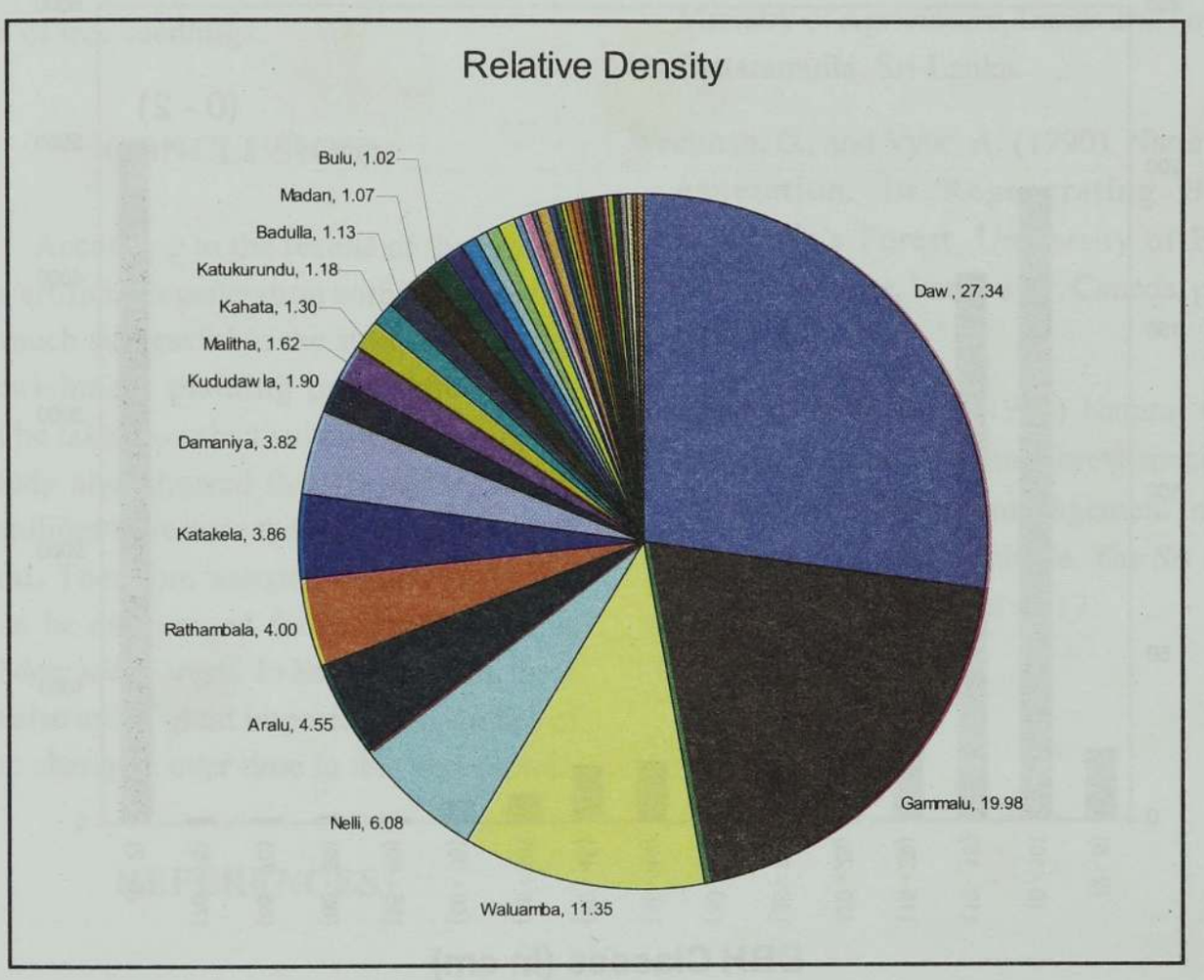
Species	Relative Dominance	Relative Density	Relative frequency	IVI
Anogeissus latifolia	36.35	0.71	8.23	45.29
Pterocarpus marsupium	18.79	0.52	7.92	27.23
Waluamba (Unknown)	8.39	0.30	7.30	15.98
Careya arborea	8.11	0.03	4.19	12.34
Terminalia chebula	4.75	0.12	5.12	10.00
Bridelia retusa	2.65	0.10	6.52	9.27
Terminalia bellirica	5.52	0.03	3.57	9.12
Phyllanthus emblica	1.15	0.16	6.83	8.14
Semicarpus coracea	1.18	0.03	2.64	3.85
Schleichera oleosa	2.63	0.00	0.93	3.57
Syzygium cumini	0.50	0.03	2.64	3.17
Vitex altissima	0.08	0.02	2.80	2.89
Woodfordia fruticosa	0.00	0.04	2.80	2.84
Scolopia schreberi	0.75	0.03	1.86	2.65
Neolitsea cassia	0.00	0.05	2.48	2.53
Ziziphus napeca	0.00	0.02	2.17	2.19

fruticosa (Malitha)

Regeneration status of the forest.

When the diameter classes and distribution of all woody species were analyzed together, it showed an inverted j-shaped frequency distribution with abundant individuals at the lower diameter classes but declining numbers of individuals as the diameter classes increased, suggesting good regeneration status. At the species level, the most abundant species, namely *Anogeissus latifolia* (Dauw) exhibited an inverted J shaped frequency distribution of its di-

Figure1: Relative density of naturally regenerated species



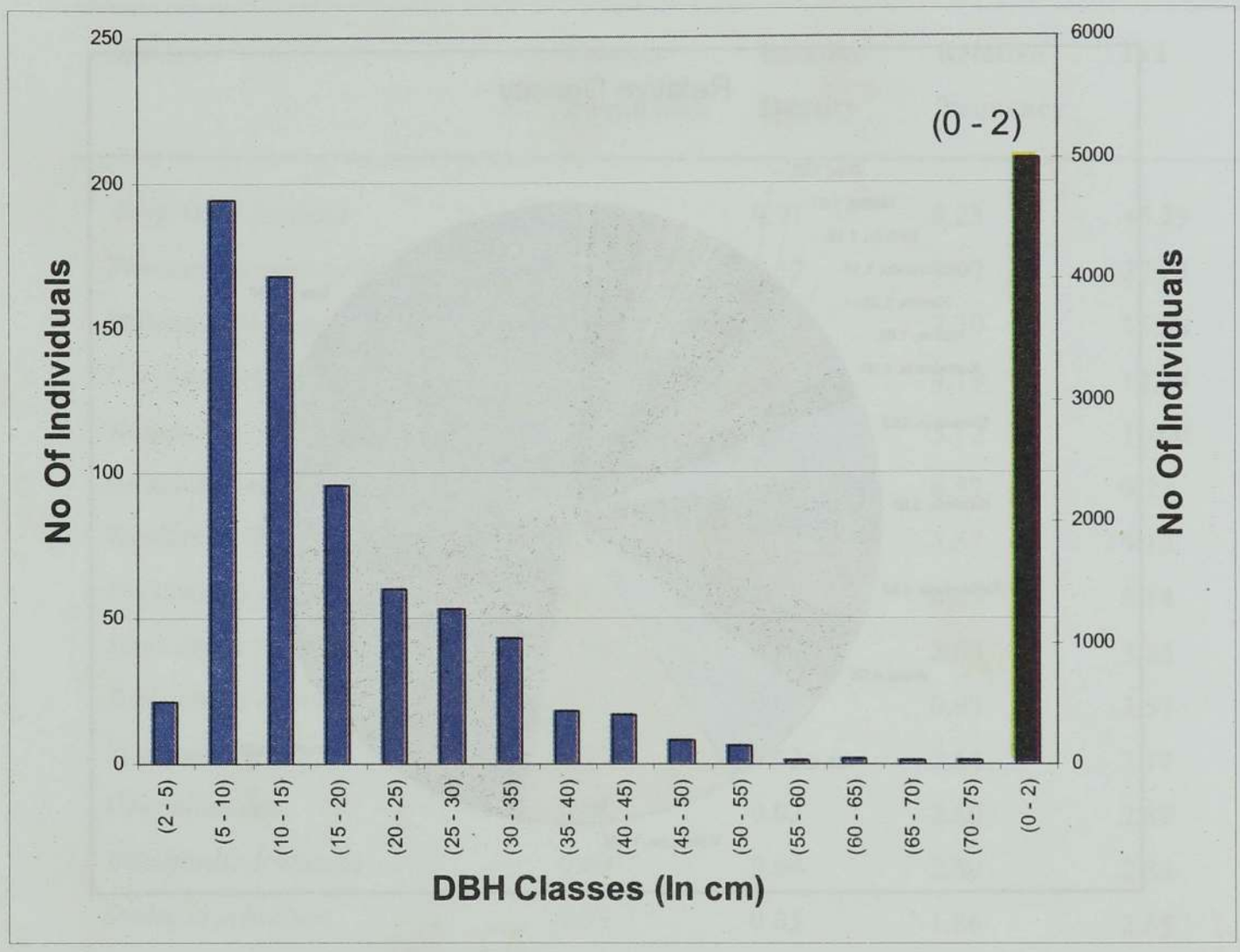
ameter classes with about 85% of its individuals less than 5cm in diameter.

The high proportion of seedlings in the forest, which is an indicator of recruitment of the plants through germination, implies the existence of a good potential for the restoration of woodland communities

DISCUSSION

Planting of native and exotic species is the most commonly used method to restore degraded forests in Sri Lanka. Natural or human assisted natural regeneration is not normally applied due to lack of information on the seedling ecology and their distribution in these degraded areas. This preliminary survey shows the status of enrichment planting and the natural regeneration potential of a degraded forest. This survey was carried out in a heavily grass invaded savannah type forest which is annually subjected to fire. This site has enriched with nine local tree species in 2004, 2005 and 2006. The present study shows that the survival of the artificial regeneration of local species differ from spe-

Figure 2. DBH Class distribution of naturally regenerated species



cies to species. In most of the study locations, *Berrya cordifolia* and *Syzygium cumini* had the highest survival percentage. Planted *Pterocarpus marsupium* and *Phyllanthus emblica* seedlings exhibited poor survival percentage even though they are naturally regenerating in the area. This may be due to poor adaptation of these planted seedlings to the unfavorable micro-climatic conditions created by surrounding grasses and frequent fires. This study also showed that naturally regenerated tree species in the same forest have enough seedlings under the canopy of *Imptera cylindrica*. *Anogeissus latifolia* was found to be a dominant naturally regenerated tree species in the present survey and followed in decreasing order by *Pterocarpus marsupium* , Waluamba, *Phyllanthus emblica* , *Terminalia chebula* , *Grewia tiliifolia* , *Ixora coccinea* and *Bridelia retusa* . The density of naturally regenerated tree species were 2050 per ha. and were well distributed in the area. This suggests that tree seedlings have the ability to survive in this unfavorable conditions created by *Imptera cylindrica* and the potential to regenerate the area back to a forest. However the aggressive growth of

Imptera cylindrica may provide the major barrier for the future survival and growth of tree seedlings. Therefore, it may be necessary to control the growth of grass to enhance the growth of tree seedlings.

CONCLUSIONS

According to the results of the present survey, artificial regeneration with local species is not much successful in the study area. In future enrichment planting programmes, care should be taken to select suitable plant species. The study also showed that there are enough tree seedlings to restore the degraded area back to forest. Therefore assisted natural regeneration can be encouraged for restoration of this type of degraded forests. In addition to that, these results also are of great importance in studies of floristic changers over time in this vegetation.

REFERENCES

Kathleen S.F., Drilling M.E., and Garrity D.P. (1999) *Imperata* Grassland Rehabilitation using Agroforestry and Assisted Natural Regeneration. Bogor, Indonesia.

Panwar P. and Bhardwaj S.D. (2005), Handbook of practical forestry. p 62-75

Senarathna L K., (2001). A Check list of flowering plants of Sri Lanka.

Wijesinghe Y., (1994). Check list of woody perennial plants of Sri Lanka

Singhakumara B M P., (1995). Floristic Survey of Adam's Peak Wilderness. A publication of the Sri Lanka Forest Department pp 16-18.

Sri Lanka Forestry Sector Master Plan, (1995). Ministry of Agriculture, Lands and Forestry, Battaramulla, Sri Lanka.

Weetman, G., and Vyse, A. (1990). Natural Regeneration. In Regenerating British Columbia's Forest. University of British Columbia Press, Vancouver, Canada. pp118-129.

Weerawardane N.D.R., (1999) Natural regeneration of some dry zone forest species assisted by silvicultural management in a dry zone woodland at Dambulla. *The Sri Lanka Forester*, Volume XXII: 7-17.

Apendix 1: Tree species identified in the study area.

Local Name	Botanical Name	Family
Ankenda	*Acrinychia laurifolia*	Rutaceae
Aralu	*Terminalia chebula*	Combretaceae
Atticka	*Ficus racemosa*	Moraceae
Badulla	*Semicarpus coracea*	Anacardiaceae
Bo	*Ficus religiosa*	Moraceae
Bulu	*Terminalia bellirica*	Combretaceae
Buruta	*Chloroxylon swietenia*	Rutaceae
Damaniya	*Grewia tilifolia*	Tiliaceae
Dawu	*Anogeissus latifolia*	Combretaceae
Demata	*Gmelina arborea*	Verbenaceae
Ehela	*Cassia fistula*	Fabaceae
Erabadu	*Erythrina variegata*	Fabaceae
Eraminiya	*Ziziphus napeca*	Rhamnaceae
Eraminiya	*Zizipus lucida*	Rhizophoraceae
Gammalu	*Pterocarpus marsupium*	Fabaceae
Halmilla	*Berrya cordifolia*	Tiliaceae
Hik	*Lannea coromandelica*	Anacardiaceae
Himbutu	*Salacia chinensis*	Hippocrateaceae
Hulanhik	*Chukrasia tabularis*	Meliaceae
Indi	*Phoenix pusilla*	Aristolochiaceae
Kahata	*Careya arborea*	Lecythidaceae
kala	*Dalbergia lanceolaria*	Fabaceae
Kalawel	*Derris benthamii*	Fabaceae
Kaluwara	*Diospyros ebenum*	Ebenaceae

Karaw	*Syzygium rotundifolium*	Myrtaceae
Katukurundu	*Scolopia schreberi*	Flacourtiaceae
Kende	*Macaranga peltata*	Euphorbiaceae
Ketakela	*Bridelia retusa*	Euphorbiaceae
Kolon	*Adina cordifolia*	Rubiaceae
Kon	*Schleichera oleosa*	Sapindaceae
Kotadimbulla	*Ficus hispida*	Moraceae
Kududawla	*Neolitsea cassia*	Lauraceae
Kudumberiya	*Diospyros walkeri*	Ebenaceae
Liniya	*Helicteres isora*	Sterculiaceae
Madan	*Syzygium cumini*	Myrtaceae
Madatiya	*Adenanthera pavonina*	Fabaceae
Maila	*Bauhinia racemosa*	Fabaceae
Malitha	*Woodfordia fruticosa*	Lythraceae
Masan	*Ziziphus mauritiana*	Rhizophoraceae
Milla	*Vitex altissima*	*Verbenaceae*
Nelli	*Phyllanthus emblica*	Euphorbiaceae
Pihimbiya	*Filicium decipiens*	Sapindaceae
Pelan	*Bhesa ceylanica*	Celastraceae
Rathambala	*Ixora coccinea*	Rubi aceae
Suriyamara	*Albizia lankaensis*	Fabaceae
Urulumee	*Maduca indica*	Sapotaceae
Walbeli	*Naringi crenulata*	Rutaceae
Walkapuru	*Plectranthus barbatus*	Lamiaceae
Welan	*Pterospermum suberifolium*	Sterculiaceae
Weralu	*Elaeocarpus serratus*	Elaeocarpaceae
Yakinaran	*Atalantia ceylanica*	Rutaceae

ASSESSING THE PUBLIC PERCEPTIONS TOWARDS RISKS TO THE BIODIVERSITY OF DRY ZONE FORESTS IN THE ANURADHAPURA DISTRICT

N. R. P. Withana[1] and U. K. Jayasinghe-Mudalige[2,]

Summary

The purpose of this study was to find favorable solutions for a number of issues related to the forest diversity, including: (1) the knowledge and familiarity of people, whose livelihood is associated with a forest, towards the concept and applications of biodiversity; (2) the "Bio-centric" and "Anthropocentric" orientation of those people towards the forest environment; (3) general risk perceptions of them towards the hazards coupled with forest diversity, and (4) their perceptions about the effectiveness of various conservation strategies used to protect the forest biodiversity. There were 225 people selected randomly from individual households' located close proximity to natural forest in the Anuradhapura district, including the Wilpathu, Ritigala, Hurulu, Issinbassawewa, Mihintale, Nuwaragama, Weddakanda, and Yodaela were used to collect data. For the majority of issues, the responses were obtained on multi-point Likert scales and the scores provided were used to estimate the Means and other useful estimates. A composite knowledge index was developed using the correct responses to a set of self-rated statements to evaluate the issue (1). The results revealed that more than 90% of respondents were aware satisfactorily about the term forest biodiversity and related issues. The outcome of the analysis on Bio-centric and Anthropocentric orientation of people, which was captured by means of a set of statements written explicitly to reflect these aspects, show that a majority of respondents belong to the former (3.57) in compared to the later (2.83). Out of 15 hazards identified, illegal timber felling (4.45), forest fire (4.38) and damages caused by elephants (3.91) were rated as the most important by respondents, while grazing of forest land (2.88) and damage by use for recreation (2.49) were regarded the least important. Awareness programs for forest users about biodiversity [3.48], developing buffer zones and home gardens to reduce pressure on existing forests [3.45], stringent regulations on forest use [2.95], and increasing the area of protected forest cover [2.92] were considered the most effective conservation strategies. The results provide useful information to any party who involve with augmenting forest biodiversity in Sri Lanka, since such attempts would be more effective once the peoples' perceptions on these aspects are taken in to account.

1 Forest Department, Rajamalwatta Road, Battaramulla, Sri Lanka

2 Dept. of Agribusiness Management, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP), Sri Lanka

INTRODUCTION

The social science literature on biodiversity has been much focused on assigning value to biological resources with regard to their prevailing and potential "uses" (e.g. to produce pharmaceuticals) or "non-uses" (e.g. willingness to pay for environment conservation). Although these have contributed substantially to enhance general understanding of the economics of biodiversity conservation and the tradeoffs associated with options available for conservation, there remains a need to understand public perceptions of risks associated with biodiversity conservation and the factors that can have influence on these perceptions. The ecological risk can be from various sources, including those threats from wide range of human activities such as development, pollution and industrial activity.

According to McDaniels *et al.*, (2005), peoples' risk perceptions on ecology were highly predictive of supporting stricter regulations to industrial and development activities that threaten to the environment. The outcome of this study suggests that nuclear war, loss of animal and plant species, loss of habitats, depletion of the ozone layer and deforestation were the greatest risks to natural environments. Cavanagh *et al.* (2000) showed that the general public was more concerned about the risks caused by large number sources of pollution (e.g. acid rain, automobile emissions and depletion of the ozone layer etc.) and climate change as well as forest industry related hazards. Similar issues were raised in a number of other studies conducted recently, for example, Lazio *et al.*, 2000 on expert and layperson perceptions of ecosystem risk; Stedman *et al.*, 2004 on perceptions of key policy actors in Canada regarding risks associated with climate change; Gardner *et al.*, 1987 on risk perceptions and policy response toward wildlife fire hazards by urban home-owners.

General attitudes towards the environment are commonly referred to as value orientation and are non-issue specific cognitive orientations that form the basis for specific beliefs (such as risk perception) and behaviors. They are frequently categorized into two contrasting belief systems labeled as "*anthropocentric*" and "*bio-centric*". An anthropocentric orientation reflects a utilitarian view of nature whereby natural resources are defined in term of satisfying human wants and needs and their contribution to economic prosperity and human well-being. A bio-centric orientation, in contrast, reflects a broader ranger of values including, for example, esthetic, spiritual and passive use values. Although human uses and benefits are also included, nature is considered and viewed as having an inherent worth under the bio-centric orientation, i.e. a right to exist for its own sake regardless of its usefulness to humans (Gagnon-Thompson and Barton, 1994).

Environmental value orientation has been found to be instrumental in people's assessment and response to environmental risk, and preferences for natural resource management (O'Connor *et al.*, 1999; Stedman *et al.*, 2004. For example, bio-centric oriented values have been associated with higher levels of perceived risk and support for protection oriented management. Thus, it is hypothesized that a bio-centric orientation is associated with higher risk ratings to forest biodiversity and greater perceived effectiveness of conservation strategies aimed at reducing human use. In con-

trast, an anthropocentric orientation is associated with lower risk ratings and lower perceived effectiveness of reducing human use. It is also expected that social-cultural factors such as gender, age, education and income etc. are known to interact with individual cognitions in risk assessment.

The specific objectives of this study were to examine empirically the perceptions of people towards a specific hazard domain of ecological risk and the effectiveness of conservation strategies in place to minimize such risks associated with the biodiversity of Dry Zone forests in the Anuradhapura district in the North-Central Province (NCP) in Sri Lanka. It has explored whether the cognitive structures (i.e. environmental value orientation and knowledge) and those socio-cultural factors of people can have an impact on their general perceptions of risk to biodiversity in forest environments.

Forest Biodiversity in the Anuradhapura District

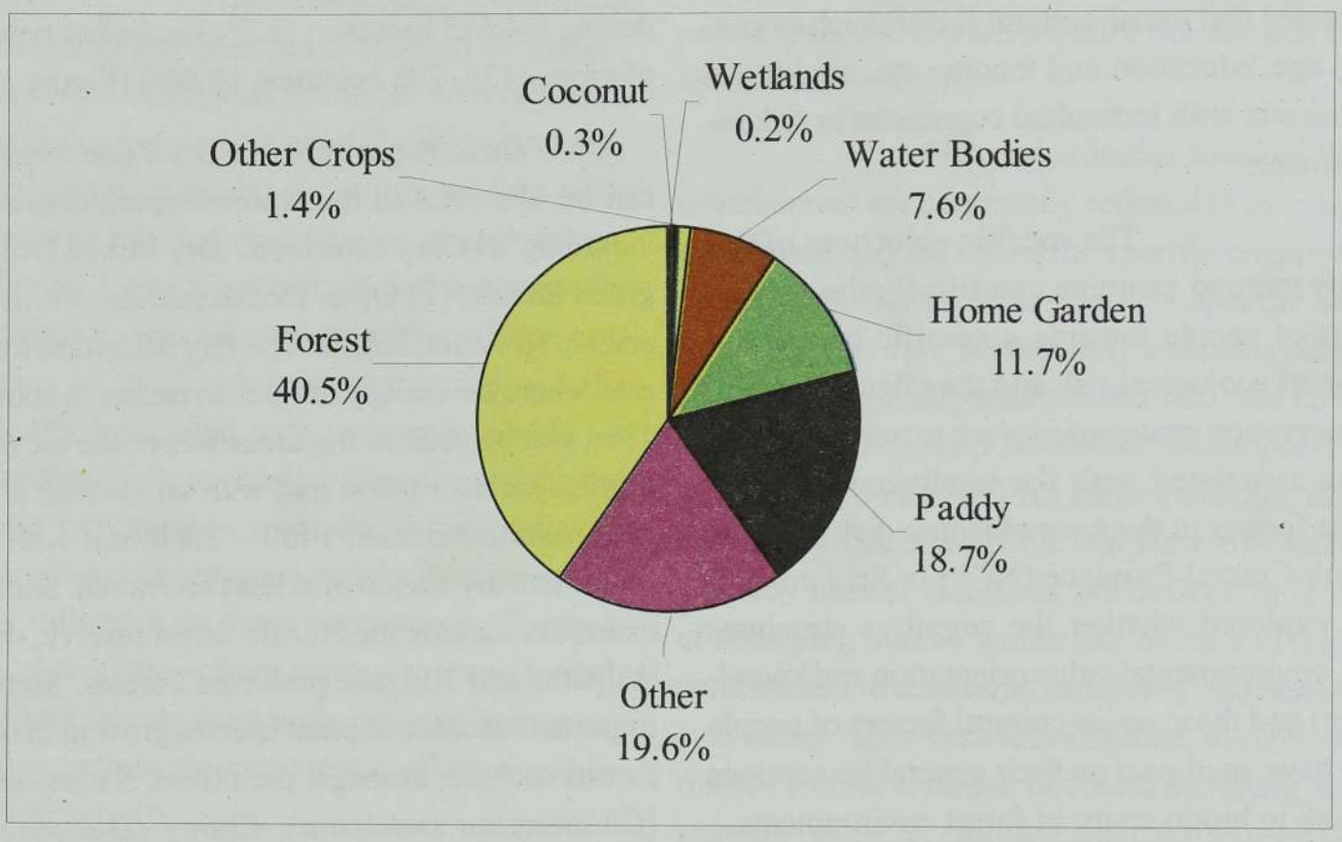
Being the largest district in Sri Lanka with respect to the geographical area (i.e. 6,664 square km), Anuradhapura district is administered by dividing into 22 Divisional Secretariats. The total population of the district was 745,693 in 2006 with a population density of 112 persons per square km. The annual rainfall ranges between 1,000 – 1,500 mm, and the mean temperature is approximately 29^{0}C. The relative humidity is, on an average, 69% during the daytime and 91% during the night.

The Land Use Office in the Anuradhapura district report that there are about 291,250 hectares (40.5%) of lands are covered with forests and the rest of the areas are covered predominately with agricultural crops such as Paddy (134,233 hectares; 18.7%), home gardening (84,685 hectares; 11.7%) and other types of crops (138, 798 hectares; 19.6%) (Figure 1).

Three major types of Dry Zone forests can be observed in the Anuradhapura district, including: (1) Dry Monsoon / Dry Mixed Evergreen forests; (2) Open forests (shrubs, villus), and (3) Reverine forests. The Dry Monsoon forests, where the canopy of forests reaches to about 18m, can be seen in the areas where the elevation is less than 600m and with an average annual rainfall between 1400 – 2000 mm with a prominent dry season of at least six month. Some examples include the Hurulu forest reserve, the Wilpattu and Ritigala protected forests. Some important deciduous plant species grow in these forests include, amongst the others, Satinwood (*Chloroxylon swietenia*), Ebony *(Diospyros ebenum*), Palu (*Mainlkara hexandra*), Weera (*Drypetes sepiaria*) and Halmilla (*Berrya cordifolia*).

Open forests are characterized by shrubs and villus and are found in very dry areas in the district that receive an average annual rainfall less than 1500 mm. These are scattered as small patches all over the district. The shrubs are developed overtime as a result of degradation of monsoon forests. The prominent characteristic belong to these forests is that they have only one layer of scattered dominant trees that is less than 6m height. Villu is, of course, a grass land, which is grown in abandoned irrigation systems and tanks. They provide water to several fauna species mainly during dry season. Riverine forests are located along the riverbanks, which protect the riverbank stability while controlling the hydrological balance of the river. A

Figure 1: Land use patterns of the Anuradhapura district



number of tree species can be seen in riverine forests, including Kumbuk (*Terminalia arjuna*) and Mee (*Madhuca longifolia*).

METHODS

Economic Problems

This study was focused to find answers to four important economic problems coupled with ecological risks to the forest biodiversity, including:

(1) extent to which people who live in a village that is located adjusant to a forest environment and whose livelihood is closely associated with the forest are knowledgeable and familiar towards the term biodiversity;

(2) degree of *bio-centric* and *anthropocentric* orientation of these people towards the forest environment that they are linked with;

(3) general risk perceptions of these people towards the major hazards coupled with forest diversity, and

(4) perceptions of these people on the effectiveness of various conservation strategies used to protect the forest biodiversity.

The variables developed to assess the economic problems explained above and the methods used to collect and analyze data are explored, in turn.

Assessing Peoples' Knowledge on Biodiversity

The first specific objective of the analysis was to assess the level of understanding of people whose livelihood is closely connected with a forest that is close to their home on the term biodiversity and various aspects related to forest management. There were two different methods adopted to evaluate this phenomenon, including: (a) self-rating the familiarity of a person towards the concept of biodiversity, and (b) estimate the real knowledge of these people on this aspect using their response to a set of questions explaining the nature and importance of it.

With respect to the (a) above, each respondent was supposed to self rate his/her level of understanding on a 4-point scale ranging from "completely unfamiliar" (1) to "completely familiar (4). In the case of (b) above, a list comprised of 12 statements that explaining the respondent's knowledge on forest biodiversity and related factors was formulated and forwarded them to the respondent in the form of a questionnaire.

The majority of these statements were written by giving special attention to the forests in the Anuradhapura district, for example "teak is an indigenous tree to the forests in the Anuradhapura district", "the biodiversity of Dry Zone forests is, in general, greater then that can be seen in the forests in the Wet Zone", and "the most predominant forest type in the Anuradhapura district is Dry Monsoonal Forests" and so on. The respondents were asked to state whether each statement is "right" or "wrong", and in the questionnaire certain statements were inverted purposely to avoid giving answers hurriedly. The number of correct answers out of 12 different questions was used to develop a composite index ("*knowledge index*") where the values were ranging from "0" (i.e. no question was answered correctly) to "1" (i.e. answer all the questions correctly).

Assessing People's Value Orientation towards the Forests

The "*Bio-centric*" and "*Anthropocentric*" orientation of a respondent toward the Dry Zone forests was assessed using 10 standard statements developed for that purpose. A similar technique is used in McFarlane (2005) to evaluate risks to forest biodiversity in Canada. These 10 statements were grouped into 2 categories (i.e. 2 x 5) to reflect two different orientations.

The first statement within a category is written to reflect the bio-centric behaviour and other statement to reflect the anthropometric behaviour, for example, "one can not price or assign a specific value to environment or to a forest" (i.e. bio-centric, since the person's perception on this aspect is intrinsic) versus "one can workout a specific value to environment and to a forest by taking into account of his/her own desires on it" (anthropocentric, since the person's perception on this aspect is instrumental). Another two statements used in the questionnaire were: "teak should be cultivated as forests, and must be kept without using them for commercial purposes" (bio-centric) and "teak should be cultivated as forests, but people should be allowed to use them for their basic needs as appropriate" (anthropocentric).

Having formulated 5 sets of statements

in this nature, each respondent was asked to rate each statement in all the sets on a 5-point scale ranging from "strongly disagree" (1) to "strongly agree" (5). The scores were used to formulate two indices reflecting value orientation for each respondent by summing the responses for items that loaded on the corresponding factors.

Assessing Risks to Forest Biodiversity

To assess the perceptions of respondents towards potential risks associated with the hazards linked to biodiversity, they were asked to rate 15 such hazards on a 5- point likert scale ranging from "not a threat at all" (1) from one end to "a great threat" (5) at the other by taking into consideration of their long term threat to forest biodiversity in the Anuradhapura district. The scores given by respondents on each item were, in turn, used to calculate the corresponding Mean Scale Score.

Assessing the Effectiveness of Conservation Strategies

The respondents were asked to indicate the most effective forest conservation strategy that the public institutions may be employed to safeguard to biodiversity of forests in the district. There were four different strategies considered for the purpose of this study, including: (1) formulation of more restrictive regulations and legislation restricting use of forests; (2) increase the extent of protected forest cover; (3) aware of general public and forest users about importance of preserving biodiversity through formal and informal means of education, and (4) development of buffer zones and home gardens to reduce the pressure on existing Dry Zone forests. The respondents were asked to rate each of these strategies on a 4–point scale ranging from "not effective at all" to "completely effective".

Collection of Data

The data were collected from a 225 people who were selected randomly to represent individual households located in peripheral villages to a forest, including Ritigala Strict Natural Reserve, Wilpathu National Park, Hurulu, Issinbassawewa, Mihintale, Nuwaragama, Weddakanda and Yodaela forest reserves. An interview schedule comprised of various structured and attitudinal statements to obtain answers for the four different questions explained above were administered through face-to-face interviews with these respondents from August to October 2007.

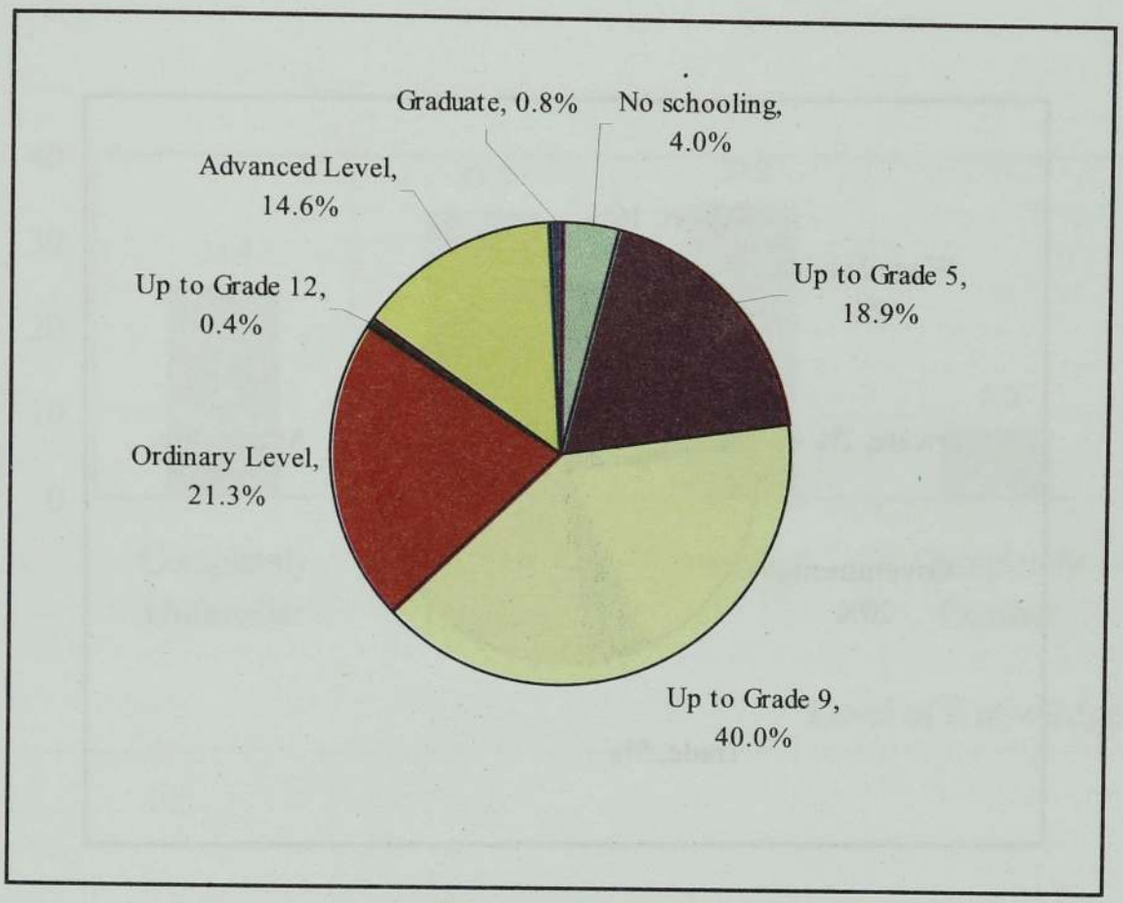
RESULTS AND DISCUSSION

This section first provides a brief discussion about descriptive statistics of the sample followed by results from the survey data analysis.

Descriptive Statistics of the Sample

Almost 63% of respondents belong to individual households were educated up to grade 9. However, there were only about 15% attended to schools until completion of the Advanced Level examination (Figure 2)

Figure 2 : Educational level of respondents to the survey



With regard to the occupation, there were about 52% of respondents depending on agriculture related activities, including crop and livestock production. Another 20% were employed in different types of middle to low category jobs in the public sector, of which majority were related with the environment and forest management. Amongst the people who belong to the category of "others" (16%), a considerable number of people were engaged in military related jobs (Figure 3).

There were almost three fourth of respondents in the sample earn less than Rs. 10,000 income per month. Out of 225 households in the sample, there were only 2.5% earn more than Rs. 20,000 per month (Figure 4).

People's Knowledge about Forest Biodiversity

The results show that only 18 out of 225 participants (8%) to the study judged that they possess a sufficient knowledge about the concepts and applications of biodiversity and managing the forest environment. There were nearly 25% respondents have indicated that they were not familiar with these concepts (Figure 5).

The distribution of values of the "knowledge index", which was derived to assess the real knowledge of respondents on matters related to forest biodiversity, is shown in Figure 6.

Figure 3: Type of occupation of respondents to the survey

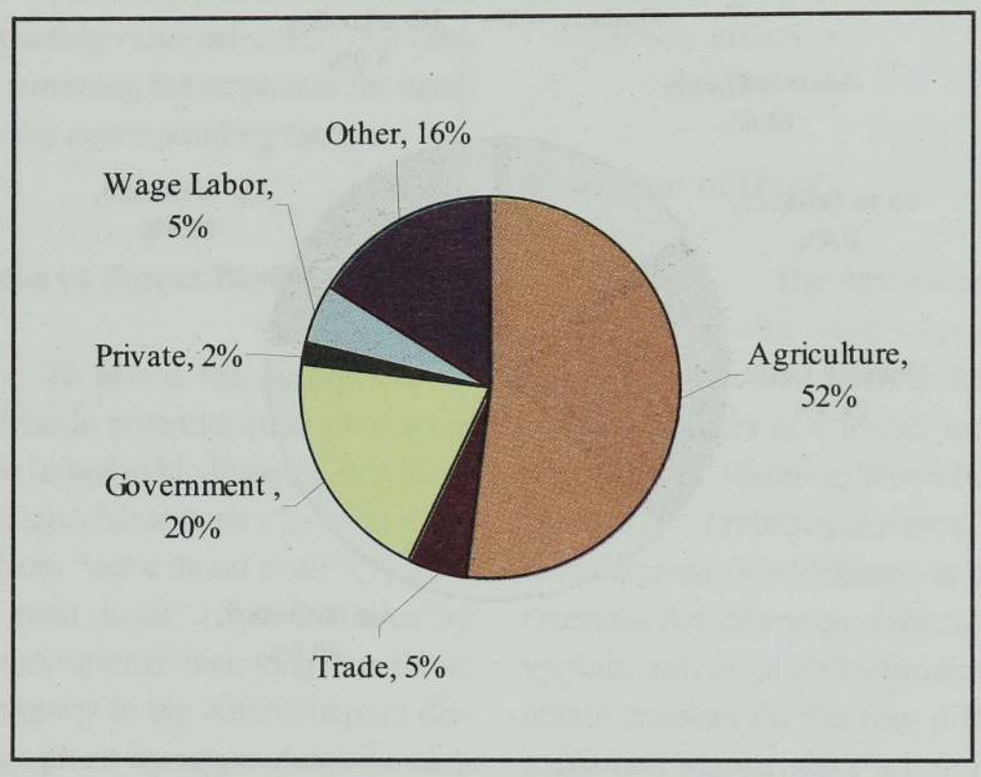


Figure 4 : Distribution of monthly income of respondents to the survey

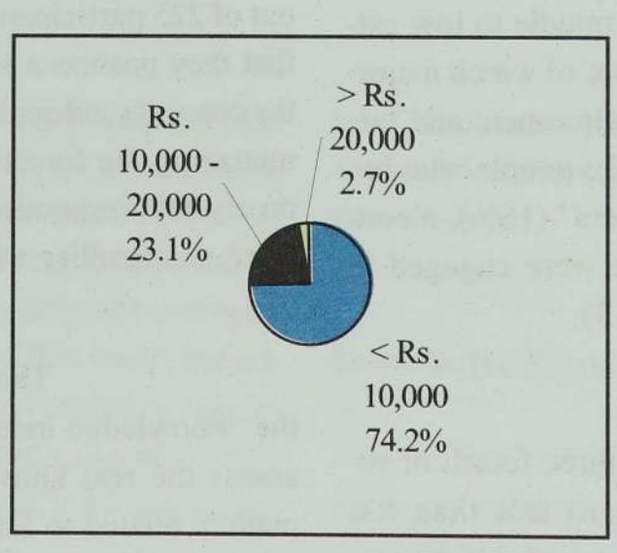


Figure 5 : Self-rated familiarity of respondents to the survey

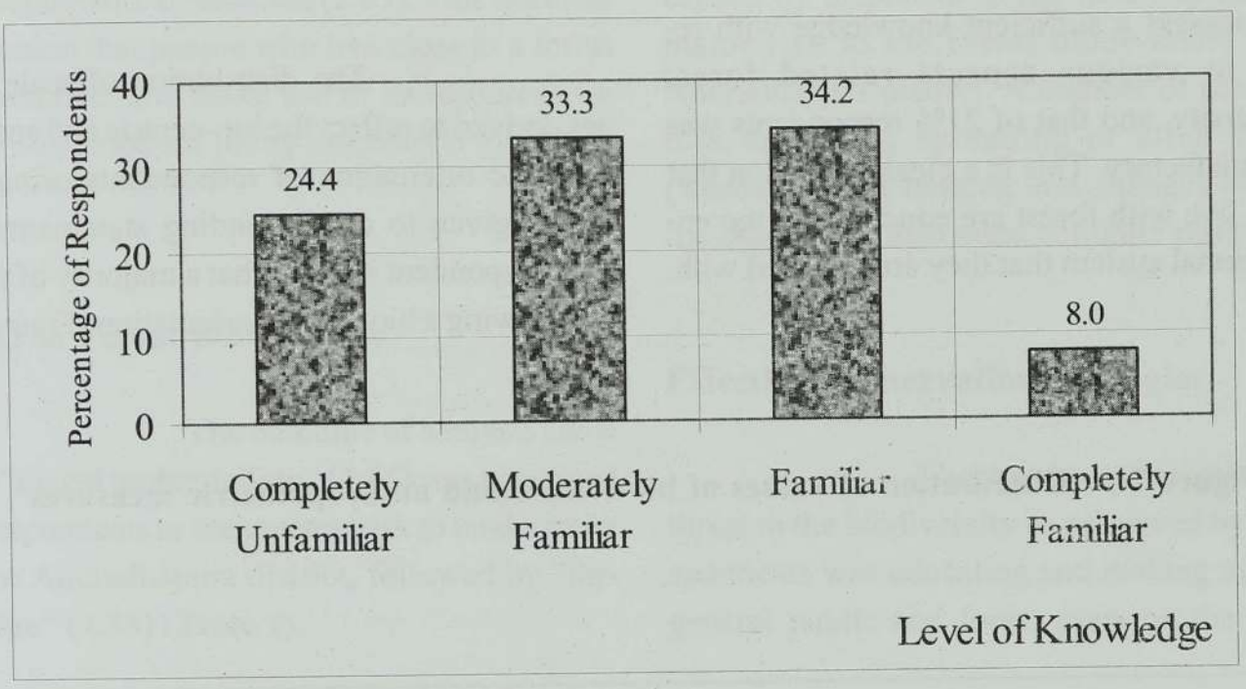
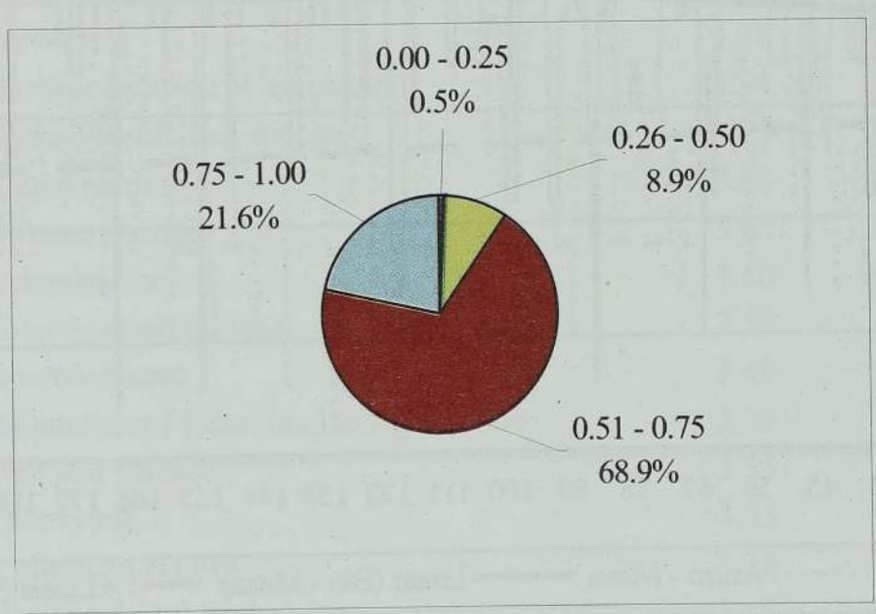


Figure 6 : Distribution of values of the knowledge index

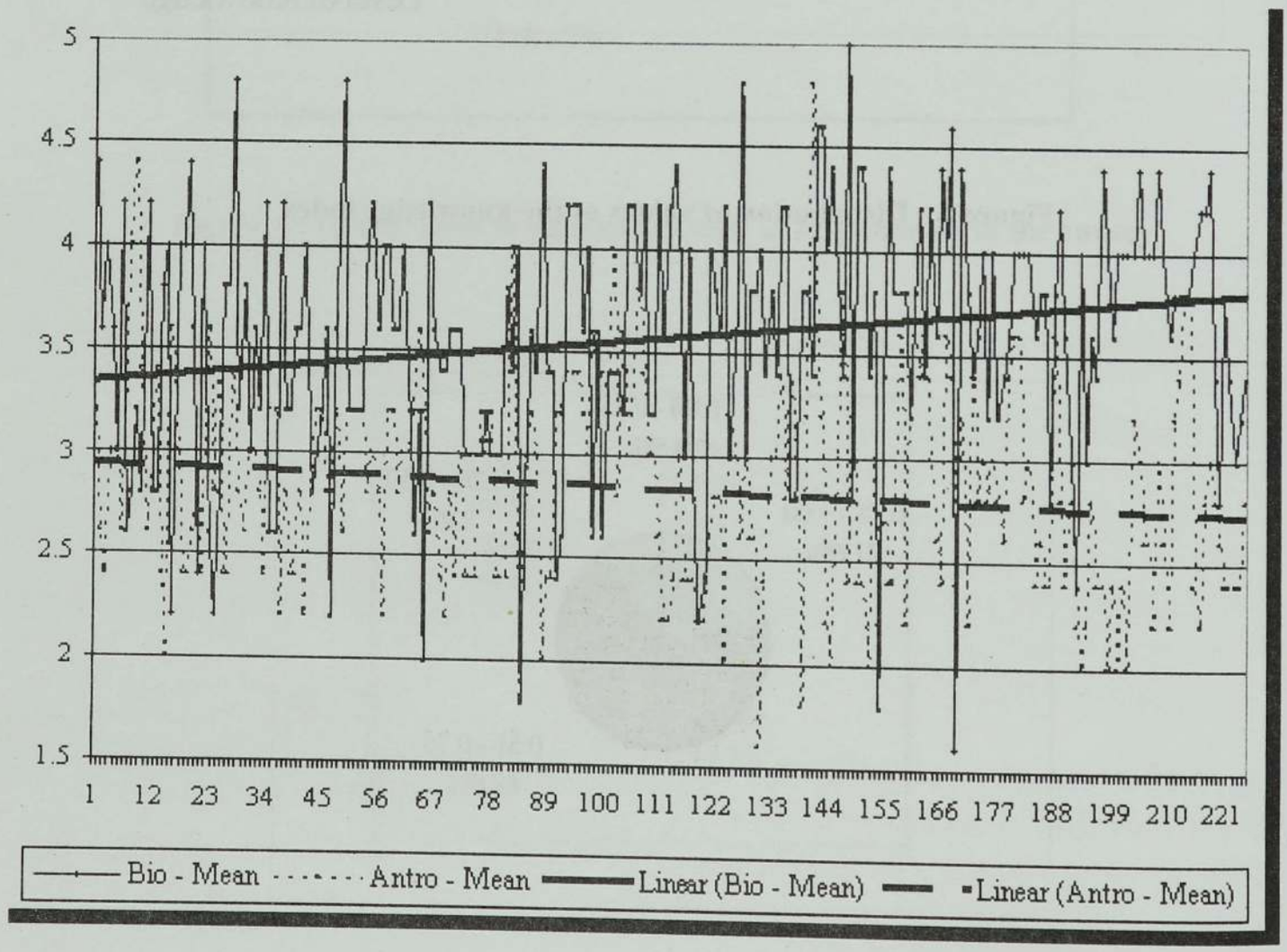


The Mean of the knowledge index was 0.64. It shows that more than 90% of respondents possess a sufficient knowledge with respect to various aspects related forest biodiversity, and that of 21% respondents was very satisfactory. This is a clear indication that people live with forest are educated on the environmental system that they are engaged with.

Value Orientation of People Towards Forests

The distribution of scale values derived to reflect the bio-centric and anthropometric orientation of respondents using the scores given to corresponding statements for each respondent suggest that a majority of them are showing a bio-centric orientation (Figure 7).

Figure 7 : Distribution of values of bio-centric and anthropometric measures



The Mean scale value of bio-centric orientation (3.57) is greater than that obtained for anthropometric orientation (2.83). This is a clear indication that people who live close to a forest environment and make use of its resources for their livelihood are pretty much loyal to the forest.

Risks to Forest Biodiversity

The outcome of analysis show that "illegal timber felling" (4.45) was perceived by respondents as the greatest risk to biodiversity in the Anuradhapura district, followed by "forest fire" (4.38) (Table 1).

Interestingly, these villagers living adjusant to a forest rated the damages caused by elephants to the forest as the third major risk to the forest biodiversity in the Anuradhapura district. A number of other factors, including spreading of alien species (weeds), illegal hunting and changes occur in the climate are also rated at higher positions.

Effective Conservation Strategies

The best way to minimize threat to the biodiversity as perceived by the respondents was educating and making aware of general public and forest users on the impor-

Table 1 : Risks associated with forest biodiversity

Issue	Mean	Std. Dev
Illegal timber felling	4.45	0.79
Forest fire	4.38	0.98
Damages caused by elephants	3.91	1.18
Spreading of alien species	3.77	1.10
Illegal hunting	3.66	1.09
Climate change	3.66	1.02
Urbanization	3.60	1.10
Unauthorized mining	3.55	1.03
Encroachment	3.49	1.13
Alienation of forest land to Agriculture	3.39	1.05
Pest and disease	3.35	1.10
Quarrying	3.25	1.11
Collecting NTFPs	3.16	1.14
Grazing forest land	2.88	1.20
Use for recreation	2.49	1.11

Table 2 : Effective conservation strategies

Conservation strategies	Mean	Std Dev
Education and make aware of people	3.48	0.67
Home stead and buffer zone	3.45	0.79
Regulation and legislation	2.95	0.98
Increase protected forest area	2.92	0.95

tance of securing forest biodiversity (3.48) (Table 2).

Development of homestead and buffer zones so as to reduce the pressure on existing dry zone forests (3.45) was placed at the second place, while increase of protected forest area (2.92) was considered to be least effective strategy (Table 2).

CONCLUSIONS AND POLICY IMPLICATIONS

This study provides a more extensive analysis of explicators of ecological risk perception by including the interaction of cognitions with socio-economic influences. The outcome of analysis suggest, in contradictory to the general belief, that a majority of people who live in villages adjusant to forests in the Anuradhapura district and make use that forest to support their livelihood believe that a forest should be managed as a sustainable system. Although these people did not want to consider a forest as an entity that they can never approach into, they wish to see that a forest should be kept away from people who value everything from the commercial point of view.

The results also prove that despite the relatively low level of formal education received by respondents, they possess a sufficient knowledge on various aspects related to biodiversity. While accepting that encroachment, grazing etc. can impose a risk to biodiversity, there was a common perception that the damages caused by illegal timber felling and forest fire were the greatest risk to forest biodiversity. All these highlight the fact that value orientation has a greater effect on perceived risk of people than the level of knowledge or socio-cultural variables.

The results provide some useful insight to both policymakers and environmentalist as to how biodiversity of forests should be augmented. This study shows that people who make use of a natural resource like a forest on a non-commercial basis, or in other words, utilize it only for the purposes of securing their basic needs should be allowed to use such resources at a non-diminishing rate, may be with a proper mode of frequent monitoring of the status of forest, and at the same time they should be educated and employed to secure the forest to make it a sustainable system. While the out-

come of study provides some useful information with respect to perceived risks associated with a single dimension to ecological risk (i.e. forest biodiversity), future studies on this area should be extended towards a multidimensional framework, for example take into account of certainty that these impacts will occur and their level of controllability. Also, the risk perceptions of outsiders to the forests (i.e. urban communities / researchers) who may be presumed to possess anthropometric value orientation towards a forest environment should also be taken into account.

REFERENCES

Cavanagh, N., McDaniels, T., Axelord, L. J., and Slovic, P. (2000). Perceived Ecological Risks to Water Environments from Selected Forest Industry Activities. *Forest Science* 46(3): 344-355.

Gagnon-Thompson, S. C., and Barton, M. A. (1994). Ecocentric and Anthropometric Attitudes towards the Environment. *Journal of Environmental Psychology* 14: 149-157.

Gardner, P. D., Cortner, H. J., and Widaman, K. (1987). The Risk Perceptions and Policy Response toward Wildland Fire Hazards by Urban Home-Owners. *Landscape and Urban Planning* 14: 163-172.

Lazio, J. K., Kinnell, J. C., and Fisher, A. (2000). Expert and Layperson Perceptions of Ecosystem Risk. *Risk Analysis* 20(2): 179-193.

McDaniels, T., Axelord, L. J., Cavanagh, N., and Slovic, P. (1997). Perception of Ecological Risk to Water Environment. *Risk Analysis* 17(3): 341-352.

McDaniels, T., Axelord, L. J., and Slovic, P. (1995). Characterizing Perception of Ecological Risk. *Risk Analysis* 15(5): 575-588.

O'connor, R. E., Bord, R. J., and Fifher, A. (1999). Risk Perceptions, General Environmental Beliefs, and Willingness to Address Climate Change. *Risk Analysis* 19(3): 461-471.

Stedman, R. C., Davidson, D. J., Wellstead, A. (2004). Risk and Climate Change. *Risk Analysis* 24(5): 1395-1406.

SPECIES DIVERSITY OF PTERIDOPHYTE FLORA IN LOOLKANDURA LOWER MONTANE FOREST

S.R.W.A.B.M.R.J. Kandapola[1], R.H.G. Ranil[1], D.K.N.G. Pushpakumara[2], T. Sivananthawerl[2] and K.T. Premakantha[3]

Summary

A survey of the Pteridophyte flora of Loolkandura lower montane forest area revealed the occurrence of 56 species representing 20 families and 41 genera. This represented 17% of the Pteridophyte flora in Sri Lanka which included three endemic species. The richest families were Polypodiaceae (nine species in eight genera) and Pteridaceae (nine species in five genera). Based on their habitat categories, 35 species were terrestrial, 18 species were epiphytic and 14 species were lithophytic. No relationship was observed with Shannon-Wiener diversity index with change of elevation. Cumulative number of species showed a significant asymptotic relationship with cumulative area surveyed. The density of two species increased significantly whilst one species declined significantly with increasing elevation. Species restricted to different elevations were also identified. A checklist of Pteridophytes was prepared for the study area.

[1] *Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya.*

[2] *Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.*

[3] *Dishict Forest Officer, Forest Department, Kurunegala.*

INTRODUCTION

The Pteridophyte flora forms an important component of the understorey and epiphytic communities of tropical forests. They have ecological, edible, ornamental and medicinal values. Unlike flowering plants, detailed studies on Pteridophytes are limited in Sri Lanka to Beddome (1883), Sledge (1956; 1960; 1965; 1972; 1973; 1981; 1982), Abeywickrama (1978), and recently to Fernando (2002), Herat and Rathnayake (2003) and Ranil *et al.* (2004) where almost all studies have been concentrated to develop checklists. The analysis of diversity and ecological relationships of Pteridophytes are lacking. Despite the limited studies, it has been reported that more than 30 species of ferns have not been collected in Sri Lanka during the present century (Sledge, 1982). Based on historical records and the present level of taxonomic diversity of Pteridophytes in Udawattakele forest, Ranil *et al.* (2006) recently stressed the necessity of urgent assessment and continuous monitoring of the Pteridophytic flora to understand whether any of these species are indicators of ecological changes.

Sri Lanka's first tea plantation has started in Loolkandura although the remaining hilly areas still exists as undisturbed forests. The forest area is located at the northern end of the Piduruthalagala mountain range and acts as a barrier to the northeast and southwest monsoons creating a unique environment. According to elevation of the area, the forest can be classified as lower montane forest (Ashton *et al.*, 1995). Due to misty climate, and variations of soil and elevation (1,090 to 1,455 m), Loolkandura lower montane forest area can be considered as one of the biodiversity richest areas of the country. However, limited studies have been carried out on the biodiversity of entire Piduruthalagala mountain range. Consequently, objectives of this study were to identify the diversity of the Pteridophytes at species level and their life forms, and examine their diversity along the elevational gradient at Loolkandura lower montane forest.

METHODOLOGY

The study was conducted in Loolkandura lower montane forest area close to the tea plantation at about 7°08' N and 80° 42' E. The area located in Kandy district of the Central Province has a humid tropical climate, with a mean annual precipitation of over 2,300 mm. Precipitation is distributed rather evenly throughout the year, with a minimum in the months of February and August. The mean annual temperature is 16 °C. Drainage networks and other geographical data of Loolkandura lower montane forest area were obtained by using 1:50,000 Gampola (Sheet 61) map published by the Survey Department of Sri Lanka and Google satellite maps obtained from internet. After reviewing these maps, a preliminary field survey was carried out to identify the distribution of Pteridophytes in this forest. For the establishment of plots, the north end of the eastern slope was selected because of easy access from the tea plantation area. At each of nine elevational levels the Pteridophytes were sampled in one 10×10 m square plot (Table 1). Plots were located as far as possible in ecologically and topographically homogenous and

Table 1: Locations of plots used for the Pteridophyte study at Loolkandura lower montane forest.

Plot number	Elevation (m)	Approximate Location (GPS reading at the centre point)
E_1P_1	1,090	7°08'12.620" N; 80°42'15.210" E
E_1P_2	1,125	7°08'19.162" N; 80°42'24.285" E
E_1P_3	1,180	7°08'13.795" N; 80°42'22.467" E
E_2P_1	1,329	7°08'42.776" N; 80°42'05.786" E
E_2P_2	1,335	--
E_2P_3	1,341	7°08'45.095" N; 80°42'04.836" E
E_3P_1	1,412	7°08'46.756" N; 80°42'03.417" E
E_3P_2	1,415	7°08'45.662" N; 80°42'00.614" E
E_3P_3	1,455	7°08'46.179" N; 80°41'59.663" E

Note: E and P represent elevation level and plot number, respectively.

physiognomically representative forest samples.

All Pteridophytes growing in each plot were counted and then they were identified to species level by observing morphological characters of sterile and fertile fronds, scales of rhizome and spores. In each plot, crown and stem of each tree species were observed for epiphytic Pteridophytes. Samples were also collected for further identification at the National Herbarium, Royal Botanical Gardens, Peradeniya only if fertile fronds were not observed. Drawings were made and photographs taken of the Pteridophytes encountered for future use. Species diversity was estimated by the number of species recorded in each 100 m^2 plot. Species were categorized according to life form groups as lithophytes (growing on rocks with little or no soil), epiphytes (growing on other host plants); terrestrial (on the ground). Species were assigned to several categories, where appropriate.

Number of families, genera and species and number of individuals of each species were correlated with elevation gradients. Logistic regression model was fitted to identify the relationship of species and number of individuals with increasing elevation. Species diversity was estimated using Shannon-Wiener's Diversity Index defined by Magurran (1988). In addition to assessment of plots, the occurrence of Pteridophyte species along streams were also observed and identified to species level to prepare a checklist for Loolkandura lower montane for-

est area. The study was carried out from June to December 2006. The taxonomic classification of Pteridophytes used in this study was based on Shaffer-Fehre (2006) and Sledge (1982).

RESULTS AND DISCUSSION

Taxonomic and habitat diversity of Pteridophytes at Loolkandura lower montane forest

A total of 56 Pteridophyte species representing 20 families and 41 genera were identified from the plot assessments and observations along stream banks of northern end of the eastern slope of the Loolkandura lower montane forest (Table 2). This represents 17% of the Pteridophyte flora of Sri Lanka and three endemic fern species, *Cyathea walkerae, Meringium macroglossum* and *Diplazium beddomei*. The richest families were Polypodiaceae and Pteridaceae followed by Dennstaedtiaceae and Dryopteridaceae (Figure 1). The richest genera were *Asplenium* with four species followed by *Diplazium* and *Pteris* with three species each. A comparision of taxonomic diversity of Pteridophyta in Loolkandura lower montane forest in Sri Lanka is given in Table 2. A checklist of Pteridophytes identified from Loolkandra lower montane forest area including their status and life forms is given in Annex 1. Considering different habitats there were 35 terrestrials species, 18 epiphytes and 14 lithophytes. Terrestrial habitat includes mountain slopes, dense forest (shady areas), stream banks and open areas whereas lithophytes grew on bare rocks, humus rich rocks and in rock crevices or cliffs. Generally, epiphytic Pteridophytes grow on tree trunks, on mossy tree trunks or on branches of trees. Some species occure in more than one habitat (Annex 1).

This is the first study to document the diversity of Pteridophytes at Loolkandura lower montane forest area. Although limited studies have been conducted on diversity of Pteridophytes in other mountainous forests in Sri Lanka, analysis of checklist of Pteridophyte species in the entire Knuckles forest range revealed 120 species from 20 families and 64 genera, which represent almost one third of the country's Pteridophyte flora with 21% of endemic species (Herat and Rathnayake, 2003). Ranil *et al.* (2004) also identified 70 species of Pteridophytes belonging to 20 families, representing 21% of the endemic Pteridophyta in Sri Lanka from Kanneliya Man and Biosphere reserve where the extent of forest area is almost half compared to the Knuckles forest range. In contrast, assessment of permanent forest dynamic plot at Sinharaja forest using a set of 89 points, Sedayu (2006) reported the occurrence of only 12 terrestrial Pteridophyte species from nine families much less than the 30 families of the Pteridophyte flora of Sri Lanka. The main factor influencing the richness of Pteridophytes in Loolkandura forest may be the high and constant rainfall in the area that creates high air humidity. Herat and Rathnayake (2003) also suggested that the mountain mist increases the abundance of Pteridophytes. In addition, the richness of Petridophytes may also be due to the presence of different micro habitats in the

Table 2: Comparision of taxonomic diversity of Pteridophyta in Loolkandura lower montane forest with Sri Lanka.

Category	Ferns	Fern allies	Total	Total recorded in Sri Lanka
Number of families	18	2	20	30 [A]
Number of genera	38	3	41	113 [A]
Total number of species	51	5	56	362 [A]
Number of endemic species	3	-	3	50 [A]
Species per genus	1.37	1.67	1.39	3.20
Species per family	2.88	2.50	2.85	12.06
Number of introduced species	4	-	6	18 [B]
Number of threatened species	1	2	3	90 [C]
Number of rare species	1	-	1	50 [D]

Note: Superscript letters A, B, C and D are based on Shaffer-Fehre (2006); Sledge (1981); MFE (1999) and Fernando (2002), respectively.

area. There are exposed rocks, streams, natural banks and thick, partly decomposed litter areas that creates a favourable environment for shade loving plants.

Variation of species diversity in plots and their relationship to elevation gradient

The total number of Pteridophyte individuals recorded in the nine study plots (0.09 ha) was 2,755 of which *Selaginella involvens* made up 54% of individuals. Four common species, *Selaginella involvens* (over 200 individuals per plot), *Leptochilus decurrens* (more than 30 individuals per plot), *Tectaria decurrens* (more than 20 individuals per plot) and *Nephrolepis cordifolia* made up more than 79% of the individuals enumerated. Some species were rare and only a single individual per plot was observed, e.g. *Vittaria microlepis*, *Pteridium revolutum*, *Sphenomeris chinensis*. The number of Pteridophyte individuals per plot varied from 155 to 374.

Figure 1: Number of genera and species in each family of Pteridophytes

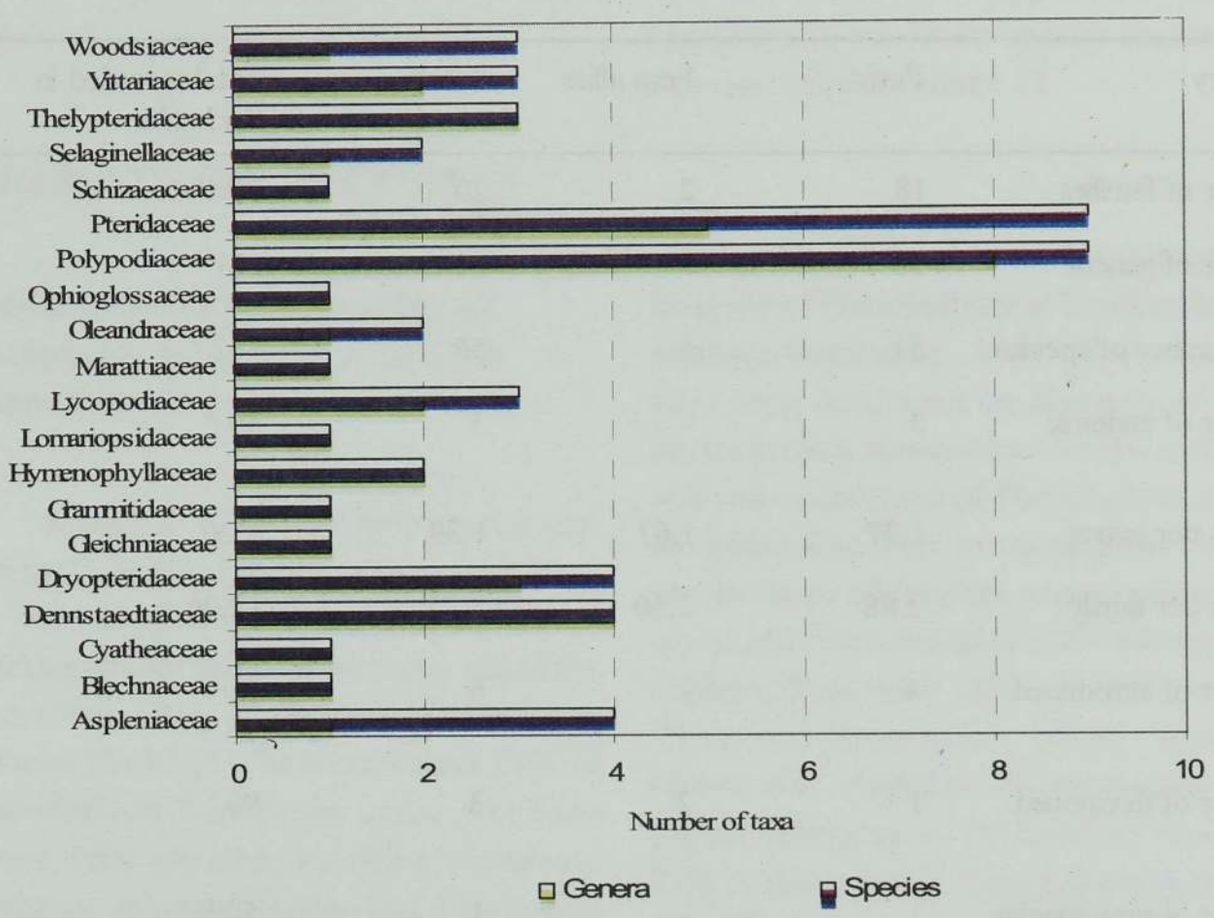


Figure 2: Change in the cumulative number of Pteridophyte species with the cumulative area surveyed.

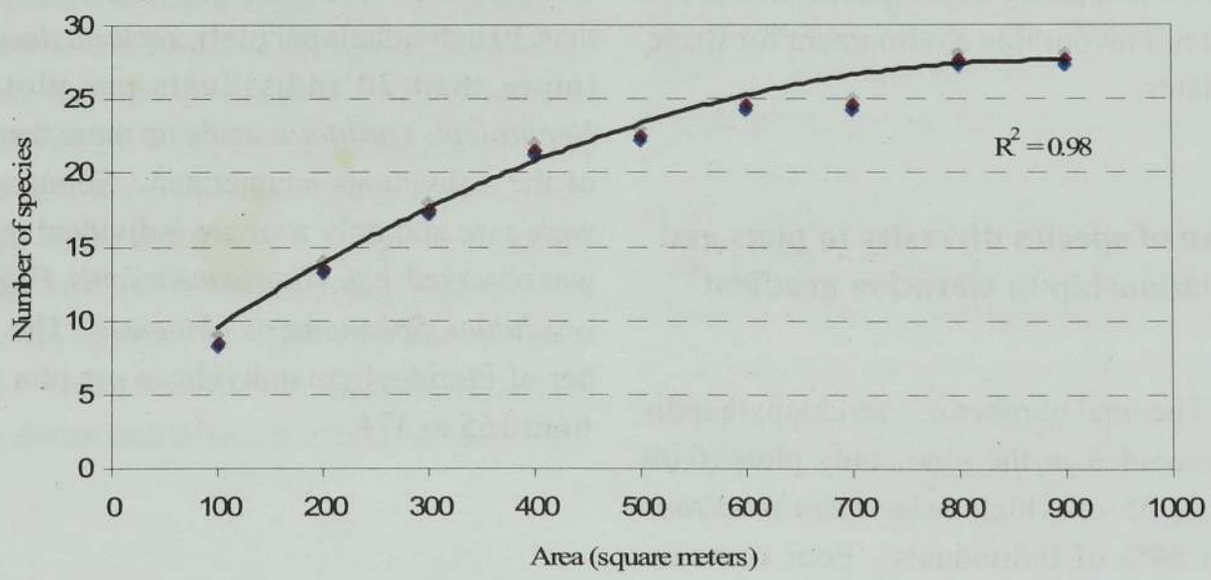
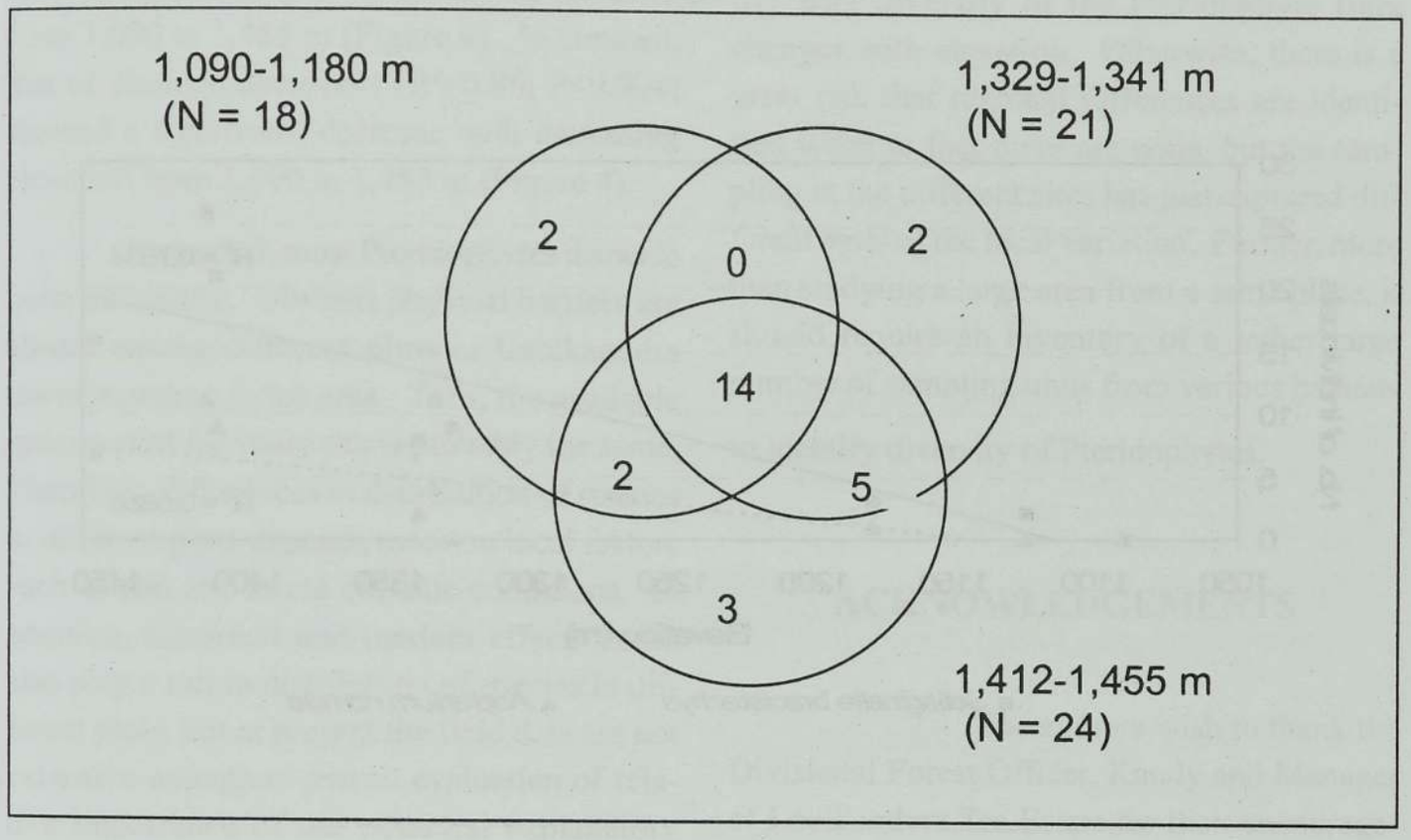


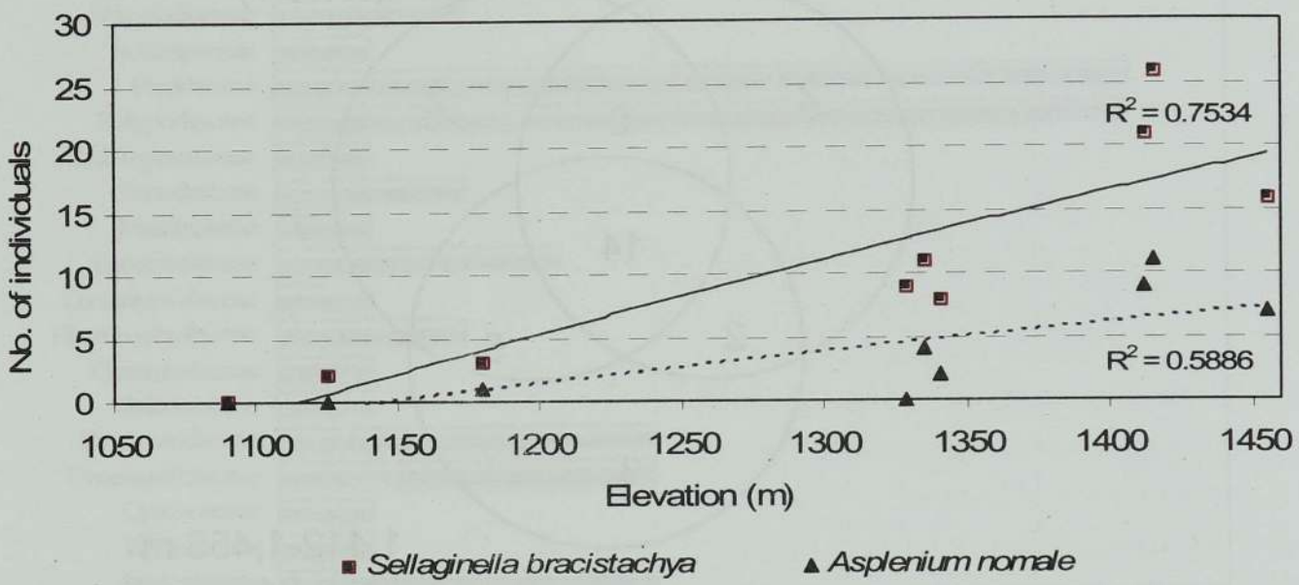
Figure 3: Comparison of the number of Pteridophyte species observed at three elevations at Loolkandura lower montane forest (N=Number of species observed).

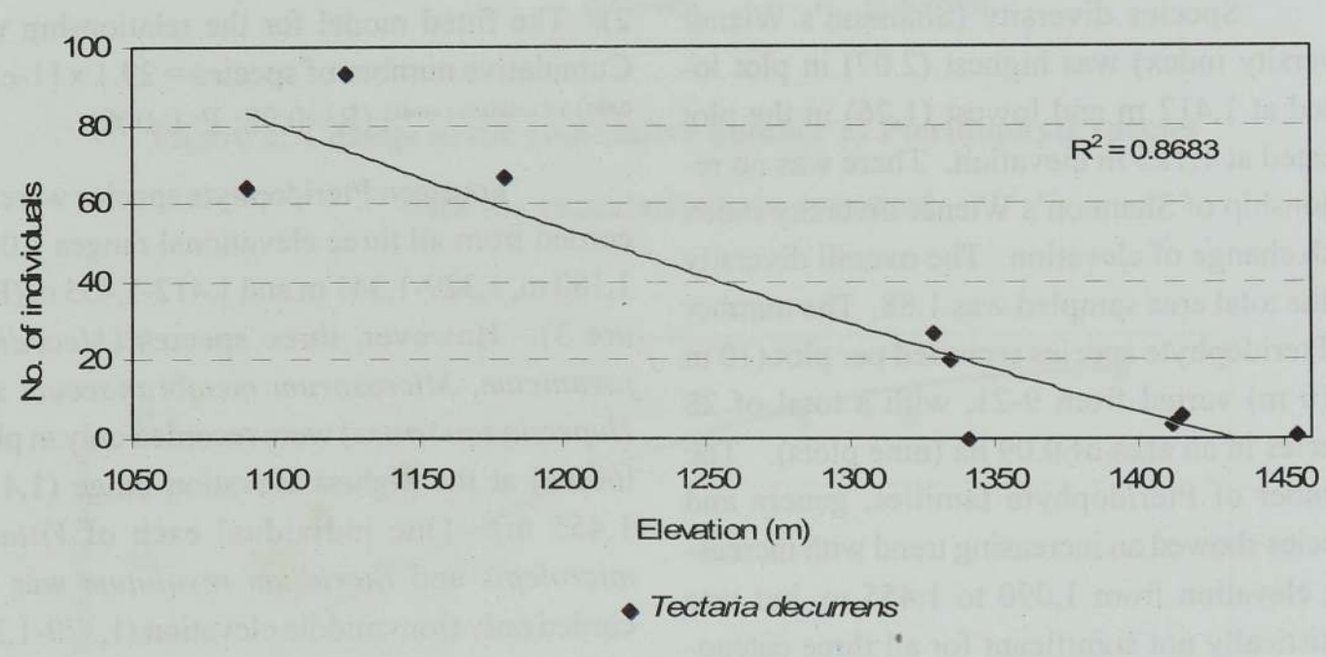


Species diversity (Shannon's Wiener diversity index) was highest (2.07) in plot located at 1,412 m and lowest (1.26) in the plot located at 1,125 m elevation. There was no relationship of Shannon's Wiener diversity index with change of elevation. The overall diversity of the total area sampled was 1.88. The number of Pteridophyte species recorded per plot (10 m x 10 m) varied from 9-21, with a total of 28 species in an area of 0.09 ha (nine plots). The number of Pteridophyte families, genera and species showed an increasing trend with increasing elevation from 1,090 to 1,455 m, but was statistically not significant for all three categories ($P<0.05$). The cumulative number of species showed a significant asymptotic relationship with the cumulative area surveyed (Figure 2). The fitted model for the relationship was Cumulative number of species = $29.1 \times [1-\exp^{(-0.0033 \times \text{Cumulative area})}]$ ($R^2=0.98$; $P<0.000$).

Fourteen Pteridophyte species were recorded from all three elevational ranges 1,090-1,180 m, 1,329-1,341 m and 1,412-1,455 m (Figure 3). However, three species (*Mecodium javanicum, Microsorum membranaceum* and *Huperzia squarrosa*) were recorded only in plots located at the highest elevation range (1,412-1,455 m). One individual each of *Vittaria microlepis* and *Pteridium revolutum* was recorded only from middle elevation (1,329-1,341 m) and another two species, *Pteris ensiformis* and *Nephrolepis hirsutula*, were recorded only at lower elevation (1,090-1,180 m) (Figure 3).

Figure 4: Variation of the density of three Pteridophyte species with increasing of elevation.





The diversity of individuals of *Asplenium normale* (R^2=0.58; P<0.048) and *Selaginella brachystachya* (R^2=0.75; P<0.026) increased significantly with increasing elevation from 1,090 to 1,455 m (Figure 4). In contrast, that of *Tectaria decurrens* (R^2=0.86; P<0.004) showed a significant decrease with increasing elevation from 1,090 to 1,455 m (Figure 4).

In general, most Pteridophytes disperse quite efficiently. Obvious physical barriers are absent among different plots at Loolkandura lower montane forest area. Thus, the available species pool for study site is probably the same. Therefore, differences in distribution of species in different plots depends more on local factors such as soil and micro climatic conditions. In addition, historical and random effects could also play a roll in distribution of species in different plots, but at present the field data are not extensive enough to permit evaluation of relative importance of the potential explanatory factors.

It is clear from results that the plots sampled help to identify only half of the total diversity of Pteridophytes at the forest. Differences of number of species recorded in the plots sampled and the general area surveyed indicate that the sampling effort was insufficient to capture all the species. Although correlation was tested with elevation and the number of species and families, elevation cannot be the only explanation for differences in the distribution of species in different plots. The physio-chemical characteristics of the soil, degree of spatial heterogeneity in soil, vegetation, the light environment, forest floor and profile may also influence the number of species/families per plot. Therefore, in future studies, more than two sample plots per elevation, the local soil, light and humidity variations at each site as completely as possible need to be examined to identify why diversity of the Pteridophyte flora changes with elevation. Otherwise, there is a great risk that regional differences are identified when in fact there are none, but the sampling at the different sites has just captured different parts of the local variation. Further, more than studying a large area from a same place, it should require an inventory of a rather large number of sampling units from various habitats to identify diversity of Pteridophytes.

ACKNOWLEDGEMENTS

The authors wish to thank the Divisional Forest Officer, Kandy and Manager of Loolkandura Tea Estate for their encouragement and permission to carry out this study. Members of the National Herbarium at Royal Botanical Gardens, Peradeniya are also acknowledged for their support in identification of the Peridophyte species.

REFERENCES

Abeywickrama, B.A. (1978) A checklist of the Pteridophytes of Sri Lanka. UNESCO: MAB National Committee for Sri Lanka. Publication No. 3. National Science Council of Sri Lanka, Sri Lanka.

Ashton, M., Gunatilleke, S., de Zoysa, N., Dassanayaka, M.D., Gunatilleke, N. and Wijesundara, S. (1997) A field guide to the

common trees and shrubs of Sri Lanka. WHT Publication (Pvt.) Ltd., Colombo, Sri Lanka.

Beddome, R.H. (1883) Handbook of the ferns of British India, Ceylon and the Malay Peninsula. Second Edition. Today and Tomorrows Printers and Publishers, New Delhi, India.

Fernando, B. (2002) Ferns of Sri Lanka (in Sinhala). The Ferns Society of Sri Lanka, Sri Lanka.

Herat, T.R. and Rathnayake, P. (2003) An Illustrated Guide to the Fern Flora of Knuckles Conservation area. Forest Department.

Magurran, A.E. (1988). Ecological diversity and its measurements. Croom Helm Limited, Sydney.

MFE. (1999). Biodiversity conservation in Sri Lanka: A framework for action. Ministry of Forestry and Environment, Sampathpaya, Rajamalwatta Road, Battaramulla, Sri Lanka.

Ranil, R.H.G., Pushpakumara, D.K.N.G., Wijesundera, D.S.A., Dhanasekara, D.M.U.B. and Gunawardena, H.G. (2004) Species diversity of Pteridophyta in Kanneliya Man and Biosphere Reserve. The Sri Lanka Forester 27: 1-10.

Ranil, R.H.G., Kandepola, S. R. W. A. W. B. M. R.J., Pushpakumara, D.K.N.G. and Wijesundara, D.S.A. (2006) Pteridophyte flora of Udawattakele forest: the past, present and future. Proceedings Part 1- Abstracts of Papers of the Ninth Annual Forestry and Environment Symposium 2006. Department of Forestry and Environmental Science, University of Sri Jayawardenapura. pp. 69.

Sedayu, A. (2006) Distribution of terrestrial pteridophytes with respect to topography and light exposure in a tropical rain forest. Proceedings of the International Field Biology Course 2006 held in Sri Lanka. Centre for Tropical Forest Science-Arnold Arboretum Asia Program, University of Peradeniya, Forest Department Sri Lanka. pp 95-97.

Shaffer-Fehre, M. (2006). (ed.). A revised handbook of the flora of Ceylon. Volumes XV (Part A and B): Ferns and fern allies. Science Publishers, Enfield (NH), USA.

Sledge, W.A. (1956) The Ceylon Species of *Leptochius*. Annuals and Magazine of Natural History Series 12 (9): 865-877.

Sledge, W.A. (1960) The Polypodiaceae and Grammitidaceae of Ceylon. Bulletin of the Britsh Museum (National History), Botany Series, London 2(5): 133-185.

Sledge, W.A. (1965) The Ceylon species of *Asplenium*. Bulletin of the British Museum (Natural history) Botany Series, London 3(6): 236-277.

Sledge, W.A. (1972) The Tectaroid Ferns of Ceylon. Kew Bulletin 27(3): 412-415.

Sledge, W.A. (1973) The Dryopteris Fern of

Ceylon. Bulletin of the British Museum (National History), Botany Series, London 5(1): 1-43.

Sledge, W.A. (1981) The Thelypteridaceae of Ceylon. Bulletin of the British Museum (Natural History), Botany Series, London 81(1): 1-54.

Sledge, W.A. (1982) An annotated check list of the Pteridophyta of Ceylon. Botanical Journal of the Linnaean Society 84: 1-30.

Annex 1: Check list of Pteridophytes identified in Loolkandura lower montane forest.

Family	Species	Life form
Aspleniaceae	*Asplenium aethiopicum* (Burm. fil.) Bech	EP
	Asplenium affine Sw.	EP
	Asplenium decrescens Kunze	EP
	Asplenium normale D.Don.	EP
Blechnaceae	*Blechnum orientale* Linn. (Barukoku)	TB
Cyatheaceae	*Cyathea walkerae* Hook. (Ginihota)	TB
Dennstaedtiaceae	*Dennstaedtia scabra* (Wall. ex Hook.) Moore	TO
	Histiopteris incisa (Thunb.) J.Sm	TO
	Pteridium aquilinum (Lin.) Kuhn	TO
	Sphenomeris chinensis (Linn.) Maxon	TB
Dryopteridaceae	*Arachniodes aristata* (G. Foster) Tindale	TO
	Arachniodes tripinnata (Goldm.) Sledge	DF
	Polystichum biaristatum (Blume) T. Moore	DF
	Tectaria decurrens (Pr.) Copel	TB
Gleichniaceae	*Dicranopteris linearis* (Burm.fil.) Underwood	TO
Grammitidaceae	*Prosaptia alata* (Blume) Christ	EP
Hymenophyllaceae	*Mecodium javanicum* (Spreng.) Copel.	EP
	Meringium macroglossum (Bosch) Copel.	EP
Lomariopsidaceae	*Elaphoglossum commutatum* (Mett. Ex. Kuhn) Al dew.	EP

Lycopodiaceae	*Huperzia phlegmaria* (L.) Rothmaler +	LP
	Huperzia squarrosa (G.Forst) Trevis +	LP
	Lycopodiella cernua (L.) Pichi-Serm.	TO/TB
Marattiaceae	*Angiopteris evecta* ((G.Forster) Hoffm.	TB
Oleandraceae	*Nephrolepis cordifolia* (L.) Presl	LP/TB
	Nephrolepis hirsutula (G.Forster) C. Presl	LP/EP/TB
Ophioglossaceae	*Botrychium daucifolium* Wall.ex Hook. & Grev. +	TB
Polypodiaceae	*Crypsinus montanus* Sldge	LP
	Drynaria quercifolia (L.) J. Sm.	EP
	Lepisorus nudus (Hook.) Ching	EP/LP
	Leptochilus decurrens Blume	EP/LP
	Loxogramme involuta (D.Don) C. Presl	LP
	Microsorum membranaceum (D.Don) Ching	LP
	Microsorum scolopendria (Brum. fil.) Copel.	LP/EP
	Phlebodium aureum (L.) J.Sm. *	LP/EP
	Pyrrosia lanceolata (L.) Farwell.	EP
Pteridaceae	*Adiantum capillus-veneris* L.	TB
	Adiantum hispidulum Sw.	TB
	Parahemiontis arifolia (Burm.f.) Panigrahi	TB/TO
	Pellaea viridis (Forsskal) Kaulf *	TB
	Pityrogramma calomelanos (L.) Link *	TB
	Pityrogramma dealdata (C. Presl) Tryon *	TB
	Pteris biaurita L.	TB

	Pteris ensiformis Burm.	TB
	Pteris quadriaurita Retz.	TB
Schizaeaceae	*Lygodium microphyllum* (Cav.) R. Br.	TB
Selaginellaceae	*Selaginella brachystachya* (Hook. & Grev.) Spring	DF
	*Selaginella involvens (*Sw.) Spring	LP
Thelypteridaceae	*Christella dentata* (Forssk.) Brownsey & Jermy	TB
	Metathelypteris flaccida (Blume) Ching	TB
	Sphaerostephanos unitus (L.) Holttum	TB
Vittariaceae	*Antrophyum reticulatum* (Forst.) Kaulf.	LP/EP
	Vittaria elongata Sw.	LP/EP
	Vittaria microlepis Hieron	LP/EP
Woodsiaceae	*Diplazium beddomei* C.Chr. †	DF
	Diplazium decurrens Bedd.	DF
	Diplazium dilatatum Bl.	DF

Note: Species in bold letters indicate endemic Pteridophytes. *, + and † indicate introduced, threatened and rare species. Life forms: EP=Epiphytic; LP=Lithophytic; DF=Terrestrial dense forest; TO=Terrestrial open; TB=Terrestrial stream banks.

VOLUME PREDICTION MODELS FOR *Eucalyptus grandis* W. Hill ex Maiden GROWN IN THE UPCOUNTRY OF SRI LANKA

T. Sivananthawerl

Summary

Volume is the most valuable product in a plantation. It can be estimated by different methods. In this study, the stand volumes were estimated according to the Forest Inventory Manual used by the Forest Department, which is still in use to estimate the volumes of eucalypts grown in Sri Lanka.The estimated volume of each tree was regressed with their respective basal area to provide the field officers with some information about the volume without measuring the height of the trees. This relationship was regressed for different beats separately. The beats Dixon Corner and Bambarakele had the R^2 of 0.94 and 0.95 respectively. All the other beats had the R^2 more than 0.97. The beat Bopaththalawa found to be the best volume producer in Nuwara-Eliya division compared to the other beats. Poor volume production was found in Pattipola and Conical Hill. The volume production of other beats was lying within these two limits.Volume prediction was carried out based on the explicit method. Under this method, four different models found to be good to predict the current volume. The best fitted four models with different independent variables have been chosen. Among these four models, which have had the height as the independent variable, showed very high R^2 of 0.99. The fourth model had only R^2 of 0.91.Future volume prediction is another challenge and important procedure to fulfil the economic requirements of a forest stand. In most cases, the predictions are based on the present (current) stand volume. Future volume prediction model was developed for E. grandis *by using the current volume prediction equations, for the same stand (or site), at projection age.*

Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka

INTRODUCTION

In the economic view, the volume and the biomass are the important estimates of the growing stock of a forest stand. Measuring the stand volume directly in the field is a practically difficult process and also it could not be logic to do so. Therefore, volume is mostly predicted or calculated by using other related variables such as basal area, tree height, form factor and in some cases stand age. Basically there are two major ways to predict them. The first method is the stem analysis in which calculations are based on the segmented stems, and the other is by predicting through available volume equations or the volume tables.

METHODOLOGY

Study Area

Sampling was done in seven beats of Nuwara-Eliya division, which were chosen according to the different age categories. As *E. grandis* is grown as plantations, the spacing is already fixed. Randomly selected 20 x 20 m of square plot was sampled for height and dbh. Plot size was re-adjusted according to the slope (slope correction was done), and a minimum of two sampling units was chosen for each stand. A Sunnto clinometer was used to measure the tree height and the heights were taken up to the tip of the tree (total height).

Available Volume Models

The fundamental volume calculation of a single tree (based on the form factor) is the function of dbh, height and form factor. Depends on the end product, stem mass could be expressed either in volume or in weight. Similarly the tree height could be measured either to the tip (total height) or up to the merchantable height. The commonly used measures of stem form (form factor) are ratios of diameters at specified heights to tree dbh. The volume function could be written as:

$$V = f(D,H,F)$$

Where V = Volume, D = dbh, H = Height, and F = Form factor

There are number of volume equations available for *E.grandis*. Interesting element in these equations are the form factors. This is because that the form factors and the increment in the form factors within the diameter ranges are quite different from author to author. Table 1 shows some of the form factors used by various authors and countries. Chen et al. (1996) derived the form factors from 0.44 to 0.60 for the diameter range of 5 to 17 cm. In Sri Lanka, for *E.grandis*, volume function that derived from the form factor given in UNDP/FAO (1969) "Pre-investment study on forest industries development" has been used (Forest Inventory Manual for Sri Lanka, 1996). This function is as follows:

$$V = \left[0.337277 - \left(\frac{0.151178}{d \cdot \pi}\right)\right] \times \left[\frac{\pi \cdot d^2 \cdot h}{40000}\right] \quad (1)$$

Where V= Stem volume, upto top diameter 5 cm (m^2)

d = dbh (cm)

h = Total height (m)

In this study, equation 1 was used to estimate the volume, which has been in practice to predict the volume of *E.grandis* in Sri Lanka. According to table 1, the mean values of the form factors available for different heights and diameters are well above the form factor derived from equation 1, which is 0.336. This estimates the stem volume upto top diameter 5 cm with bark.

RESULTS AND DISCUSSION

Basal Area Prediction

Stand basal area plays the major role in most of the stand volume prediction models. Thus it is necessary to know, "how can one predict the future basal area for the projection of future volume". Hui and Gadow (1993) developed a model to predict the basal area on *Cunninghamia lanceolata* stands, which include the stem number and top height. In this study a modified version of the above model was used to fit the basal area. The variable age was also included in this prediction model. The model is as follows:

$$G = a^2 \cdot N^{\alpha} \cdot H_d^{\beta} \cdot t^{\delta} \quad (2)$$

Table 1: Available Form factors for *E.grandis* (Source: FAO, 1979)

Author / Country	Form Factor at:			
	h10, d10	h15, d15	h20, d20	h30, d30
Chaturvedi & Pande (1973)	0.443	0.429	0.430	0.428
Pande & Jain (1976)–6 yrs of age	0.291	0.402	0.408	0.393
Pande & Jain (1976)–14 yrs of age	0.329	0.444	0.449	0.435
South Africa	0.354	0.410	0.449	-

Where G = Stand basal area (m^2)

N = Number of stems (per ha)

H_d = Top height (m)

t = Age (years)

a, α , β and δ = Model parameters

The Relationship Between Volume and Basal Area of a Single Tree

The relationship between volume and basal area is an important tool for the prediction of the individual tree volume by measuring only the dbh (basal area). In many forest inventories, it is difficult to measure all predictor variables for every tree in each sample plot because of the involvement of different measurement costs. The dbh measurements can be obtained at little expense in almost any timber type. Height measurements are considerably more expensive under the best conditions, and the accurate measurement of heights of tall dense stands could be very difficult. This is a normal routine procedure in forest management especially in the man made forests. In this study, simple linear regression was applied to fit the equation 3, for the data available for different beats.

Table 2: Model parameters for the basal area prediction

Beat	Model Parameter				R^2
	a	α	β	δ	
Bopaththalawa	**0.009425**	**1.115118**	**0.975907**	**0.908601**	**0.79**
Dixon Corner	0.032397	0.810106	0.588776	1.180312	0.98
Kandapola	0.036866	0.048202	3.005972	-0.195145	0.99
Mahakudugala	0.543707	-0.107043	2.009738	-0.578492	0.93
Pattipola	0.034665	0.539768	1.576430	0.552138	0.96

height was included in this model which was found to be more site specific. By considering this fact, the model for predicting basal area was applied for different beats. Due to lack of data points the beats Bambarakele and Conical Hill were not included in the analysis. The parameter values for equation 2 for selected beats are given in table 2.

The same model was applied without considering the site differences. It gave a R^2 value of 0.79. The parameter values were; a=0.129202, a=0.410035, b=1.088433 and d=0.425457. This model could be used to predict the future stand basal area at the projection age based on a particular area or site.

$$V = \beta_0 + \beta_1 \times g \quad (3)$$

Where V= Individual tree volume, upto top diameter 5 cm (m^3)

g = Individual tree basal area (m^2)

β_0 and β_1= Intercept and regression coefficient

The outcome of the fitted regression of this equation for different beats is given in table 3. The fitted lines and the scatter plot for volume and basal area of individual trees are shown in figure 1.

According to the scatter plot in figure 1, there was a huge variation in volume among the sampled beats. All the beats showed very strong relationship between individual tree basal area and their respective volume. The beat Bopaththalawa (B) appears to be the best volume producer compared to the others. Poor volume productions were found in two beats namely Pattipola and Conical Hill (G and C). Within the data range, Bamberakele and Dixon Corner behaved in similar way (A and D). The fitted lines for each beat was extended only within the observed individual tree basal area (dbh). This is to say that no extrapolation was done in figure 1.

Explicit Prediction of Current Volume

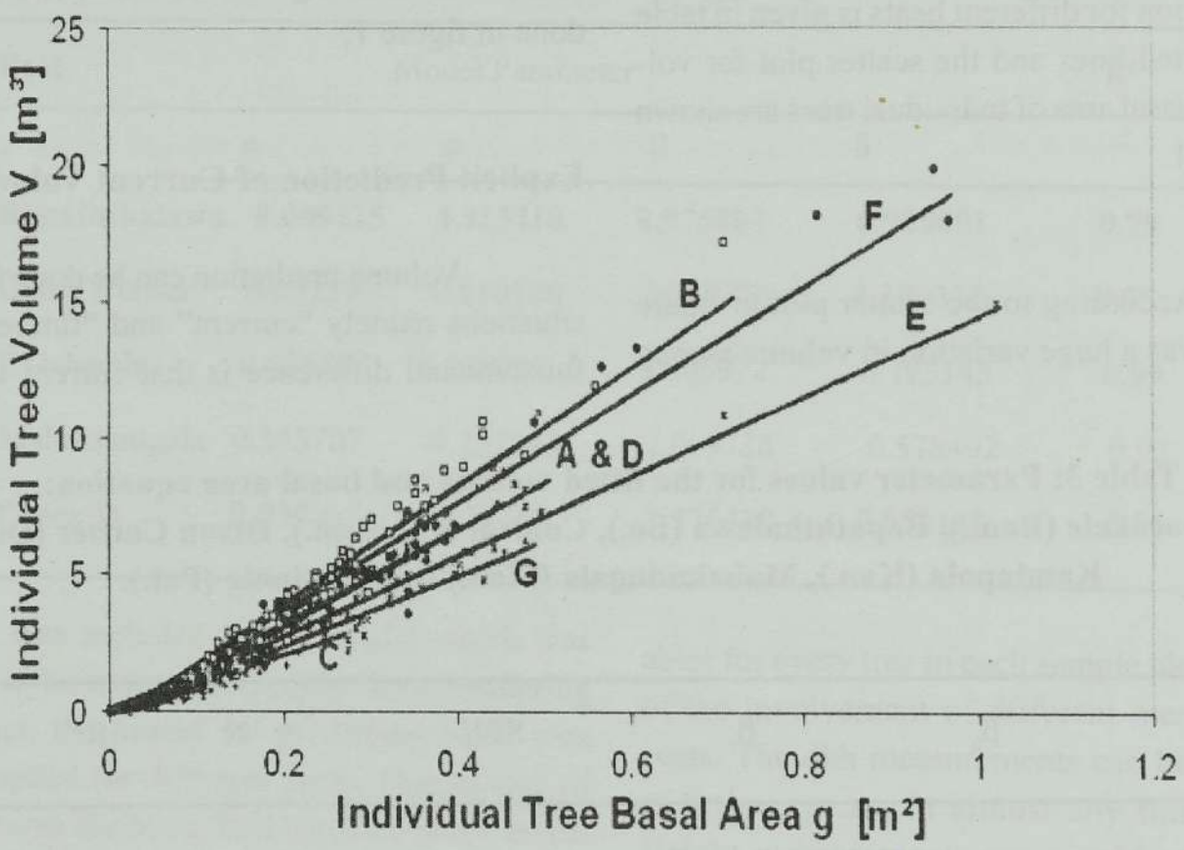
Volume prediction can be done for two situations namely "current" and "future". The fundamental difference is that current volume

Table 3: Parameter values for the fitted volume and basal area equation: Bambarakele (Bam.), Bopaththalawa (Bo.), Conical Hill (Con.), Dixon Corner (Dix.), Kandapola (Kan.), Mahakudugala (Mah.) and Pattipola (Pat.).

Beat	β_0	β_1	SEE	N	R^2
A: Bam.	-0.515380	17.80589	0.444953	85	0.95
B: Bo.	-0.465949	21.70865	0.448506	253	0.97
C: Con.	-0.051670	10.51532	0.054560	253	0.97
D: Dix.	-0.234200	17.13200	0.294909	401	0.94
E: Kan.	-0.219130	14.66672	0.321134	243	0.97
F: Mah.	-0.301360	19.81211	0.284324	541	0.98
G: Pat.	-0.176900	12.71646	0.161513	205	0.97

predictions do not involve a projection of stand density, while predictions of future yield do involve either explicitly or implicitly. Current volume prediction can be divided in to two groups. the volume estimates implied by the predicted structure are calculated from further computations based on the stand structure information (Clutter et al., 1983).

Figure 1: Scatter plot and fitted lines for volume and basal areas of individual trees for different beats: Bambarakele (A), Bopaththalawa (B), Conical Hill (C), Dixon Corner (D), Kandapola (E), Mahakudugala (F) and Pattipola (G).



In the first group, the solution of the equation that comprises the system provides estimates of volume per unit area. This system is called as an explicit prediction systems. The second group is called as implicit prediction system. With this system, solution of the equation involved produces basic information on stand structure. Then

Under explicit system, four different models gave good results (based on R^2) for the prediction of current volume, based on the volume calculated from equation 1. Those models are as follows:

$$V = a \cdot G \cdot H_d \quad (4)$$

$$V = a \cdot G\left[1 - e^{-b \cdot t}\right]^c \quad (5)$$

$$V = a \cdot G \cdot H_d\left[1 - e^{-b \cdot t}\right]^c \quad (6)$$

$$V = a \cdot S \cdot G\left[1 - e^{-b \cdot t}\right]^c \quad (7)$$

Where V = Stand volume (m^3)

G = Stand basal area (m^2)

H_d = Top height (m)

S = Site index (base age30 years)

t = Age (years)

a, b & c = Model parameters

The above models could be used in the forest inventory work or in some other volume predictions, based on the available variables. For example measuring top height is a difficult and time-consuming procedure. Under this circumstance, by using equation 5, one can predict the volume of a known age stand by measuring only dbh. And in case if the site index is known, then the equation 7 is more applicable. If the age of the stand is not known or difficult to project, then the equation 4 could be used. The stand volume (based on the volume table; equation 1), stand basal area, top height, site index and age were used to fit the above models for 47 different stands in 7 beats. The volume of three stands was not included in the model while the values were more than 1000 m^3/ha. The fitted models for *E.grandis* are given below:

$$V = \mathbf{0.3156} \cdot G \cdot H_d$$

(R^2=0.99) (8)

$$V = \mathbf{12.05036} \cdot G\left[1 - e^{-0.130572 \cdot t}\right]^{2.32124}$$

(R^2=0.91) (9)

$$V = \mathbf{0.31853} \cdot G \cdot H_d\left[1 - e^{-0.110504t}\right]^{0.135706}$$

(R^2=0.99) (10)

$$V = \mathbf{0.33865} \cdot S \cdot G\left[1 - e^{-0.115594t}\right]^{1.783651}$$

(R^2=0.99) (11)

These predicted yield equations could be used to any *E.grandis* stand in Sri Lanka. The equations 8, 10 and 11 explained almost 99% of the volume variation, with their stand parameters (basal area, top height or site index, and age). The explained variation of volume in the model where basal area and age are included, were only 91%. The site index used in equation 11 was taken by the average of top heights at reference age 30 years for that particular site class.

Prediction of Future Volume

There are number of models available to predict the future volume of various species. All these explicit future yield prediction models include variables such as basal area, age and/or site index. In most cases the predictions are

based on the present (current) stand volume. Therefore, by solving equation 7 for the same stand (or site) at projection age, one can re-write the equation as follows:

$$V_2 = V_1 \cdot \frac{G_2}{G_1}\left[\frac{[1-e^{-b\cdot t_2}]}{[1-e^{-b\cdot t_1}]}\right]^c \qquad (12)$$

Where V_1 = Current stand volume (m^3)

V_2 = Projected stand volume at the projection age (m^3)

G_1 = Current stand basal area (m^2)

G_2 = Stand basal area at projection age (m^2)

t_1 = Current age (years)

t_2 = Projection age (years)

b & c = Model parameters

In the same way equation 4 and 6 can be re-written to predict the future yield if the top height could be estimated (top height at projection age). By substituting the predicted stand basal area from equation 2, the final equation for the future yield prediction could be written as below (13):

$$V_2 = V_1 \cdot \frac{G_2}{G_1}\left[\frac{[1-e^{-0.13057\cdot t_2}]}{[1-e^{-0.13057\cdot t_1}]}\right]^{2.32124} \qquad (13)$$

Equation 13 could be used to predict the future volume based on the current volume. It is valid under the same site circumstance, i.e., the volume growth of a stand at different age and it could be explained by the above function.

CONCLUSSION

The models developed to predict the current volume could be used depend on the situation and the data available. The height dependent models were performed with high significant R^2 values (0.99). These models are very flexible in the usage. For instance, model 11 can be used in a situation where site index is known. In another occasion if the age of the stand is not known, then the model 8 can be used. The height independent model gave only R^2 of 0.91. These yield functions could be used to any *E.grandis* stands grown in Sri Lanka. Model 13 can be used to predict the future volume of a stand based on the current data.

REFERENCE

Bredenkamp, B. (1984). The Langepan CCT. A Visitors Guide to a Correlated Curve Trend Spacing Experiment in *E.grandis*. Directorate of Forestry, South Africa.

Chen, C.F., Horng, F.W. and Chang, T.Y. (1996). Study on the Growth of Three Eucalyptus Species in Eastern Taiwan. Taiwan Journal of Forest Science. Vol. 11, No. 3, pp 233-238.

Clutter, J.L., Fortson, J.C., Pienaar, L.V., Brister, G.H. and Bailey, R.L. (1983). Timber Management: A Quantitative Approach. John Wiley & Sons, New York, USA.

FAO. (1979). Eucalypts for Planting. Food and Agriculture Organisation of the United Nations, Italy.

Forest Inventory Manual for Sri Lanka. (1996). Forest Department, Ministry of Agriculture, Land and Forestry, Sri Lanka and Overseas Development Administration of the UK.

Helms, J.A. (1998). The Dictionary of Forestry. The Society of American Foresters and CAB International. Bethesda, USA.

Hui, G. Y. and Gadow, K. V. (1993). Zur Modellierungder Bestandesgrund flächenentwicklung dargestellt am Beispiel der Baumart *Cunninghamia lanceolata*. Allg. Forst- u. J. -Ztg., 164 (8): 144-145.

Luna, R.K. (1996). Plantation Trees. International Book Distributors, Dehra Dun, India. pp 350-353.

FIRE RELATED ECOSYSTEM DYNAMICS OF A MOIST DECIDUOUS FOREST IN KERALA

A. R. R. Menon[1] and K. Swarupanandan[1]

Summary

Degradation and desertification of forest areas particularly the moist deciduous forest in India, are mainly due to the recurrent incidence of fire. Fire causes extensive damage in these forests, not only affecting regeneration and stocking ultimately leading to poor productivity, but also interferes in various ways with their functioning. However, the problem of forest fire has not been adequately researched in this country and it is more so with the South Indian moist deciduous forests. Taking into account of this lacuna, the present study was conducted to gain an in-depth understanding of the impact of fire on forest ecosystems and to identify practical methods to minimize the damage. The study, in general deals with the impact of seasonal fire on South Indian moist deciduous forest ecosystem of Western Ghats of Kerala and examines the recuperation ability of the system and also the effect of fire on its various components. The extent of fire tolerance of various tree species and the mechanism of recovery was also studied. The feasibility of silvicultural techniques in improving fire tolerance of tree regeneration was tested by experimental trials. Attempts were also made to standardize the size of planting materials. The final goal of the study was to provide useful information on the nature of damage on the vegetation and to help in identifying management inputs required for designing appropriate fire management strategies. The study area is located in the moist deciduous forests of Thrissur Forest Division, Kerala State. To study the ecological aspects of fire, twelve 0.25 ha plots were established for different burning treatments, viz. *early burn, mid burn and late burn and control with replications. Regenerating elements of tree species (1-10 cm gbh) shrubs (height > 50 cm, and dbh < 1 cm) and herbs were identified, tagged and enumerated in all plots before and after prescribed burn and compared with the control (no burn) plots. It is observed that once the fuel quantity and fuel moisture content exceed a certain limit which is sufficient for occurrence of fire, further change in fire behavior is controlled by fuel porosity and fuel continuity. Other factors, which control the rate of fire spread, are leaf size and thickness, soil moisture regime, wind speed and presence of grass. The results observed after three months, indicate that impact of fire is more on the lower diameter classes (< 5 cm gbh) whereas regeneration of plants (> 5 cm gbh) is less affected. Among the different moist deciduous tree species, those species such as* Gmelina arborea Roxb. *and* Pterocarpus marsupium Roxb. *with thick bark were found to be more resistant to fire.*

[1]*Kerala Forest Research Institute, Peechi 680 653, Thrissur, Kerala, India*

INTRODUCTION

Occurrence of fire is a regular feature in South Indian moist deciduous forests. It is a recurrent annual phenomenon coinciding with the drier periods of the year and hence very often regarded as a normal event in the seasonal cycle (Champion and Seth, 1968). Although uncontrolled fire is an agent of ecosystem degradation, it is considered to be an effective management tool (Brown and Davis, 1973). Planned and prescribed fire allows managers to set the timing and spatial extent of burns in advance of the event. It is in this context, that the effect of fire on ecosystem function and the flora and fauna gains relevance (Saha, 2002).

Forest fire has been viewed upon both for and against. On the positive side, fire cleans the forest floor and thus increases accessibility. It also enables establishment of newly formed recruits (Christensen, 1991). It releases nutrients locked up in the dead and fallen litter. This helps growth of living trees and advances grass growth required for wildlife (Gruell, 1991). All the more, certain forest ecosystems continue to retain the same composition solely because of fire (Champion and Seth, 1968). On the adverse side, depending upon the type and intensity, fire can burn seed and seedlings banks, injure or kill trees of any age or size, affect wildlife population by depleting forage (Boyce and Merrill, 1991), consume or downgrade merchantable timber (Brown and Davis, 1973) and accelerate susceptibility of plants to decay, diseases and pests. It is estimated that in India, an average of 650 fires, affecting over 500 km^2 of forest area, occur every year (Gogate *et al.* 1983).

Fire, when happens in the forest, will produce radical changes so rapidly that the changes in some degree are quite sufficient to form an altered "niche" different from that would have been developed, in the absence of fire (Saha and Howe, 2003). Fire, as a natural factor of environment may contribute positively to maintain the development of forest ecosystems, (Kimmins, 1997). On the other hand, fire may cause injurious effects at any stage of plant development, on soil and animals in the forest, on ecosystem process including energy flow, forest biogeochemistry, and even carbon storage in forest may be considerably altered by fire.

The ecological effect of fire varies greatly based on the time of the year the fire occurred, the quantity, condition and distribution of fuel, prevailing climatic conditions and the severity and intensity of fire (Narendran *et al.* 2008). The slope, aspect and elevation of the area, the type of vegetation etc., are other factors influencing the ecological effect of fire (Kimmins, 1997). Discussion on fire should always specify the type of fire and the condition of factors determining the effect of fire. However, all types of fire can occur under any combination of factors or even altogether at the same time. A crown fire accompanied by both surface and ground fire, results in the total consumption of all organic matter above the soils.

After the fire, primary production is decreased, by the reduction or elimination of plants, and where a fire has reduced the moisture and fertility status of forest, primary production may be depressed for a long time. Alternatively, primary production may be increased by fire because of the changes in species composition and improvement in soil conditions. Primary production of a post-burnt forest is ini-

tially by ephemeral species with little biomass accumulation. These are replaced later by herbaceous and shrubby perennials, in which much of the initial biomass accumulation may be below ground. Burning might influence litter dynamics in the forest ecosystem in the following ways (i) by scorching the canopy (intense burns) and thus affecting the mass and nutrient content of subsequent litterfall (O'Connell *et al.* 1979) ii) by altering the species composition or developmental stage of understorey vegetation iii) by changing the species diversity and activities of soil and litter invertebrates and microflora (Springett, 1976) and iv) by altering the microclimate (temperature and moisture) of the litter layer.

The South Indian moist deciduous forest (Champion and Seth, 1968) is one of the most important forest ecosystems in India. The potential areas under this forest type have been estimated to be 49,750 km^2, which is about 25% of the total forest area of the country (Gadgil and Meher-Homji, 1982). Incidence of fire is a frequent phenomenon in this vegetation type, which is characterized by a number of commercially valuable timbers yielding species. The effect of forest fire on regeneration of selected species in Southern India was studied by Srivastava (2000). Properly planned experimental studies are needed so as to understand the effect of fire, during different periods and varying frequencies, on the moist deciduous forest system.

In the present study an interdisciplinary approach was taken to cover the different aspects of the problem. The major objectives of the present study are (i) to characterize the physical aspects of fire in moist deciduous forests, (ii) to study the changes brought about by fire on soil physical and chemical properties, soil-microorganisms, tree regeneration and litter dynamics in the moist deciduous forest ecosystem, and (iii) to explore the feasibility of silvicultural techniques such as stump planting to improve upon fire survival of tree seedlings.

MATERIAL AND METHODS

Study area

The study area lies between 10° 25'-10° 45'N lat. and 76° 05 –76° 30° E. long. The terrain is undulating with two major hills, Paravattani hill and Moodal hill. The major type of forest in the area is moist deciduous, even though semi evergreen type covers part of the area. The altitudinal range of the site varies from 30 to 900 m. The general direction of the drainage system is of east-west with three major rivers, and the area is will drained.

The total rainfall at Peechi, adjacent to the study site, in 1998 was 2601.3 mm per year. The temperature varied between a minimum of 19.8°C (3rd January 1998) and maximum of 36.7°C (28th March 1998). Month with highest mean temperature was March (29.1°C) and the day with maximum wind speed was 4th August 1998 (9.9m/s). With regard to sunshine, in 1997 the month with maximum sunshine was February (705MJ/m2) and that with minimum sunshine was July (357 MJ/m2). Relative humidity varied with a minimum of 54.3% (February 1998) and maximum of 100% (June-December) with an average minimum of 62.4% (January) and average maximum of 95.3% (July) for the period 1993-1998.. The weather parameters were recorded using an au-

tomatic weather station. The soil is dark brown to dark reddish brown in colour turning reddish yellow down the profile. It is shallow, loose, acidic and with high organic carbon and nutrients.

Vegetation

The moist deciduous forests, as the name denotes, is in leafless condition, especially the upper canopy, during the dry season (January to March). An appreciable number of trees, however, come to new leaf before the onset of the rains. They occur on the lower slopes and on the ridges of rich loamy soils and lateritic areas. Occurrence of fire is common in these areas.

The main species in the canopy are the following: *Albizia odoratissima (L. f.) Benth. Alstonia scholaris (L.) R. Br., Bombax ceiba L., Dalbergia laltifolia, Grewia tiliifolia Vahl, Haldina cordifolia, Lagerstroemia microcarpa Wight,, Miliusa tomentosa (Roxb.) Finet & Gagnep., Pterocarpus marsupium Roxb., Tectona grandis L. f., Terminalia cuneata Roth, Terminalia bellirica (Gaertn.) Roxb.* and *Xylia xylocarpa (Roxb.) Taub..*

The sub canopy consists of species like *Briedelia retusa (L.) A. Juss., Careya arborea Roxb., Cassia fistula L., Gmelina arborea Roxb., Sterculia urens Roxb.* etc. *Acacia caesia (L.) Willd., Caesalpinia bonduc (L.) Roxb., Butea superba L.f. etc;* are the main climbers.

Burning experiments

Burning was initiated by igniting several spots simultaneously along the down slope base line at 11.45 am when the atmospheric humidity was at a minimum and air temperature at ground level was at the maximum. Torches made of coconut leaf were used for the purpose.

The experiment included three burn treatments, early burn, mid burn and late burn, each replicated three times. Early-burn experiment was carried out in three replicate plots *viz.* T6R1, T6R2 and T6R3 during the second week of February 1997, 1998 and 1999. Mid-burn experiment was carried out in T5R1, T5R2 and T5R3 plots in the second week of March 1997, 1998 and 1999. Late burn experiment was applied in T4R1, T4R2 and T4R3 plots on 25th April 1997. For two-year and three year fire frequency studies, experimental plots *viz.* T3R1, T3R2 and T3R3 were subjected to prescribed fire during the second year (*i.e.* 1998) owing to little difference with regard to fire behavior and its ecological impacts when compared with midburn experiment.

Early burn experiment

The first application of prescribed early burn was applied to the treatment plot T6R2 on 31st January 1997. But, the experiment could not be performed, as the litter moisture content was high. The trial was conducted on 19 February 1997 with the replicate sample plots T6R1, T6R2 and T6R3; subsequently repeated in the second week of February in 1998 and 1999.

Mid burn experiment

Three triplicate; *viz.*, T5R1, T5R2 and T5R3 were subjected to prescribed midburn during March 1997 and 1998 (middle of the dry season in Kerala.)

Late burn experiment

The prescribed late-burn treatment was carried out with three replicate plots *viz.* T4R1, T4R2 and T4R3 with the objective of comparing its impacts to that of early-burn and mid-burn treatments. The burning was conducted in 25th April 1997.

Fire line clearing

Prior to burning, fire lines (3m width) around the replicate plots were cleared by burning litter.

Burning procedure

The burning was initiated by igniting several spots simultaneously along the down-slope base line at 12 noon, when the atmospheric humidity was at a minimum.

Fire temperature

Thin foils of metals, of the size 1 cm x 8.5 cm were used for temperature measurement. The metals used (50 numbers each) were copper, silver zinc, lead and tin. The metal foils were tied on to a wooden post at 10cm. height from the ground using GI wire. After burning, the metal pieces were taken out and observed (Table 1).

Weather

Atmospheric temperature and humidity were measured using a hygrothermograph, since January, 1997.

Litter load

The total quantity of litter on the ground available for burning was calculated by drawing the litter from two randomly selected

Table 1: Impact of early-burn on different metal foils

No.	Metal	Melting point (°C)	Impact on burning
1.	Tin (Sn)	231.9	Burned out
2.	Lead (Pb)	327.4	Burned out
3.	Zinc (Zn)	419.5	Burned out
4.	Silver (Ag)	960.8	Burned out
5.	Copper (Cu)	1083	Not burned out

samples of 1 m^2 area in each 0.25 ha plot before control burning in the month of February 1997, 1998 and 1999 with two replications. Samples were weighed and moisture content determined after oven drying at 25° C for 5 days to evaluate its porogenicity. The total quantum of litter on the ground available for burning was calculated after oven drying.

Flame height measurement

In order to measure flame height, 2 m long wooden sticks painted with yellow enamel paint were used so that charring could be detected on the clear yellow background. These sticks were placed randomly at six points at 1.5 m apart, in each plot. However, this method was found not very satisfactory, as the flames charred only the lower 10-15 cm.

Vegetation study

Conventional phytosociologial methods framed within proper statistical designs were used for studying different vegetation strata. The details were as follows:

a. As a follow up of the establishment of the plots for study, more than 18,000 tree regeneration in the 18 quarter-hectare plots (3 replicates during 1997,1998 and 1998; 3 treatments viz. early burn, mid burn and late burn; 2 enumeration each viz. before burn and after burn) were tagged and completely enumerated. All damaged stems were marked, so that recovery after burning can be detected.

b. Trees having $\geq$ 30 cm gbh in the sample plots were identified, gbh measured and recorded for the entire area of the burned replicate after one month.

c. Shrubs with > 50 cm height and < 3 cm gbh were identified; height was measured and recorded in five randomly selected 4 m x 5 m quadrates in each of the 0.25 ha plots.

d. For enumeration of herbs, six 1 m x 1 m quadrates were demarcated in each of 0.25 ha sample plots. Plants with <50 cm height were identified, and recorded.

e. The enumeration data were analyzed for various ecological parameters using suitable computer programs.

RESULTS

Early burning process

Fire spreads out from individual spots and converged to a continuous moving front, thus creating a creeping ground fire spread by upward. Spatial heterogeneity of fuel load and topographic variation of land surface caused certain portions of the line to advance faster, thus making a rather irregular moving front.

Although the weather was calm, occasional winds swept hot gases across the moving front of the fire and contributed to heating of the fuel immediately ahead of the burning edge.

The average macroscopic flame height varied from 15cm to 150 cm in accordance with the quality and quantity of the fuel. The ignition of grasses present in canopy open-

ings occasionally increased the flame height at isolated points and the fire became turbulent. In the case of *Cycas circinalis* trees *the* drooping dry leaves of the previous year always carried the flame to the top of the tree. Thus, trees of three meter height burned right to the top its crown.

The rate of spread of fire changed directly with quantity and moisture content of fuel and to a lesser extent with wind velocity. In the plot T6R3, where the canopy was almost naked without any foliage, the combustible material load was comparatively high and the fire crossed 50 m, along the elevation gradient in 35 minutes (approximately 42 sec\m).

The effect of burning on metal foils is given in Table 1. Except copper, all other metals melted away, inferring that the approximate average temperature at 1-10 cm above the ground was more than 960^0 C. Latter, in a separate experiment, using indigenously designed electronic equipment it was inferred that the approximate average temperature at 1-10 cm above the ground was less than 980^o C.

Interestingly, in the plots T6R1 and T6R2 occasionally fire cooled down and extinguished the flame leaving un-burnt fuel in the form of several fire escape lands. In third replication plot T6R3, the area of the fire escape islands was less than one per cent against 20 percent in the other replicates T6R1 and T6R2.

As the litter load was comparatively less, the ground fire extinguished automatically as it reached the fire lines. Very rarely a piece of fallen bark continued to burn for a few minutes or continued to produce smoke for a while, even after the plot was completely burned up.

Status of the vegetation before the Burn

The plot T6R3 carried a total of 35 trees (gbh >30cm) with dominance of *Grewia tilieafolia* (34%) and *Bombax ceiba* (28%). Other important species were *Dillenia pentagyana, Lagerstroemia microcarpa, Xylia xylocarpa* and *Cordia sp*. The plot T6R2 supported 20 trees, most abundant species being *Xylia xylocarpa* (35%) and *Lagerstroemia microcarpa* (20%). The plot T6R1 consisted of 23 trees, the dominant species being *Xylia xylocarpa* (26%) and *Grewia tileafolia* (26%). The remaining trees in the T6R1 plot were composed of *Terminalia paniculata. Lagerstroemia microcarpa, Bombax ceiba, Albizia procera* and *Dillenia pentagyna*. The effect of fire on woody regenerations was given in table 2.

The status of dried plants is given in figure1.

Grewia, Bombax and *Dillenia* began their leaf shedding early, by the last week of December. Both the species completed leaf fall by the end of January, while *Dillenia* continued the process till the end of February.

The shrub layers in all the plots were thick with more than 50 percent green foliage on them before burn in January.

The plots T6R1 and T6R2, owing to higher tree density, much of the ground cover comprised of herbs which remained green under the canopy. The third plot (T6R3) differed from the rest with almost naked canopy having very little of green foliage.

The average litter load turned out to be 535 g/m^2.

The maximum temperature recorded in the hygrothermograph was 37.78°C. The relative humidity oscillated between a maximum of 97 and minimum of 45 within an year.

Status of the vegetation after the Burn

Prior to burning, the ground layer of herbaceous vegetation was green, but were completely relished along with the litter, by the fire, except the few that remained in fire escape islands.

The seedlings of arborescent and other species (including that of shrubs) with a stem width up to 3mm were almost completely wiped out. The survival of species, with a root collar diameter >1cm were not affected, especially that of arborescent species. The stems of trees were most affected between 1-10 cm above the ground, the bark having been charred out.

The foliage of shrubs and tree regeneration between 30-90 cm above the ground were almost completely burnt out, leaves of upper regions dried up and curled. This created a magnificent ground clearance. The foliage of most of the shrubs was almost intact, 1-1.5m above the ground. The foliage of *Strychnos nuxvomica* was seen badly affected; up to a height of 2-3 m above the ground and the leaves became curled and brittle.

Mid burning process

Fire behavior

From the point of ignition, fire radiated in all directions and met fronts from neighboring points of ignition, becoming a continuous moving line of fire. This spread uphill thus forming a slow moving surface fire.

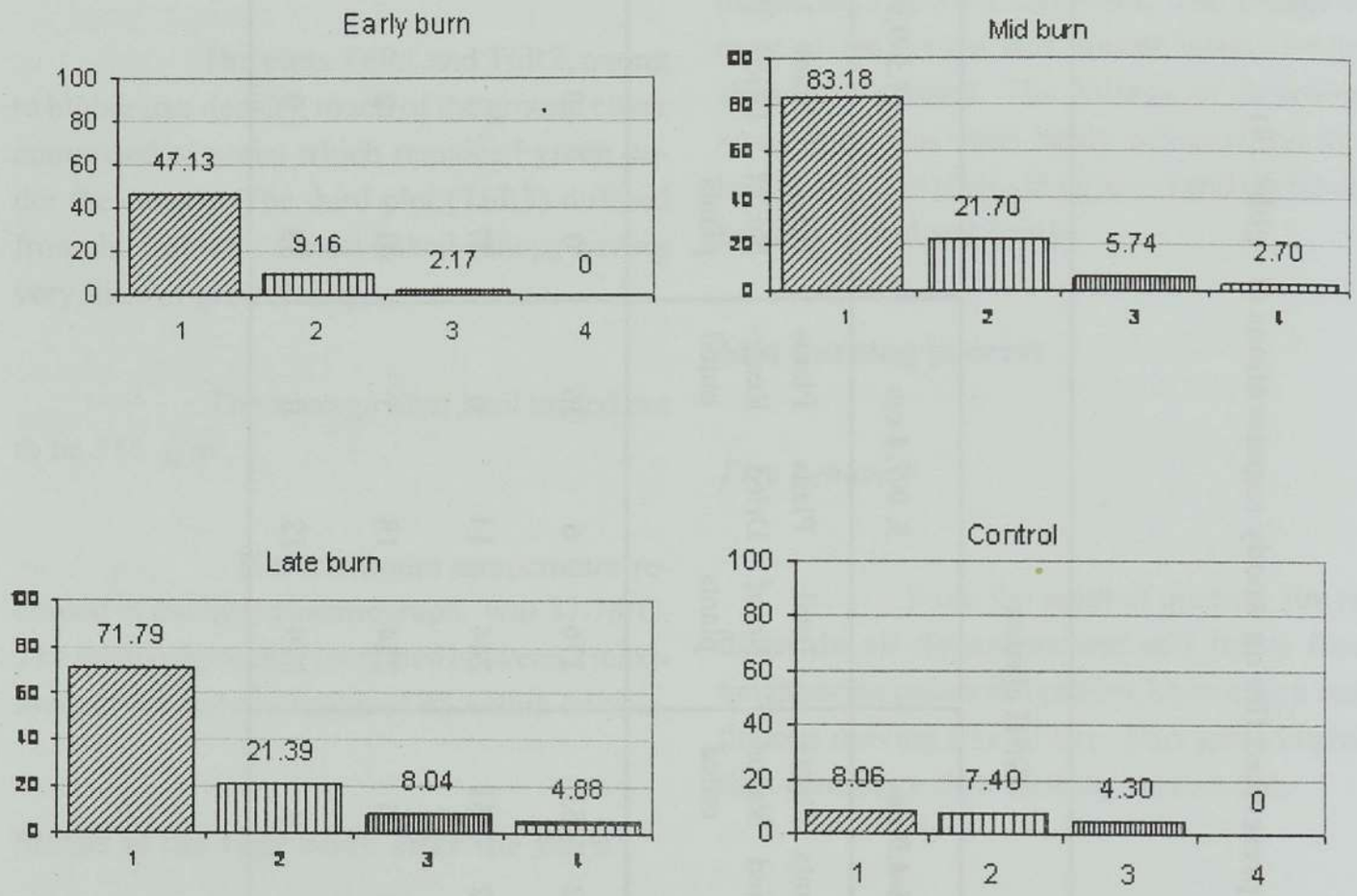
In the first and second replicate plots, fire spread slowly, over the gently slopping terrain with constant speed. However, occasional wind swept along supporting and across retarding the direction of fire. Interestingly, the plot T5R3 with thick layer of ground fuel (and dried herbage and grasses) favored the quick spread of fire. The fire crossed 50 m across the contour in 23 minutes.

In certain areas, flame reached up to the top of shrub layer through dried climbers and it continued for a while. The average time taken by the mid season fire to cover the distance of 50 m was only 53.6 minutes. This is far

Table 2: Effect of prescribed fire on woody regenerations (1 <gbh< 10)

Treatments	GBH classes											
	1-2.4 cm			2.5-4.9 cm			5. 0-7.4 cm			7.5-9.9 cm		
	Total No.of Plants (0.25ha)	Plant Dried	Plants Respr-outed	Total No.of plants	Plants Dried	Plants Respr-outed	Total No.of plants	Plans Dried	Plants Respr-outed	Total No. of plants	Plant Dried	Plants Respr-Outed
Early- burn	2209	1041	875	1223	112	63	276	6	36	0	0	0
Mid- burn	1587	1320	1136	1023	222	151	244	14	6	37	1	0
Late-burn	1404	1008	757	879	188	95	224	18	5	41	2	0
Control	1663	134	31	1014	75	9	279	12	0	33	0	0

Figure 1 . Relative density of naturally regenerated species



(gbh class 1= 1-2.4 cm, 2= 2.5-4.9, 3= 5.0-7.4, 4= 7.5-9.9; values in %)

slower, compared to the speed of fire in the early-burn treatment (approximately 85 min.).

The major driving forces behind the rate of fire spread was seemed to be the higher volume of fuel and its continuity over the terrain. In the plots T5R1 and T5R2, a large portion of the fuel bed was composed of the leaves of *X. xylocarpa, G. tileafolia* and *L. microcarpa*.

These leaves are comparatively smaller in size and on drying they became curled and brittle and thus formed a compact layer. In some isolated pockets, curling of larger leaves such as that of *D. pentagyna, T. bellirica, Ficus* sp. *etc.*, after drying led to the discontinuity of fuel bed. In such areas fire intensity and speed of spread was low. Fire was most intense and spread last wherever fuel porosity was optimum.

In certain points, sufficient fuel thickness and the presence of large sized twigs created a rugged fire front.

It was observed from the experiment that once the quantity and the moisture content of the fuel crossed a certain level, further changes in fire behavior, determined by fuel porosity and its continuity. Presence of grasses and larger herbs like *Eupatorium* are other factors which creates large turbulent fires.

Wind accelerated the fire spread rate when it swept along the direction of moving front, especially in areas where the fuel porosity was at a maximum. In compact litter layers wind helped burning of the entire litter by penetrating the flame into deeper layers, otherwise only the top layer was burnt. This may be due to the persistence of moisture in the bottom layers of litter. This was observed mainly in areas where litter of *Xylocarpa* was preponderant.

Flame height varied from 1.5 cm to 200 cm above the ground level and flame height was influenced by the following:

(i) Vertical arrangement of the fuel and the thickness of fuel on ground.

(ii) Burning of partially or fully dried up standing fuels permitted flames to reach 2 m height.

(iii) Thick litter layer accumulated in depressions on the ground.

(iv) Grassy patches and bushes of *Chromolaena*, generated gigantic flames to about 6 m height.

(v) Wind also influenced flame height.

The fuel discontinuity at certain points on the ground favored the formation of the fire escape islands in the litter. In the compact litter layer, water vapor formed by fuel burning displaced air surrounding the fuel and extinguished the fire, thus forming fire escape islands. Presence of large size twigs, fuel moisture and wind direction were other factors which contributed to the formation of these islands.

Composition of the stands

The plot T5R1 consisted of total of 32 trees, with the average gbh of 151 cm. Of these, 18.7 percent trees were of *X. xylocarpa*, 15.6% of *D. pentagyna* and 12% of *G. tileafolia* .The second replicate plot (T5R2) supported twenty trees with dominance of *X. xylocarpa* (30%), *G. tileafolia* (20%) and *B. ceiba* (10%). The average tree gbh was 148.7 cm. The plot T5R3 carried very few trees with average gbh 119cm. The tree species were mainly *B. ceiba* (29.4%), *G. tileafolia* (23.5%), and *T. paniculata* (11%). Two large sized trees of *T. bellirica* located near the outer boundaries of the plot T5R3 also contributed a considerable amount of litter at these sites.

Most of the trees are in their defoliation stage in August-September and a few of them were flushing. *Xylia* and *Dillenia* had initiated flowering, after the leaf shedding.

The shrub layer comprising mainly of *Helicteres isora* and *Wrightia tinctoria,* had shed their foliage completely. In the plot T5R3, lianas (*Calycopteris floribunda Lam.*) covered the roof of the shrub canopy and remained green and leafy. *Chromolaena odorata (L.) King & Robins.* and *Hibiscus* sp. occupied the canopy openings up to the height of 1.5 m to 2 m above the ground. Both species were at various stages of wilting due to soil water shortage.

Herbs and grasses occupying canopy gaps had a dried up, while some herbs under tree crowns remained green.

The average litter load was found to be 934 g/m^2

The average maximum temperature recorded during the study period was 37°C and the minimum temperature was 27°C. The relative humidity ranged from 51% to 98% during the burning week.

All herbs and grasses burnt out together with the ground fuel. Tree regeneration <50 cm height were killed by the surface fire. The foliage of smaller trees and shrubs up to 2 m height were dried up and curled. Where flame height reached 5-6 m, leaves of 10 m tall canopy trees dried up and remained attached to the trees for 2 days after the burn. Dead and peeled bark, especially of Lagerstroemia *microcarpa* burnt quickly.

Late burning process

Fire behavior

The fires lighted at several spots on the baseline at the lower slope of the plot spread upward hill, thus forming a continuous front. This surface fire spreading very slowly in the beginning, gained momentum on heating the fuels ahead. Trunks and branches of fallen trees, sufficiently dry, was subject to the fire. Fire took only 52 minutes to cover a distance of 50 m along the elevation gradient.

In all three replicate plots, ground phytomass was comparatively thick and more than that seen in previous treatments. The phytomass consisting of fallen dead leaves, twigs, fruits, and seeds were completely dried and compacted, and decomposed at the bottom layer. This reduced the total fuel porosity, which retarded the rate of fire spread. Protruding rocks and freshly fallen twigs were also responsible to slow the fast moving fire.

Fire spread a little faster than in the mid-season burn, in the absence of heavy fuel loads. When the thicker fuel ignited, fire was sustained there for a longer period; where much of the surface litter was burnt and the soil was exposed. In plot T4R1, a fallen tree of *Xylocarpa* burnt fiercely, consuming most of the fuel available at the site. This type of strong fire brought more damage to the micro ecosystem. In certain areas fire propagated on ground, spread to the upper level of standing fuels, through ladder fuels, such as lianas and droop-

ing leaves of *Cycus* plants. Pealing bark of the *Lagerstromia microcarpa* burnt easily lifting the surface fire few feet above the ground along the trunk. Thus, the bulk quantity of the component species plays a key role in the spread of fire.

The observations on the plot T3R2 (burnt in two consecutive years) was quite different from rest of the plot of same treatment which also burnt on the same day (29 April 97). The better soil moisture regime associated with thick undergrowth was peculiar to this plot. Though, the plot had a thick litter layer on the ground it failed to produce a continuous fire. The litter layer here generated a mosaic of burnt and unburned patches, which gave the appearance of an early burn plot. This kind of fire appeared to be non lethal to tree regeneration. In this plot, fire covered a distance of 50 m in two hours compared to 50 minutes in the two other plots. All the replicates failed to generate a spreading fire on cloudy day even during the noon time.

Flame height in the late burn varied between 20 cm to 200 cm. Burning of fallen trees and dried herbs lifted the flame to a height of 5 m. Fire spread with a minimum flame height over the fuel bed, comprised of leaves of *Xylia, Dalbergia, Lagerstroemia* etc., whereas presence of large sized leaves such as *Dillenia, Terminalia*, etc. could increase the flame to 2 m height. The percentage of fire escape islands was negligible as compared to the early-burn treatment probably due to low soil moisture content.

Except copper all other metal foils used for labeling melted. Burning of wood might have produced very high temperature which could not be measured.

Composition of stands

In all the three replicate plots *X. xylocarpa* was the dominant species, interspersed with *D. pentagyna, G. titliaefolia, B. ceiba. Lagerstroemia microcarpa, Terminalia paniculata* and *Rademacheria xylocarpa.* They contributed considerable amount of litter to the fuel bed.

Plot T4R1 supported a total of 25 trees with average gbh of 136.3 cm. The second and third replicate plot (T4R2, T4R3) also supported 25 and 26 trees respectively, but slightly higher average gbh (166.5 and 164.5 cm).

Except *Dillenia pentagyna* and *Bombax ceiba* all other tree species of the upper storey had started sprouting and formed a thin canopy cover after the burn.

Plots with higher canopy closure hindered direct sun light reaching the fuel bed. Bamboos had shed most of their leaves and only had a woody skeleton.

Helicteres isora, Wrightia tinctoria and *Hollarrhena antidysenterica* which comprised major part of the shrub layer and a liana community covered the dried shrubs.

Figure 2: Effect of burning treatments on regeneration

(< 1 cm gbh & > 50 cm height)

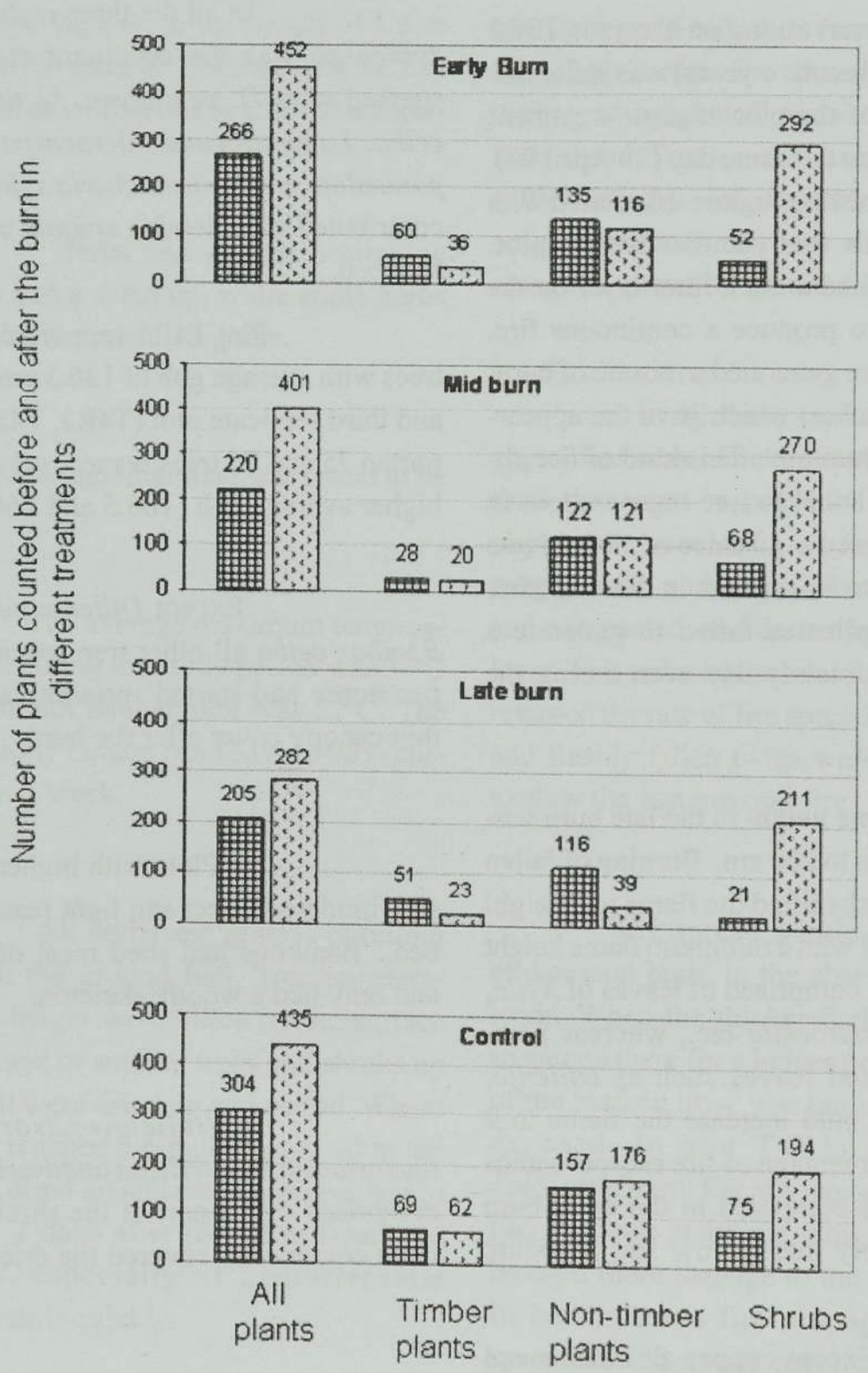


Table 4: Effect of burning treatments on regeneration (< 50 cm height)

(1st & last strips were excluded to avoid edge effect)

Burning treatments	Total number of plants	Number of species	Number of Timber plants	Number of non timber plants	Number of shrubs & herbs	Number of grasses
Early-burn						
Before burn	233	26	5	7	211	10
After burn	475	34	17	42	337	79
Mid-burn						
Before burn	192	28	3	15	166	8
After burn	338	33	2	29	260	45
Late-burn						
Before burn	228	28	5 5	186	30	
After burn	280	34	10	19	204	27
Control						
First year	158	24	2	14	139	—
Second year	224	22	6	15	177	23

Herb growth was comparatively poor and most had dried. Very few that sustained healthy aerial shoots were beneath a thick canopy.

The average weight of the ground fuel drawn from 1 m^2 area randomly was 917.133 g /m^2. It was slightly less than that obtained before the mid season burn.

Daily atmospheric temperature fluctuated from a minimum of 29°C to a maximum of 37°C. Relative humidity varied between 57-98%. Wind was calm and did not affect much the rate of fire spread much.

Burning and vegetation

Burning procedure was same as that followed for early burn and mid-burn treatments. All herbaceous forms and tree regeneration burned to a height of 1 m. Newly emerged leaves of shrubs and small trees dropped and curled after the fire. Burning of fallen trunk and branches in T4R1 plot wiped out all plants form present in its immediate surroundings and created a wide gap of about 1000 sq. m.

Of 1663 tree seedlings of size 1-2.5cm gbh, tagged in the control plots, only 8% of seedlings dried naturally and 23% of the total

tal that dried resprouted from underground stems during the next growing season (rainy season). In the early-burn treatment plots out of 2209 seedlings tagged, (belonged to 1-2.5cm gbh class) 47% dried after the fire. Of these 84% of regenerated seedlings resprouted from the underground stem in the next rainy season. In mid-burn treatment plots of the 1587 regenerated seedlings, 83% got dried up, 86% resprouted. In late-burn plots, of the total of 1404 regenerations tagged belonged to the above class, 72% were dried and 75% resprouted (Fig.2).

The total number of seedlings that regenerated after fire showed more than 100% increase compared with number of plants recorded before fire. Early-burn and mid-burn plots showed a significant difference compared with the control, whereas in late-burn plots, increase in number of plants was less, than that recorded in control plots.

The total number of species recorded was markedly higher after fire in the early-burn and only by one species in the mid-burn plots. Late burn and control plots showed a decline in species richness. It was observed that in all treatments, seedlings of economically imported tree species declined in number after the fire (second year). Again, this difference was more significant in early-burn and mid-burn plots.

The total number of regenerations recorded after fire showed an apparent increase in abundance; however it was more reflected in early-burn and mid-burn plots compared with control plots. Interestingly, late-burn plots showed a marginal; reduction compared with that in the control. Except control treatment, all other treatments showed a significant increase in number of herbaceous species after fire (second year). It is observed that prescribed fire carried out in the early summer season was found to support the germination of tree species. However it was more favorable for non economic tree species than economic trees. Burning also favored the growth of grasses in all plots.

CONCLUSION

Results of the experiment clearly indicate that impact of the fire is more pronounced in lower diameter classes (1-2.5cm & 2.6-5cm), whereas regenerations above 5 cm gbh as poorly affected. Prescribed burning carried out in the early summer season was found to cause minimum damage compared with that conducted in mid and late summer months. Natural death of seedlings in control plots are due to fungal attack and falling of tree branches.

ACKNOWLEDGEMENTS

We appreciate the financial assistance and co-operation extended by the Ministry of Environment and Forest, New Delhi. Authors are also grateful to the officials of the Kerala Forest Department for permitting to establish the plots and conduct the study in the forests of Kerala.

REFERENCES

Boyee, M..S and Merill, E.H. (1991.)Effects of the 1988 fires on Angulates in Yellowstone National park. *Proc. Tall Timbers Fire Ecol.*

Conf. 17: 121 - 132.

Brown, A.A. and Davis, K.P. (1973.) *Forest fire: control and use.* McGraw-Hill, New York.

Champion, H.G. and Seth, S.K. (1968.) *A revised survey of the forest types of India.* Manager of Publications, Delhi.

Christensen, N.L., (1991.) Wilderness and high intensity fire: how much is enough. *Proc.Tall Timbers Fire Ecol. conf.17:* 143-147.

Gadgil, M.and Mehr-Homji, V.M. (1982.) *Conserving India's Biological Diveristy.* Dept. Environment. Govt.of India (mimeograph).

Gogate, M.G., Mital, R.C. and Lal, P. (1983.) Fire break maintenance in India: a preliminary study on efficiency, suitability and economics of the back-pack blower (Model KW1 + 664) and Power blade fire break. *Indian For. 109:*91-100.

Gruell, G.E. (1991.) Historical perspective: a prerequisite for better public understanding of fire management challenger. *Proc. Tall Timbers Fire Ecol. Conf. 17:* 24-41.

Kimmins, J.P. (1997.) *Forest Ecology. A foundation for sustainable management* Second edition. Prentice Hall. New Jercy. 596.

Narendran Kodandapania, Mark A. Cochraneb and R. Sukumar. (2008.) A comparative analysis of spatial, temporal and ecological characteristics of forest fires in seasonally dry tropical ecosystems in the Western Ghats, India. *Ecology and Management 256: No4.* pp 607-617.

O'Connell, A.M., T.S. Grove, and D. Lamb. (1981.) The influence of fire on the nutrition of Australian forests. In (Walker, J and Reuter, D) : *Proc. Aust. Forest Nutrition Workshop.* CSIRO, Melbourne. Pp.277-289.

Saha, S. (2002.) Anthropgenic fire regime in a tropical deciduous forest of central India. *Current Science 82;* 101-104.

Saha, S. and H.F.Howe. (2003.) Species composition and fire in a dry deciduous forest. *Ecology 84:* 3118-3123.

Srivastava, R. (2000.) Forest fires causing poor stocking of *Santalam album* and *Terminalia chebula* in Southern India. *International Forest Fire News 22:* 28-30.

Springett, J.A. (1976.) The effects of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. *Aust. J. Ecol. 1:*77-82.

APPRECIATION

W.B.J. DE SILVA
Assistant Conservator of Forests

Mr. Basil Joseph De Silva born in Moratuwa in 1945 and had his secondary education at St Sebastian's College Mortuwa which was one of the leading schools in the country during that time. He represented Cricket and Soccer at the college team. After qualifying with his General Certificate of Education in science stream in English medium he joined the Forest Department as a Probationary Forest Ranger on 11th June 1966. After completion of the probation period, he had his two year Forest Ranger's Training at Southern Forest Rangers College at Coimbatore in India in the year 1969-1971.

Basil returned with the Highest Standard Certificate of the Course, after completion of training in India. Then he was posted to Pullumale Range. Thereafter he was in charge of Batticaloa, and Kurunegala Ranges for a long period. Then he was in charge of new reforestation programme of Matale under IRDP where he was instrumental to pioneer the Pine planting in the Matale hills. Subsequently in year 1973, a new range was opened in Matale and Basil was placed in charge of the new range.

In 1975, Basil was promoted as a Forester and posted to the Division of Forest Protection and Law Enforcement at the Forest Department Head Office to assist the Deputy Conservator of Forest.
Basil was seconded for service to the Plywood Corporation where he held a Senior Executive Position as the Manager Timber Supplies.

Basil was promoted as Assistant Conservator in year 1986 and was posted as the Project Manager at the Community Forestry Project based in Badulla. Subsequently, he was in charge of Kalutara Districts as Divisional Forest Officer for a long period. Basil had his training at the University of Georgia USA, in Forestry Extension. During his period before the retirement Basil was the Assistant Conservator in the Silviculture branch. Basil was a keen, devoted and a very hard working personal during his carrier in the Forest Department. He was a pleasant superior to his subordinates and was an asset to his superiors and especially to Forest Department. He was a very popular friend among all his colleagues.

At his retirement from Forest Department, Basil was selected as an Investigation Manager of the Water Supply and Drainage Board where he detected a large number of frauds. Besides these, he was an Inquiry Officer of the Disciplinary cases appointed by the Ministry of Public Administration.

Apart from all these achievements, Basil was an active member of the *Association of Retired Professional Foresters* since 2002. He was selected as the Treasurer of the Association in 2004 and offered an enormous contribution to the success of the association until his demise in 2009.

May he rest in Peace.

- Association of Retired Professional Foresters

GUIDELINES FOR AUTHORS

The Sri Lanka Forester is a scientific journal published by the Sri Lanka Forest Department and devoted to forestry (in a broad sense) in Sri Lanka. Articles are published subjected to the approval of the Editorial Board whose current members are listed in the front pages of each issue. Particular articles may also be submitted to appropriate scientific referees. Acceptance does not imply that any opinions expressed by the authors are shared by the Board , Forest Department, or the Government of Sri Lanka. Articles are subjected to editing; the final version will usually be sent to the author, or to one of the authors for approval before printing.

Articles must be originals. If they have been published elsewhere, either in the same or another language, or if there is any intention of submitting them for publication elsewhere, this must be stated. Generally they should record the the results of new studies; this may include reviews or compilations of older work by same authors or by others. Quotations , or the incorporation of parts of other peoples work must always be acknowledged and permission obtained when approprioate.

Your article must be in accordance with our format. It may contain an Abstract/ Summary, Introduction, Methodology, Results, Discussion, Conclusion , Acknowledgements & References.

Articles may vary in length between 3500-4000 words. It should be submitted in a diskette preferably in MS word format. You may also e-mail your article to ***forlib@ sltnet .lk*** *Illustrations of all kinds (photographs, drawings, maps, graphs, tables) can be printed and their use is encouraged, except that for reasons of economy colour should only be used if it serves a purpose. All of these should be prepared in such a way that they can easily be fitted to B5 page size.*

Printed & Designed by:
Art Printers 09, Jayanthawerasekera Mawatha, Colombo 10. Tel 2327575
E-mail: artprinters9@yahoo.com