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Stock assessment and yield regulation for teak plantations in Kerala

(Final Report of the project KFRI 591/2010)

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Project proposal in brief

1. Project number	:	KFRI 591/2010
2. Title of the project	:	Stock assessment and yield regulation for teak plantations in Kerala
3. Objective	:	1. To evaluate the status of teak plantations in the State and to identify plantations of poor stocking and site quality. 2. To devise a scheme for yield regulation of teak plantations in Kerala
4. Expected outcome	:	1. Information on the present status and expected future returns with respect to each teak plantation in the State excluding those in wildlife sanctuaries. 2. A scheme for yield regulation/harvest schedule for teak plantations in the State.
5. Date of commencement	:	March 2010
6. Scheduled date of completion	:	February 2011 (Originally proposed) (Extension requested for six months i.e., up to August 2011 without additional funding) Further extension requested for 6 months from September 2011 to February 2012 with request for additional funding)
7. Funding agency	:	Kerala Forest Department
8. Project team		
Principal Investigator	:	Dr. K. Jayaraman
Associate Investigator	:	Dr. B. Shivaraju

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Abstract

The status of teak plantations in the Territorial Forest Divisions under the management of Kerala Forest Department was assessed with respect to the site quality distribution and stocking and the current levels of productivity were ascertained. The plantations of teak and teak mixed with other species as of the year 2011 were covered. Each plantation was evaluated through a systematic sampling plan using sample plots along transects. Measurements were taken from plots of size 24 m x 24 m laid along randomly placed transects in the plantations. The total extent of teak plantations was 56,509.45 ha as of 2011. Nearly 85 per cent of the plantations were above 30 years of age.

An assessment of site quality distribution of the area showed that only 3 per cent of the area belonged to site quality class I. Nearly 33 per cent of the area was of site quality class II and 56 per cent was of site quality class III. Around 8 per cent of the area fell under site quality class IV. There was considerable variation in site quality distribution over the different Divisions. Nemmara and South Nilambur Divisions recorded a good share of area under better site quality classes (SQ I and SQ II) whereas Thiruvananthapuram, Waynad, Ranni, Kottayam and Kothamanagalam had larger area under poorer site quality classes.

The evaluation of stocking status based on basal area ignoring miscellaneous growth revealed that, nearly 15 per cent of the plantation area was under-stocked, 47 per cent fully stocked and 38 per cent over-stocked indicating that the growth was poor in many plantations in the State. The corresponding figures based on number of trees were 7, 24 and 69 per cent. Thus the over-stocking was found partly due to the presence of larger number of trees in the stand rather than due to the better growth of trees. Based on basal area density, under-stocked plantations were more common in North Nilambur, Munnar, Thenmala and Malayattoor Divisions. The case of over-stocked plantations occurred more frequently in Ranni, Punalur and Kannur.

This in turn reflected in the MAI of commercial volume attained in these Divisions. The average MAI of maincrop came to 2.42 m^3 ha^{-1} at 60 years. This value is based on the standing volume of trees and thus excludes yield from thinning. Considering the values of MAI obtained, three productivity classes were identified viz., MAI < 2 m^3 ha^{-1}, MAI of 2-3 m^3 ha^{-1}, MAI >3 m^3 ha^{-1}. None of the Divisions qualified for the high productivity group. The low productivity group included North Wayanad, South Wayanad, Kottayam and Thiruvananthapuram Divisions. The rest of the Divisions fell into the medium group. The middle group is the one which is supposed to respond to treatment and holds promise for the future.

A comparison with potential MAI of 4.968 m^3 ha^{-1} at 60 years under site quality class I with full stocking, as reported in the All India Yield Table for teak indicated the wide gap between the actual and potential yield levels. Nearly 89 per cent of the area falling under site quality classes II and III qualifies for improvement.

The estimates of growing stock of teak in terms of timber and smallwood for plantations under reference in the State were found to be 4.265 million m^3 of timber and 2.569 million m^3 of smallwood in 56,344.24 ha excluding 165.21 ha in age group 0-4 years. The overall proportion of miscellaneous species in teak plantations in the State was found to be less than 7 per cent.

An attempt was made to work out the maximum sustainable harvest level from teak plantations in the State based on the age structure. Only the area having the stands younger than 75 years was considered for the simulations which came to 56,456.15 ha. After repeated simulations the current age structure and area was found to sustain a yield level of 138,000 m^3 annually, inclusive of timber and smallwood under a rotation age of 60 years. The plantations reached a stable age class distribution after 100 years. The total effective area of 65,539 ha of Standard II/III site class under the Territorial Wing got redistributed in 62 age classes (including the currently felled and area felled in the previous year) almost equally after the simulations.

The major output of the study is the information generated at the individual plantation level on number of trees/ha, basal areas/ha, mean diameter, mean height, site index, site quality, stocking status, growing stock and proportion of miscellaneous species. The information derived at the Divisional level include area, site quality distribution, stocking status, growing stock, productivity and proportion of miscellaneous species. Similar figures were worked out at the State level with additional information on age structure of the teak plantations and a yield regulation scheme indicating the maximum sustainable harvest based on potential yields.

1. Introduction

Teak is one of the most versatile timber known for its durability, strength and workability and is used extensively for construction purposes, making of furniture, ships and boats. Although teak has been under planting in Kerala on a plantation scale since 1844, major expansion in area occurred during the period 1960 to 1980 as part of the Five Year Plans. Teak thrives best in fairly moist, warm, tropical climate and is best grown in well drained alluvial soil. Consonant with the fairly high variability in the soil, topographical and weather conditions in the State, there is a high degree of regional variation in the productivity of the plantations. Traditionally, teak is grown under rainfed conditions under a least intensive form of management by the Forest Department. In Kerala, teak is worked on a 50 to 60 years of rotation. The demand for teakwood has been increasing over the past several years and with the reduced supply, the prices have been escalating in the State.

This project had the origin as follows. During the CGFRM meeting held on 30.6.2009 at KFRI, the PCCF, Kerala Forest Department expressed the need to evaluate the status of teak plantations in Kerala and identify plantations in poor state and so deserving to be converted to plantations of alternative species. Seeing the presently skewed age class distribution of teak plantations, he also indicated the need to bring it to an even status resulting in an even and sustainable flow of wood from these plantations. It was also pointed out that Kerala Forest Department (KFD) shall provide the necessary data and funds for carrying out the work. Accordingly, a project was granted in February 2010 in response to submission of a proposal by KFRI with the following objectives.

- To evaluate the status of teak plantations in the State and to identify plantations of poor stocking and site quality.
- To devise a scheme for yield regulation of teak plantations in Kerala

The work carried out under this project are reported here.

2. Materials and Methods

The study was confined to the plantations of teak and teak mixed with other species in the Territorial Divisions under the management of KFD. The data were to be gathered from each and every plantation of the Department. The data were collected by the Departments as follows in line with the guidelines drawn.

In each plantation, sample plots were selected along a transect mostly running through the center of the plantation. The transects were laid out along the longer dimension of the plantation and the plots were selected at fixed intervals starting from a random point within the first 100 m of the start of the transect. The number of plots varied proportionally with the size of the plantations. Plots were of size 24 m X 24 m selected roughly at the rate of one plot for every 10 ha. A minimum of two plots and a maximum of ten plots from any plantation were considered good enough. From each selected plot, observations on girth at breast height, measured at 1.37 m above ground level and species

identity were made on each tree. Year of planting and extent of the plantation and whether the plantation is of first or subsequent rotation were noted. The proforma drawn for the purpose and other guidelines followed for data collection are given in the Appendix 1.

2.1. Evaluation of status of the plantations

The data from the plots were first processed to generate plot level information which was then projected to the plantation level, providing information related to the status of individual plantations. The plantation level information was then aggregated to the Divisional level. The State level information was generated by integrating the information at the Divisional level. The computations involved in generating the summary statistics at various levels like plot, plantation and Division are detailed below.

Let 'n' denote the number of trees in the plot, 'g_i' the girth at breast-height of ith tree in the plot (cm), 'h_i' the height of the ith tree in the plot (m), and 'a' the area of the plot (m^2) which is equal to 576 m^2.

Plot level information

Number of trees/ha: Observations on the number of live trees in the plot at the time of data collection were utilized to compute the number of trees/ha for each plot.

$$N = \frac{n \times 10000}{a} \tag{1}$$

Crop diameter: Crop diameter was calculated as the diameter corresponding to mean basal area of trees in the plot.

$$\bar{d} = \frac{1}{\pi}\sqrt{\frac{\sum_{i=1}^{n} g_i^2}{n}} \tag{2}$$

Basal area : Basal area ha^{-1} for each plot was worked out using the formula,

$$B = \frac{\sum_{i=1}^{n} g_i^2}{4\pi a} \tag{3}$$

Crop height : Crop height was computed as the mean of the predicted height of trees in the plot.

$$\bar{h} = \frac{\sum_{i=1}^{n} \hat{h}_i}{n} \tag{4}$$

where $\hat{h}_i$ is the predicted height of the ith tree.

Height of each tree in the plot was predicted using the height-diameter relation developed by Nair *et al.* (1997) when measurement on diameter was available. For small trees, height reported through direct measurement was utilized.

Top height : Top height was computed as the height corresponding to the quadratic mean diameter of the largest 250 trees (by diameter) per ha as read from the height–diameter relation developed and reported by Nair *et al.* (1997).

Site index: Site index (S) is an estimate of the productive capacity of the site. Site index practically is the projected top height at the base age. It was estimated using the following equation reported by Nair *et al.* (1997).

$$\ln S = \ln H + 7.41014\left(A^{-1} - A_0^{-1}\right) \qquad (5)$$

where H = Top height (m)
A = Age of the stand (year)
A_0= Base age, taken as 50 years

Site quality: Site quality level of each plot carrying stands of age greater than 5 years was ascertained by first computing the top height for each plot and then referring the 'Top height by Age Table for teak' (Anonymous, 1970).

Stocking status: Basal area/ha and number of trees/ha were worked out for each plot carrying stands above 5 years of age. The stocking status was determined based on basal area/ha or number of trees/ha as expected by the yield table for teak (Anonymous, 1970). In particular, the stocking ratio for each plot was obtained by dividing the observed number of trees or basal area/ha by the corresponding number of trees or basal area/ha as expected by the yield table for the particular age and site quality class pertaining to the plot. A deviation of 10 per cent on either side from the expected number of trees was allowed for fully stocked stands. Plots having a stocking ratio between 0.9 and 1.1 were taken as fully stocked. Plots having stocking ratio less than 0.9 were considered as understocked and greater than 1.1 as over-stocked.

Crop volume: Estimates of timber and smallwood volume in each plot were obtained first by applying the following equations reported by Chaturvedi (1973) on each tree in the plots and added up to the plot level.

$$V_T = -0.0645 + 0.2322 D^2 h \qquad (6)$$

$$V = 0.1217 + 0.2257 D^2 h \qquad (7)$$

$$V_S = V - V_T$$

where V_T = Volume of timber from the tree (m^3)
V = Volume of timber and smallwood from the tree (m^3)
V_S = Volume of smallwood from the tree (m^3)
D = Dbh of the tree (m)
h = Total height of the tree (m)

Plot level estimate was converted to hectare level by dividing it by area of the plot in ha.

Plantation level information

Age of the plantation: Age of the plantation was computed as the difference in years between the age at measurement and the year of planting.

Area of the plantation: Area of the plantation in ha as reported in the data sheets was reproduced.

Number of trees/ ha: The mean number of trees/ha was calculated taking the average over the plots within the plantation.

Basal area/ ha: Basal area/ha was also computed as the mean basal area/ha of the plots in that plantation.

Site index: Site index of any plantation was computed as the average site index of the plots in that plantation. Site quality of the plantation was ascertained by comparing the mean site index with corresponding tables in the all India Yield Tables (Anonymous, 1970).

Stocking status: Stocking status of each plantation was estimated by comparing mean basal area/ha and mean number of trees/ha of each plantation with basal area/ha or number of trees/ha as expected by the yield table for teak (Anonymous, 1970).

Proportion of miscellaneous species: This was estimated by first computing the mean basal area/ha of miscellaneous species in the plantation and then dividing it by the mean basal area/ha inclusive of teak in that plantation.

Rotation status: This was taken from the figures reported in the proforma (not included in the report due to many missing values).

Average height: Average height was worked out using mean predicted height values at the plot level.

Growing stock in volume : Growing stock in volume was obtained by taking the average volume/ha (volume of timber and smallwood) of plots in that plantation and multiplying it by total extent of that plantation.

Division level information

Site quality distribution of area: The proportion of area belonging to different site quality classes in a Division was estimated by first computing the area under different site quality classes in each plantation, summing over the plantations in the Division and dividing by the total area under plantations of the Division.

Stocking status: Having assessed each plot for the stocking status, the area belonging to each stocking class in a plantation was estimated. These values were aggregated to the Division and divided by the total area to get the proportion of area belonging to each stocking class in the Division.

Growing stock in volume: Growing stock in volume (volume of timber and smallwood) in any Division was computed by adding the volume of each plantation in that Division.

Age structure: The age structure of the plantations of pure teak and teak mixed with other species was generated from the database created on each plantation with respect to age and area of the plantations.

Productivity: One of the measures of productivity in the case of forest plantations is the MAI in commercial volume. The MAI is supposed to vary with age, site quality and the thinning schedule followed. For a particular region, the marginal distribution of MAI over age can be obtained by condensing the variation of MAI over the site quality and stocking levels existing in that region.

From a cross sectional survey like the present one, the MAI can be obtained only with respect to the standing volume in the field for a particular age. Plot-specific information on yield from thinning was not obtainable. The existing volume at any age is technically comparable to final yield which is the sum of the main crop volume and current year's thinning yield. Since the selected plots belonged to different age and site quality classes, a prediction function for MAI was to be developed for age-specific predictions. For this purpose, the estimate of commercial volume (timber and smallwood) obtained for each plot was used for fitting Equations (8) along with the corresponding top height and age.

$$\ln V = a + bA^{-1} + c \ln H + dA^{-1} \ln H \qquad (8)$$

where V = Volume of timber and smallwood ha^{-1}
A = Age (year)
H = Top height (m)
a, b, c, d are parameters

In the above equation, top height was used instead of site index because, for a given age and stocking, the variation in volume is proposed to be due to variation in top height which is identical with that of the site index. Site index refers to the top height projected to a base age. Top height has the advantage of being a direct measure from the plot without involving a projection on to a base age. The MAI for any age-site quality-stocking combination was then obtained by dividing the corresponding predicted volume for a specific age by that age. The age level for expressing MAI was chosen as 60 years. Currently, Equation (8) was fitted to data for the entire State. The age of 60 was chosen because final felling centers around the age of 60 in the State. The expected MAI for any particular Division for the chosen age was then obtainable by taking the weighted average of the predicted MAI for the different site quality classes taking weights as the proportion of area in that Division under different site quality classes.

Proportion of miscellaneous species: This was computed as the weighted mean proportion of miscellaneous species of the plantations in the Division, the weights proportional to the area of the plantations.

State level information

Site quality distribution of area: The proportion of area belonging to different site quality classes in the State was estimated by first computing the area under different site quality classes in each plantation, summing over the plantations in the State and dividing by the total area under plantation of the State.

Stocking status: Having assessed each plot for the stocking status, the area belonging to each stocking class in a plantation was estimated. These values were aggregated to the State and divided by the total area to get the proportion of area belonging to each stocking class in the State.

Growing stock in volume: Growing stock in volume (volume of timber and smallwood) in the State was computed by adding the volume of all plantations in the State.

Productivity: Productivity is measured in terms of expected MAI. The expected MAI for the State for the chosen age was obtainable by taking the weighted average of the predicted MAI for the different site quality classes taking weights as the proportion of area in that Site quality class in the State.

Proportion of miscellaneous species: This was computed as the weighted mean proportion of miscellaneous species of the plantations in the state, the weights proportional to the area of the plantations.

2.2. Yield regulation for the teak plantations

The age class distribution of the plantation area as of 2011 was clearly skewed and if not regulated, will give out an uneven supply of wood over years. There was more area in middle-aged classes than that in other classes. This imbalance needs to be corrected by harvest scheduling so as to achieve an even flow of timber from these plantations. Determination of the maximum sustainable harvest requires repeated computer simulations with varying harvest levels and the methods followed are explained in the following.

The age class distribution of the area under pure teak plantations as of 2011 under management of Territorial Divisions was taken as the initial age structure of the plantations. For plantations belonging to Territorial Wing, the lowest rotation age currently adopted is 50 years. Hence harvesting age upto 50 years of age was allowed in the simulations. Also there is a gap of at least one year from clear felling to planting. The simulations assumed a constant land base for teak plantations in the State. The current area of variable productivity levels was brought to equiproductive terms by utilizing the yield relationship between site quality classes as found available in Anonymous (1970).

Thus the area belonging to different site quality classes was brought to Standard II/III site quality class using the following conversion factors applicable to the 'final yield' at 55 years.

0.534 ha of I quality site = 1 ha of II/III quality site
0.791 ha of II quality site = 1 ha of II/III quality site
1.282 ha of III quality site = 1 ha of II/III quality site
2.114 ha of IV quality site = 1 ha of II/III quality site

Information on the current productivity level is of utmost importance in the projections of future outturn. The yield tables reported in Anonymous (1970) refer to fully stocked stands and the values could be quite deviant from that of actual yield levels. Hence the following yield prediction equation developed by Sunanda (2003) was used for the purpose.

$$\ln V = \underset{(0.0678)}{0.3012} - \underset{(05021)}{16.437} A^{-1} + \underset{(0.0130)}{0.5711} \ln N + \underset{(0.0017)}{0.0838} S \qquad (9)$$

(Adj. $R^2 = 0.847$)

where V = Volume of timber and smallwood ($m^3\ ha^{-1}$)
A = Age of the stand (year)
N = Number of trees/ha
S = Site index (m)

The site index of 24.384 m corresponding to site quality class II/III and the full stocking level of 148 trees/ha corresponding to II/III site were used in the above equation for predicting the yield for different age values. The simulations were carried out following the rule that the oldest stands available shall be cut first followed by felling of younger stands. However, a gap of one year was left for site preparation before raising a new plantation in the same site.

The maximum sustained yield was found by trying different values for the target yield. The iterations were made to stop when any of the conditions specified above were not met or when the system attained a stable age class distribution of area. Stable age class distribution was considered to be attained when the area in different age classes became equal but allowing 10 per cent deviation of the expected area in any particular age class. Maximum sustainable harvest level was worked out for rotation age of 60 years.

3. Results and Discussion

The status of individual plantations is reported in Appendix 2. The compilations at the Divisional and State level are reported in the following.

3.1. Spatial distribution and age structure

The extent of teak plantations in the different Forest Divisions as of 2011 is shown in Table 1. The plantations of teak and teak mixed with other species were found to occupy about 56,509 ha in the State as on 2011.

Teak is grown in all Territorial Divisions. The Central and Southern Circles held larger shares of the teak area. At the Divisional level, Malayattoor and Konni had the largest extent under teak, Mannarkkad had the least extent.

Table 1. Area under teak plantations belnonging to Territorial Forest Divisions of Kerala as of 2011

Circle/Division	Area under teak (ha)	Percentage area
Northern	**4914.53**	**8.7**
Kannur	1511.7	2.7
North Wayanad	1187.46	2.1
South Wayanad	2215.37	3.9
Central	**18172.29**	**32.2**
Chalakkudy	4563.99	8.1
Malayattoor	7208.74	12.8
Thrissur	1773.38	3.1
Vazachal	4626.18	8.2
Southern	**14077.02**	**24.9**
Achencoil	2669.02	4.7
Konni	6665.16	11.8
Punalur	1693.94	3.0
Ranni	1350.77	2.4
Thenmala	1151.78	2.0
Thiruvananthapuram	546.35	1.0
Olavakkode	**11380.2**	**20.1**
Mannarkkad	457.19	0.8
Nenmara	924.48	1.6
North Nilambur	4097.6	7.3
Palakkad	1781.15	3.2
South Nilambur	4119.78	7.3
High Range	**7965.41**	**14.1**
Kothamangalam	3781.03	6.7
Kottayam	3568.38	6.3
Munnar	616.00	1.1
Total	**56509.45**	**100.0**

The age structure of the plantations as of 2011 is indicated in Table 2 and Figure 1. Only 15 per cent of the area is below 30 years of age and about 65 per cent of area is in between the age group of 30 to 50 years.

Table 2. Age structure of teak plantations in Kerala as of 2011

Age class (years)	Area (ha)	Percentage area	Cumulative percentage of area
0-4	165.21	0.29	0.29
5-9	1936.24	3.43	3.72
10-14	1383.11	2.45	6.17
15-19	1543.51	2.73	8.90
20-24	926.3	1.64	10.54
25-29	2625.26	4.65	15.18
30-34	10229.1	18.10	33.28
35-39	9425.88	16.68	49.96
40-44	7112.19	12.59	62.55
45-49	9805.62	17.35	79.90
50-54	5086.24	9.00	88.90
55-59	2320.61	4.11	93.01
>59	3950.18	6.99	100.00
Total	56509.45	100.00	

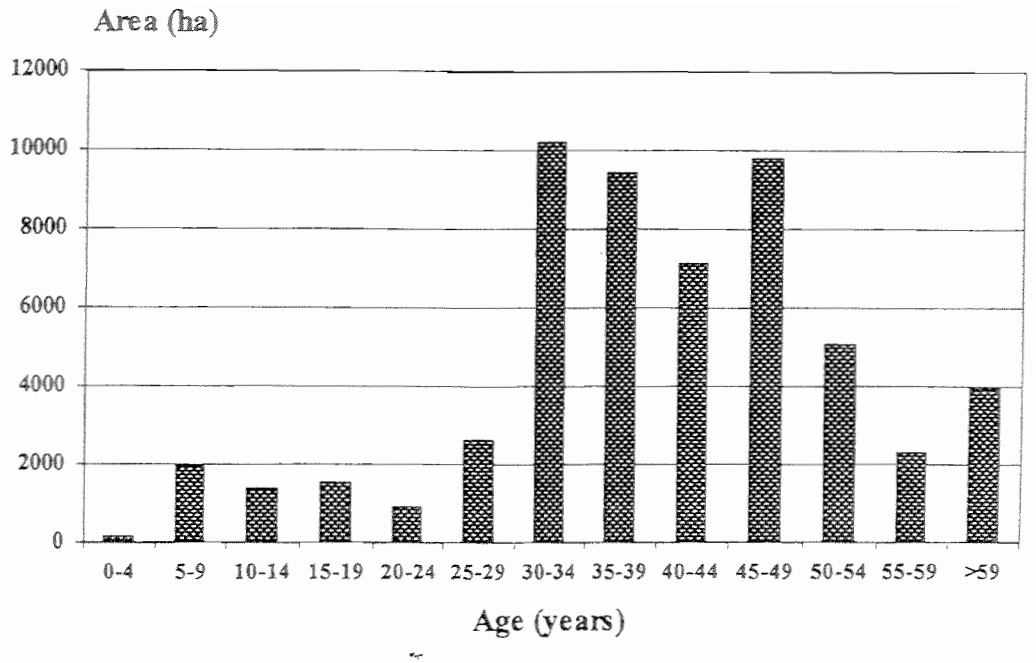

Figure 1. Age structure of teak plantations belonging to Territorial Divisions in Kerala as of 2011

3.2. Site quality distribution

The estimates of the proportion of area in different site quality classes in respect of different Divisions are given in Table 3. Nemmara and South Nilambur Divisions recorded a good share of area under better site quality classes (SQ I and SQ II) whereas Thiruvananthapuram, Wayanad, Ranni, Kottayam and Kothamanagalam had larger area under poorer site quality classes.

At the State level, nearly 89 per cent of the area fell in medium site quality classes. The extremes were rare.

Table 3. Site quality distribution of area under teak in different divisions

Circle/Division	Percentage of area in different site quality classes				Total
	I	II	III	IV	
Northern					
Kannur	6	52	41	1	100
North Wayanad	0	2	66	32	100
South Wayanad	0	1	82	17	100
Central					
Chalakkudy	3	49	48	0	100
Malayattoor	2	52	45	1	100
Thrissur	2	19	64	15	100
Vazachal	3	37	58	2	100
Southern					
Achencoil	3	48	47	2	100
Konni	4	28	64	4	100
Punalur	0	23	73	4	100
Ranni	6	14	56	24	100
Thenmala	2	20	59	19	100
Thiruvananthapuram	0	0	41	59	100
Olavakkode					
Mannarkkad	0	25	73	2	100
Nenmara	0	71	29	0	100
North Nilambur	4	43	46	7	100
Palakkad	9	22	58	11	100
South Nilambur	9	53	34	4	100
High Range					
Kothamangalam	0	11	82	7	100
Kottayam	0	5	70	25	100
Munnar	8	36	51	5	100
Overall	3	33	56	8	100

3.3. Stocking

Plantations having a stocking ratio between 0.9 and 1.1 were taken as fully stocked. Considering teak alone, based on basal area, nearly 15 per cent of the plantation area was under-stocked, 47 per cent fully stocked and 38 per cent over-stocked (Table 4) indicating that growth was poor in many plantations in the State. The corresponding figures based on number of trees (Table 5) were 7, 24 and 69 per cent.

Table 4. Stocking status of area under teak in different Divisions, based on basal area/ha

Circle/Division	Percentage of area in different stocking classes		
	Under stocked	Fully stocked	Over stocked
Northern			
Kannur	6	28	66
North Wayanad	3	93	4
South Wayanad	4	64	32
Central			
Chalakkudy	15	63	22
Malayattoor	22	51	27
Thrissur	13	39	48
Vazachal	16	37	47
Southern			
Achencoil	15	36	49
Konni	15	43	42
Punalur	13	25	62
Ranni	7	28	65
Thenmala	24	43	33
Thiruvananthapuram	12	31	57
Olavakkode			
Mannarkkad	4	82	14
Nenmara	0	94	6
North Nilambur	30	32	38
Palakkad	10	78	12
South Nilambur	14	58	28
High Range			
Kothamangalam	13	45	42
Kottayam	8	37	55
Munnar	29	20	51
Overall	15	47	38

Based on basal area density, under-stocked plantations were more common in North Nilambur, Munnar, Thenmala and Malayattoor Divisions. The case of over-stocked

plantations occurred more frequently in Ranni, Punalur and Kannur. The over-stocking was found partly due to the presence of larger number of trees in the stand rather than due to better growth of trees.

Table 5. Stocking status of area under teak in different Divisions, based on number of trees/ha

Circle/Division	Percentage of area in different stocking classes		
	Under stocked	Fully stocked	Over stocked
Northern			
Kannur	2	1	97
North Wayanad	7	3	90
South Wayanad	11	24	65
Central			
Chalakkudy	13	64	23
Malayattoor	6	23	71
Thrissur	4	6	90
Vazachal	1	20	79
Southern			
Achencoil	1	7	92
Konni	7	19	74
Punalur	6	32	62
Ranni	1	8	91
Thenmala	17	13	70
Thiruvananthapuram	0	8	92
Olavakkode			
Mannarkkad	8	33	59
Nenmara	8	72	20
North Nilambur	7	20	73
Palakkad	7	64	29
South Nilambur	16	27	57
High Range			
Kothamangalam	6	16	78
Kottayam	3	8	89
Munnar	0	17	83
Overall	7	24	69

The estimates of growing stock of teak in terms of timber and smallwood are furnished in Table 6. The plantations under reference in the State were found to carry 4.265 million m^3 of timber and 2.569 million m^3 of smallwood in 56,344.24 ha, excluding 165.21 ha in age group 0-4 years.

Table 6. Estimated growing stock of teak in teak plantations belonging to Territorial Divisions of Kerala as of 2011

Circle/Division	Timber (m^3)	Smallwood (m^3)
Northern		
Kannur	130,699	38,574
North Wayanad	94,153	45,884
South Wayanad	155,386	96,679
Central		
Chalakkudy	589,132	198,396
Malayattoor	570,137	278,221
Thrissur	129,684	75,514
Vazachal	265,703	206,569
Southern		
Achencoil	214,762	73,933
Konni	435,089	300,393
Punalur	95,322	73,488
Ranni	66,347	50,149
Thenmala	43,407	77,452
Thiruvananthapuram	25,750	19,449
Olavakkode		
Mannarkkad	50,112	27,762
Nenmara	151,312	56,526
North Nilambur	236,115	251,767
Palakkad	168,453	157,235
South Nilambur	364,465	214,173
High Range		
Kothamangalam	229,482	181,274
Kottayam	205,993	122,665
Munnar	44,291	23,244
Overall	4,265,794	2,569,347

3.4. Productivity

The equation for predicting the commercial volume including timber and smallwood at the stand level worked out to be the following

$$\ln V = \underset{(0.146)}{0.822} + \underset{(1.620)}{21.610}\, A^{-1} + \underset{(0.048)}{2.074} \ln H - \underset{(0.643)}{3.436}\, A^{-1} \ln H \qquad (10)$$

(Adj.R^2=0.322)

The figures in the brackets under the coefficients are standard errors of the estimates.

As the Adj.R^2 for the above equation was very low, the following yield prediction equation developed by (Nair *et al*, 1997) was used for the computation of MAI.

$$\ln V = \underset{(0.7418)}{0.4790} - \underset{(20.8520)}{127.8249}\, A^{-1} + \underset{(0.2361)}{1.5100} \ln S + \underset{(6.6325)}{32.6639}\, A^{-1} \ln S \qquad (11)$$

(Adj. $R^2 = 0.5570$)

where V = Volume of timber and smallwood ($m^3\ ha^{-1}$)
A = Age of the stand (year)
S = Site index (m)

Table 7. Estimates of MAI of teak at 60 years excluding yield from thinning for different Divisions to Territorial Divisions of Kerala as of 2011

Circle/Division	MAI ($m^3 ha^{-1}$)	Productivity Class
Northern		
Kannur	2.83	Medium
North Wayanad	1.70	Low
South Wayanad	1.83	Low
Central		
Chalakkudy	2.71	Medium
Malayattoor	2.71	Medium
Thrissur	2.14	Medium
Vazachal	2.53	Medium
Southern		
Achencoil	2.68	Medium
Konni	2.43	Medium
Punalur	2.24	Medium
Ranni	2.11	Medium
Thenmala	2.12	Medium
Thiruvananthapuram	1.41	Low
Olavakkode		
Mannarkkad	2.29	Medium
Nenmara	2.91	Medium
North Nilambur	2.59	Medium
Palakkad	2.43	Medium
South Nilambur	2.90	Medium
High Range		
Kothamangalam	2.06	Medium
Kottayam	1.80	Low
Munnar	2.64	Medium
Overall	2.42	Medium

Using the Equation 11, the volume at 60 years was predicted for the midpoint of each site quality class defined in the All India Yield Table for teak. The corresponding site indices were 35.66, 29.26, 22.86 and 16.46 m for site quality I, II, III and IV respectively. The predicted volume values were divided by 60 to get the MAI figures. The MAI for the Division/State was then calculated by taking the weighted average of the MAI figures taking weights as proportion of area under different site quality classes in the Division/State. The average MAI came to 2.42 m^3 ha^{-1}. This value is based on the standing volume of trees and thus excludes yield from thinning.

Considering the values of MAI obtained, three productivity classes were identified viz., MAI < 2 m^3 ha^{-1}, MAI of 2-3 m^3 ha^{-1}, MAI >3 m^3 ha^{-1}. The identity of different Divisions with respect to the productivity classes is also indicated in Table 7. No Divisions qualified for the high productivity group. The low productivity group included North Wayanad, South Wayanad, Kottayam and Thiruvananthapuram Divisions. The rest of the Divisions fell into the medium group. The middle group is the one which is supposed to respond to treatment and holds promise for the future.

Estimates of proportion of miscellaneous species found in teak platations are given in Table 8. Although species like bombax, ailanthus, etc. are grown mixed with teak, their share in the stand is very small exerting practically no influence on the growth and yield of teak. The proportion of such miscellaneous species including natural regeneration was found to be less than 7 per cent in the State.

Table 8. Estimates of proportion of miscellaneous species in teak plantations for different Divisions in Kerala

Circle/Division	Proportion of miscellaneous species
Northern	
Kannur	0.24
North Wayanad	0.07
South Wayanad	0.08
Central	
Chalakkudy	0.06
Malayattoor	0.05
Thrissur	0.09
Vazachal	0.08
Southern	
Achencoil	0.01
Konni	0.07
Punalur	0.11
Ranni	0.07
Thenmala	0.00
Thiruvananthapuram	0.05
Olavakkode	

Mannarkkad	0.05
Nenmara	0.00
North Nilambur	0.03
Palakkad	0.04
South Nilambur	0.10
High Range	
Kothamangalam	0.01
Kottayam	0.12
Munnar	0.15
Overall	0.07

3.5. Yield regulation for the teak plantations

The age class distribution of area under teak plantations managed by Territorial Wing as of 2011 which formed the initial age structure for simulations is given in the second column of Table 9. The corresponding age class distribution of standard hectares of II/III site quality class is also given in Table 9. Although five yearly values are given in Table 9, the area falling under individual years was used in the computations. Only the area having the stands younger than 75 years was considered for the simulations which came to 56,456.15 ha

Table 9. Age structure of teak plantations in Kerala as of 2011 and the corresponding area under standard (II/III) site quality class

Age groups (years)	Area (ha)	Area of II/III site class (ha)	Cumulative percentage of II/III site class (%)
0-4	165.21	165.21	0.25
5-9	1936.24	1745.70	2.66
10-14	1383.11	1508.06	2.30
15-19	1543.51	1718.74	2.62
20-24	926.30	1164.81	1.78
25-29	2625.26	2939.20	4.48
30-34	10229.10	11302.49	17.24
35-39	9425.88	10672.78	16.28
40-44	7112.19	8020.80	12.23
45-49	9805.62	12321.79	18.79
50-54	5086.24	6526.94	9.95

55-59	2320.61	2962.88	4.52
60-65	1975.17	2461.84	3.75
65-70	1340.14	1407.66	2.15
70-75	581.57	619.71	0.95
>75	53.300	38.687	0.06
Total	56509.45	65577.29	100

After repeated simulations the age structure reported above was found to sustain a yield level of 138,000 m^3 annually, inclusive of timber and smallwood under a rotation age of 80 years. The plantations reached a stable age class distribution after 100 years. The total effective area of 65,539 ha under the Territorial Wing got redistributed in 62 age classes (including the currently felled and area felled in the previous year) almost equally . It may be noted that these figures correspond to potential yield realizable over a rotation age by adopting the yield regulation scheme followed in the simulations and assuming that the yield/ha obtained is as in Equation (9). The annual harvest levels realized in practice in the State could differ considerably from the projections because of the variations in stocking levels and area harvested.

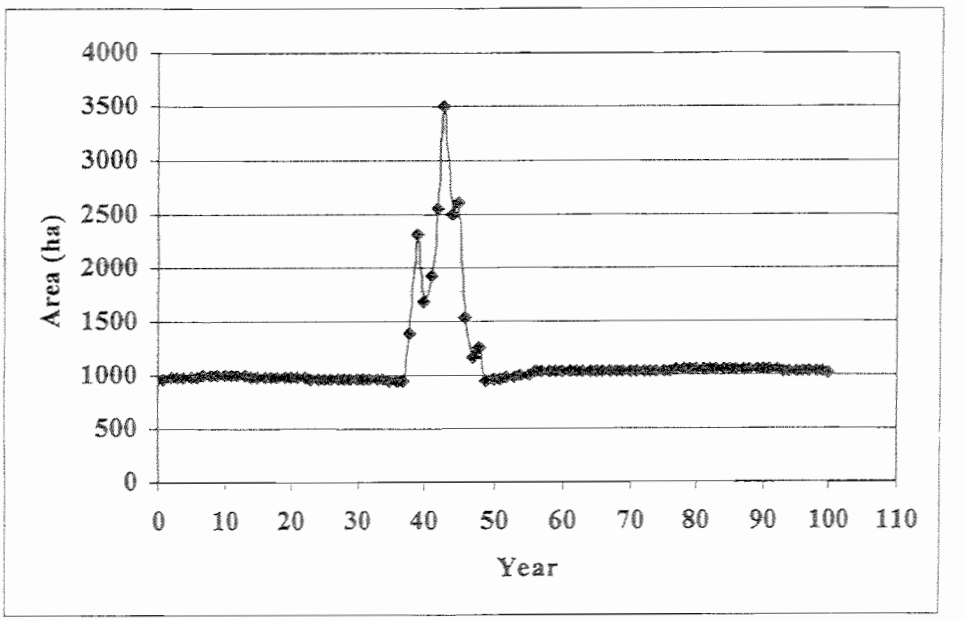

Figure 2. Area to be cut every year to realize the target yield under rotation age of 60 years

4. References

Anonymous 1970. Growth and Yield Statistics of Common Indian Timber species, Forest Research Institute and Colleges, Dehra Dun. 328 p.

Chaturvedi, A.N. 1973. General standard volume table and height diameter relationship for teak (*Tectona grandis*). Indian Forest Records (New Series), Silviculture, Vol.12. No. 8. Forest Research Institute and Colleges, Dehra Dun.

Nair, K.S.S., Jayaraman, K. and Chacko, K.C. 1997. Productivity of teak and eucalypt plantations in Kerala. KFRI Consultancy Report, Kerala Forest Research Institute, Peechi: 78 p.

Sunanda, C. 2004. Simultaneous calibration of allometric relations in even-aged teak stands using multilevel models, Ph.D Thesis submitted to FRI Deemed University Dehra Dun, Kerala Forest Research Institute, Peechi, India

Appendices

Appendix 1 : Proforma and guidelines for recording observations in sample plots

KFRI PROJECT: STOCK ASSESSMENT AND YIELD REGULATION FOR TEAK PLANTATIONS IN KERALA

PLOT MEASUREMENT FORM

I Plantation details

1. Name of the plantation :
2. Year of planting :
3. Total extent of the plantation (ha) :
4. Forest Division :
5. Forest Range :
6. Location :
7. Species planted :
8. Initial espacement (m) :
9. Rotation (I/II/III/IV) :
10. Topography (Plain/Undulating) :
11. Number of sample plots laid out :
12. Date of measurement :
11. Approach map to the plantation and a rough sketch of the plantation showing the transects and plots (Show the North by arrow mark):

Approach map to the plantation	Sketch of plantations with transects

Signature of the Field Officer:
Name of Field Officer:
Designation :

II. Measurements on live trees in the plot

Division		Range	Location	
Name of plantation		Year of planting	Plot Number	Date of measurement
Tree No.	Species	Girth at breast-height(cm)	Height* (m)	Remark* (if any)

Signature of the Field Staff

*** Height is to be recorded for trees shorter than 1.37 m, Use the following codes for Remarks**

DD = Dead/Dry, TB = Top broken, FR = Forking, CR = Crooked, CP = Coppice, WB = Water blister, LR = Loranthus, VA = Vanda, CL = Climber, BR = Borer, DF = Defoliator, SK = Skeletoniser, DS = Diseased.

Guidelines for measuring girth at breast-height (gbh)

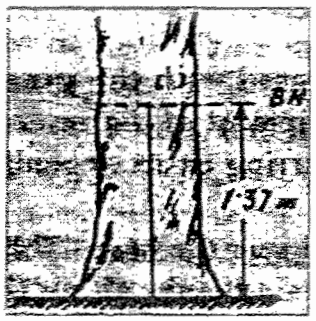

Fig. 1. Normal case

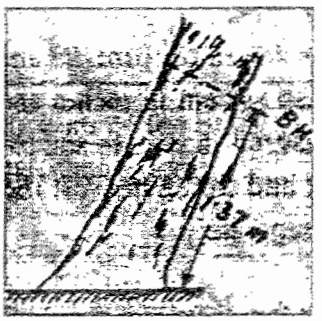

Fig. 2. Leaning tree

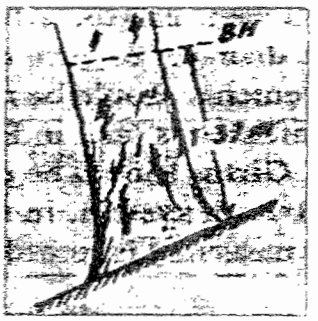

Fig. 3. Sloping ground

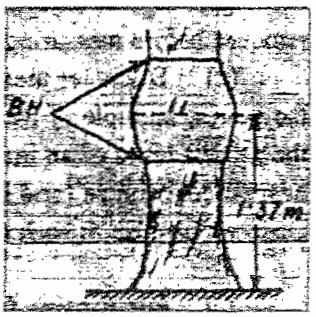

Fig. 4. Bulge

Fig. 5. Forked above BH

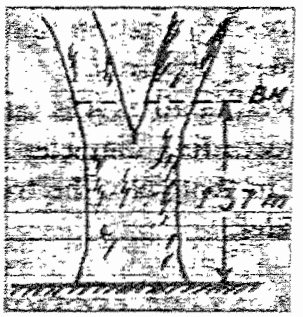

Fig. 6. Forked below BH

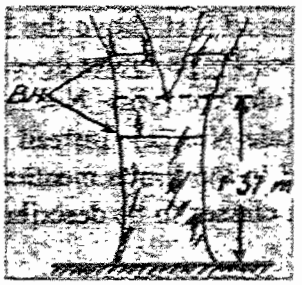

Fig 7. Forking at BH

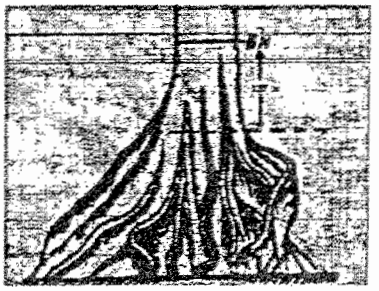

Fig.8. Buttress

Note : Measurement of girth has to be taken where the marking BH is made in all the cases

Instructions for laying out sample plots and for measurement on trees

Scope of the study: The study is restricted to the teak plantations in Territorial Divisions under the management of Kerala Forest Department.

Objectives:

1. To evaluate the status of teak plantations in the State and to identify plantations of poor stocking and site quality.
2. To devise a scheme for yield regulation of teak plantations in Kerala

Methodology

The proforma has two parts, one on the plantation details and the other on measurement of trees in sample plots. All the details called for regarding the plantations are to be entered in the first part. Measurements on trees are to be recorded in the second part along with the signature and contact details of the officer-in-charge. Verification of the data reported will be made by KFRI on a randomly selected set of sample plots.

1. Plots of size 24 m X 24 m (square) have to be laid out in each and every teak plantation in the Division. The data are to be recorded separately for each plantation. The plantation may be purely of teak or teak mixed with other species.
2. The number of plots to be taken in any plantation will be at the rate of one plot for every 10 ha. A minimum of two plots and a maximum of ten plots from any plantation regardless of the extent of the plantation would be good enough.
3. The plots may be taken along one or more transects running along the longer dimension of the plantation. In any transect, the first plot may be taken at a random point within the first 100 m from the border. Thereafter, the plots are to be taken at fixed intervals along the transect. The spacing between the plots may be so adjusted to attain the number of plots specified above for any plantation.
4. A rough sketch of the plantation showing the orientation of the transects and an approach map to the plantation showing permanent land marks may be recorded in the first part of the proforma.
5. The boundary of the sample plot should run through interspaces between the trees rather than along the tree-rows themselves.
6. The four corners of the plot may be temporarily marked by putting stone cairns or wooden sticks affixed on the ground.
7. From each selected plot, observations on girth at breast-height and species identity have to be made on each tree. The local names of trees may be recorded.
8. Dead trees may be avoided from the measurement.
9. Breast-height refers to 1.37 m from the ground level as per Indian Standards. A small reference stick of that length (1.37m) may be used for locating the measurement point on the tree trunk.
10. The reference stick may be kept leaving out any buttresses at the tree base.
11. For leaning trees, the reference stick may be kept along the inner part of the lean.
12. For trees on sloping ground, the reference stick has to be kept along the tree on the uphill side of the tree base.

13. Bulging if any at the measurement point has to be left out by shifting the measurement point either to a point above or below the bulge.
14. For trees that are forked below breast-height or at breast-height, girths of both the stems are to be recorded separated by a comma.
15. Measurement of girth is to be taken to the nearest millimetre using a non-stretchable graduated tape.
16. Any termite formation or creepers at the point of measurement on the trunk should be removed before the measurement.
17. The point of measurement should be marked clearly in full round on the trunk using yellow tree marking wax chalk for future reference.
18. For trees not taller than 1.37m, height has to be recorded to the nearest centimetre.
19. The original data sheets may be transferred to KFRI within two months of receiving the orders from the CCF. A copy of the data may be kept at the Department office for reference purposes.
20. The data are to be sent directly to the following address.

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