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STRUCTURAL DYNAMICS OF TEAK STANDS IN KERALA

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ABSTRACT

The teak plantations in Kerala under the management of the Kerala Forest Department occupied around 78,225 ha in 1992. About 17 per cent of this area was under Wildlife Sanctuaries and National Parks where clearfelling is abandoned. Of the remaining portion, 75 per cent of the area carried stands below 35 years of age, which has implications on the future management of these plantations. The teak plantations falling under the Territorial Circles were assessed for stocking and site quality distribution. in 1992-93 through a stratified sampling procedure. The plantations as of 1992 were stratified by Territorial Circles and age groups. The observations on stocking and related parameters were gathered from plots of size 50 m x 50 m, laid out in randomly selected plantations within each stratum.

The survey revealed that based on teak alone, 36 per cent of the plantation area was under stocked, and 45 per cent overstocked. However, considering the presence of miscellaneous species growing in teak plantations, the degree of understocking reduced to 18 per cent and that of overstocking increased to 60 per cent. The variation in the stocking pattern over broad age groups was also studied. With respect to the basal area of teak alone, the stocking pattern did not show significant differences over age groups. Considering the growth of miscellaneous species in terms of basal area, overstocking was more prevalent in older plantations.

The site quality distribution approximated to that of normal distribution with a mean site index of 24 m. The distribution of plots in different site quality classes were as follows; SQ I (9%), SQ II (48%), SQ III (41%), SQ IV (2%). There was a marked absence of higher site quality levels in older plantations. On the other hand, young plantations mostly belonged to higher site quality levels. The information on the present age structure, stocking and site quality distribution will be useful in projecting the future out-turn from these plantations.

A subset of the sample plots selected for the survey, was retained as semi-permanent sample plots to be remeasured periodically. Detailed measurements on tree position, crown width and height of trees were made in such plots. These plots were remeasured during 1997. The status of these plots with respect to the various stand attributes like age at measurement, stand density, site quality class etc. during the two successive measurements are reported here. Only when the measurements on successive increments are available for a longer period, the growth projection models can be developed.

Efforts were made to work out an optimum thinning schedule for teak based on a simulation exercise. The criterion imposed was that of maximizing volume production without unduly sacrificing the size of the trees (logs). The simulation started with a 10- year-old stand which is fully stocked as per the yield table for teak. The simulation covered 4 silvicultural thinnings that could take place since 10 years of growth. At each stage, the thinning intensity was allowed to vary as 0, 20, 30, 40 and 50 per

cent of the number of trees in the stand. Following through the different combinations of age at thinning and intensity of thinning, the total volume of thinning and also the yield from final felling at 60 years was computed for each combination. The thinning schedule, which maximized the total volume subject to the restriction that crop diameter at 60 years is not less than 95 per cent of the maximum crop diameter attainable in each site quality class, was identified.

The results of the simulation study on thinning indicated that there is no need for the first and second silvicultural thinning practised after 10 years currently, followed by 50 per cent removal at 30 and 42 years. This was the case when either silvicultural or mechanical thinnings were carried out before 10 years. Even when two thinnings are avoided, the diameter growth remained unaffected. The larger sized trees when harvested in later stages, resulted in increased overall volume. The advantage of carrying out mechanical thinning prior to 10 years is evident only in site quality class I. In lower site quality classes, this option was on par or worse than the standard schedule. The above results points to the need for re-examining the present thinning schedule for teak in the State and also calls for further physical experimentation with the optimum and standard thinning schedules on 10 year old stands.

The maximum sustainable harvest worked out for teak plantations under the Territorial Wing in Kerala came to 1,40,000 m^3 (timber and smallwood) for the first 14 years and 2,00,000 m^3 thereafter for a rotation age of 50 years. At the terminal stage of the simulations of 161 iterations, the total area of 71,782 ha of standard II/III site class in the Territorial Wing got redistributed in 52 age classes with around 1348 ha in each year. The simulations with 60 years as the rotation age showed a sustained yield level of 83,000 m^3 annually for the first 24 years and 1,75,000 m^3 thereafter. The stable age class distribution was achieved after 156 years. At the terminal stage, the total area of 71,782 ha of the Territorial Wing got redistributed in 62 age classes with around 1092 ha in each age class. The yield levels quoted are expected figures as per the prediction equation used in the simulation runs and their realization in the field shall depend on the validity of the prediction equation.

The proposed annual cut for the Territorial Wing was less than 2 per cent of the total area in any year. Comparison of the maximum sustained yield with the current harvest levels indicated that with the existing land base, the current harvest levels can be increased manifold without depleting the resources in any manner. However, sufficient measures are to be taken to retain the current productivity levels of the plantations over time.

The consequence of bringing the plantations to normality in one rotation period was also investigated. With a rotation age of 50 years the yield from Territorial Wing varied from 2,24,613 m^3 to 1,94,006 m^3 in the first 50 years and stabilized at 2,01,731 m^3 after 50 years. The lowest harvesting age to be followed in the first 50 years came to 46 years. For rotation age of 60 years, the variation in the yield in the first 60 years was from 1,91,301 m3 to 1,66,437 m^3. The expected yield after 60 years worked out to 1,84,062 m^3. The lowest harvesting age to be followed in the first 60 years would then be 48 years. Although the conversion strategies seem justified in terms of the total area available, the expected yield figures are subject to the validity of the yield prediction equation used in the simulation.

1. INTRODUCTION

The State of Kerala has a long history of raising teak plantations in large scale. Teak occupies nearly 50 per cent of the area under forest plantations in the State. Compared to plantation crops in the agricultural sector, teak receives very low levels of input. However, the species has come up well in some areas such as Nilambur, Wynad and Thenmala (Jayaraman and Rugmini, 1993). Teak yields high quality timber and the demand for the same is expected to remain high in the future. With the ban on clearfelling of natural forests, any further increase in the area under teak in government forests is unlikely. For this reason, productivity of the existing plantations is of utmost importance which calls for effective plantation management.

Scientific plantation management requires reliable information on stocking, age structure and productivity of the plantations. Such information is required not only for choosing the current management options but also for the regulation of future out-turn from these plantations. To a certain extent, the relevant data could be gathered from Plantation Journals and Working Plans. However, a State level compilation is not available. Data on actual yield realized from plantations of different ages and stocking levels in different regions are grossly lacking. Attempts on consolidating such data and developing models for prediction of yield under these variants have also been limited. The yield tables for teak worked out in 1959 (Anonymous, 1970) still form the basis of calculation of yield of teak in Kerala. A re-examination of the performance of these tables in practice was due in view of the large scale planting done during the National Plan Periods and also due to the varying site conditions existing in the State. The above mentioned reasons formed the basis for undertaking this study. Developing stand level models which will capture the system behaviour with respect to structural changes in response to certain exogenous variables and quantifying the spatial and temporal dimensions of the same was the main theme of the work. Working out the long term implications of the present age structure, stocking and also variation in the productivity of teak plantations in Kerala utilizing the above models was a necessary adjunct to the main substance.

The specific objectives were:

(i) to obtain information on the age structure, stocking and productivity of teak plantations in Kerala
(ii) to develop models for prediction of yield under varying age classes, stocking and site quality levels
(iii) to work out the consequences of the present structure of teak plantations on future out-turn using the yield models to be developed.

In order to meet the above objectives, a survey of the teak plantations in the State was conducted in 1992. A subset of the plots used for the survey was retained as permanent plots. A detailed interim report on the results of this survey and related results were submitted to the Forest Department in 1995. To enable re-measurement of the permanent sample plots, the project period was extended by two years. However, since the funds for the extension period were released late by the Forest Department, the project period had to be extended further by one year so as to analyse the data and prepare the report. During the extension period, a more extensive survey was conducted by the Kerala Forest Research Institute under a project supported by the World Bank, to estimate the productivity of teak plantations in the State. The latter project had similar objectives and since the concerned report contains information on productivity of the plantations based on more extensive data, those aspects are not dealt with in the present report. Also, the parameters of a few stand level allometric equations used in the present study were estimated using the data generated through the more extensive survey conducted on teak plantations in 1997.

2. MATERIALS AND METHODS

2.1. Age structure

The list of plantations raised by the Forest Department as on 1987 was obtained from the office of the Chief Conservator of Forests (Development), Thiruvananthapuram. The details of the plantations raised after 1987 were gathered from the Range Offices of the Department. The age structure of pure teak plantations in the State as on 1992 was generated from the above data base.

2.2. Stocking

To obtain an idea about the stocking and site quality levels of the pure teak plantations in Kerala, a low intensity survey was conducted. The plantations were stratified by Territorial Circles and age groups. The Wildlife Circle was avoided since the area under this Circle comes from different parts of the State. Moreover the plantations belonging to this unit do not come under the regular management operations as in other Circles. The target population thus was 64,610 ha of pure teak plantations in the State. The age groups formed were <5, 5-10, 10-15 and so on up to 60 years. Plantations older than 60 years were put in the last group. Three plantations were selected at random from each of the strata except two of the strata which contained only one plantation each. With the constraints on the resources available, only one plot could be taken for observations from each selected plantation. Moreover the variation within a stratum was more of interest than variation within a single plantation. The plots were of size 50 m x 50 m . Measurements on' girth at breast-height (gbh) of trees in the plots were taken. Observations were restricted to trees having a minimum gbh of 10 cm. Basal area ha^{-1}, number of trees ha^{-1} and composition of the stand as of teak and miscellaneous species were worked out. The stocking status was determined based on basal area ha^{-1} as expected by the yield table for teak (Anonymous,l970). This was done based on the teak trees alone and also by combining other trees in the plots. In particular, the stocking ratio for each plot was obtained by dividing the observed basal area by the corresponding basal area as expected by the yield table for the particular age and site quality class pertaining to the plot. Frequency distribution of the stocking ratio was obtained and its variation over the age groups was examined.

2.3. Site quality distribution

Site quality level of each plot included in the above survey was ascertained by referring to the yield table for teak (Anonymous, 1970). The height-diameter relation for the purpose was obtained from Chaturvedi (1973). Cross tabulation of the data as per age and site quality classes was done to know the status of teak plantations by these categories. Chi-square test of independence of two factors was, done to find out if the site quality levels were dependent on the age-groups or regions (Circles). The proportion of area belonging to each site quality class in different age-groups and Circles were estimated through the formulae applicable to stratified sampling. The overall site quality distribution for plantations of age greater than or equal to 5 years was also worked out and tested for normality.

2.4. Stand dynamics

Thirty six of the sample plots laid out during the survey were identified as permanent sample plots. These belonged to different site quality and age group combinations found available through the survey. Additional measurements on crown diameter were taken on trees in the plot. Height was recorded on a sub sample of trees covering the range of height values in each plot. Tree position was identified by coordinates with origin as one of the corners of the plot. The trees were marked with white paint at breast-height level. Also the border trees were marked with red paint. No other markings were made on trees. The plots are expected to be under the regular management operations of the Department. These plots were remeasured during 1997. Various stand attributes like age at measurement, stand density, site quality etc. were evaluated using standard methods applicable to teak stands. The status of the plots with respect to these attributes during the two measurements are reported here. The growth projection models can be developed only when successive measurements on-increments are available.

2.5. Optimum thinning schedule

Efforts were made to work out an optimum thinning schedule for teak based on a simulation exercise. The word 'optimum' refers to 'best' with respect to some criterion. The criterion that could be imposed in this context was that of maximum volume production, without unduly sacrificing the size of the trees (logs). The simulation started with a 10- year-old stand which is fully stocked as per the yield table. This presumes execution of silvicultural thinning in early years to keep the stands fully stocked. However, since the current practice in the State is to go for 2 mechanical thinnings before 12 years, the whole simulation exercise was repeated using this option as well. The simulation covered 4 silvicultural thinnings that could take place since 10 years of growth. This was done so also because there is no timber produced in most of the site quality classes below that age. The age at thinning at any silvicultural thinning was varied as shown in Table 1.

Table 1. The age levels at different stages of thinning included in the simulation

ST I	STII	STIII	STIV
10	16	26	38
11	17	27	39
12	18	28	40
13	19	29	41
14	20	30	42

At each stage, the thinning intensity was allowed to vary as 0, 20, 30, 40 and 50 per cent of the number of trees in the stand. At any stage, the crop diameter and the corresponding height were predicted through equation (1) and (2).

$$\ln d = -4.4559 + 1.1238 \ln S - 2.1586 A^{-1} \ln N \quad (1)$$
$$\ln h = 2.57876 + 0.02936 S + 0.02361 \ln N - 4.33484 A^{-1} - 0.06422 d^{-1} \quad (2)$$

where, d = Crop diameter (m)
S = Site index (m) which is the top height at 50 years
A = Age of the stand (year)
N = Number of tree (no. ha^{-1})
h = Total height of tree (m)

The parameters of the above equations were estimated using data collected from 1200 sample plots laid out in teak plantations in connection with a study on productivity of teak plantations in Kerala (Anonymous, 1997). Individual tree volume was predicted using the equation reported by Chaturvedi (1973) which is

$$V = 0.1217 + 0.2257 d^2 h \quad (3)$$

where, V = Volume of timber and small wood from the tree (m^3)
d = Diameter at breast-height of the tree (m)
h = Total height of the tree (m)

When any thinning is executed, the thinning volume was obtained by multiplying the average individual tree volume by the number of trees removed. Following through the different combinations of age at thinning and intensity of thinning, the total volume of thinning and also the yield from final felling at 60 years was computed for each combination. The total number of combinations compared amounted to 5^8 = 3,90,625 for each site quality class. The thinning schedule, which maximized the total voluine subject to the restriction that crop diameter at 60 years is not less than 95 per cent of the maximum crop diameter attainable in each site quality class, was identified. The option without any such restrictions on tree size also was tried.

2.6. Maximum sustainable harvest

In forest management, a problem of considerable practical significance involves determination of the maximum continuing harvest level that can be imposed on a given forest and sustained in perpetuity. This level is referred to as the maximum sustainable harvest or maximum sustained yield. Determination of the maximum sustainable harvest requires repeated computer simulations with varying harvest levels. The premises under which this quantity was an ived at for teak plantations in Kerala and the methods followed are explained in the following.

The age class distribution of the area under pure teak plantations as of 1995 under the management of the 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. Also there is a gap of at least one year from clearfelling 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 results of Table 6 and 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 the 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 levels is of utmost importance in the projections of future out-turn. 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 an yield prediction equation was developed from the data base generated by a recent study carried out by the Kerala Forest Research Institute on productivity of teak under the actual growing conditions in the State (Anonymous, 1997).

$$\ln V = 0.4790 - 127.8249\ A^{-1} + 1.5100 \ln S + 32.6639\ A^{-1} \ln S \qquad (4)$$

$$\quad (0.7418) \quad (20.8520) \qquad (0.2361) \qquad (6.6325) \qquad (Adj.R^2=0.5570)$$

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

The site index of 24.384 m corresponding to site quality class II/III was used in the above equation while 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. The maximum sustained yield was found out 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 at most 10 per cent deviation of the expected area in any particular age class. There is an implicit assumption involved in the simulation that the site quality distribution of the area does not undergo changes over time. Alternatively, this could mean that sufficient measures would be taken to retain the current productivity levels of the sites over time. Maximum sustainable harvest level was worked out for rotation age of 50 and 60 years.

A related and more basic concept to sustained yield forestry is that of 'normal forest'. The traditional normal forest is a collection of even-aged stands that are being managed on a rotation age of R years. Yields for these stands are given by some normal yield table, so that all stands are assumed to be fully stocked. All stands are considered as growing on equiproductive sites and the area in each age class from 1 to R years is to be the same. More recent discussions on forest regulation have abandoned the term normal forest and instead considered fully regulated forest (Clutter *et al.* , 1983). However, it will be interesting to see the consequence of bringing the forests (teak plantations in the State in the present case) to normality in one rotation period. The area to be harvested every year was calculated by dividing the total area by the rotation age including two additional years for felling and keeping buffer area for planting and the harvest levels that will be realized for a full rotation age in the future were worked out. The yield values used against any particular age in the computations were the same as those of the earlier simulations described. This was done for two values of rotation age, 50 and 60 years. No restrictions were imposed on the yield to be realized in any particular year. All the area qualifying for harvest in a year was subjected to felling. The pattern of out-turn and the lowest felling age encountered over a full rotation age were worked out.

3. RESULTS AND DISCUSSION

3.1. Age structure

The age structure of the plantations as of 1992 is indicated in Table 2 and Figure 1. As can be seen from Table 2, a substantial portion (17 per cent) of the total area under teak belongs to the Wildlife Wing. The plantations belonging to Wildlife Wing are not supposed to be available for the normal commercial operations on the crop. With respect to the area belonging to the Territorial Wing, nearly 75 per cent of the area is below 35 years of age. This has implications on the future out-turn from these plantations in the sense that a major portion of the plantations will be available for final felling only after 20 years from now. Since the distribution of area in different age classes is uneven, it is difficult to follow the sustained yield principle readily unless a policy towards that is implemented.

Table 2. Age structure of teak plantations in Kerala as of 1992

Age group (years)	Area under Territorial Wing (ha)	Area under Wildlife Wing (ha)	Total area (ha)	Cumulative % of area for Territorial Wing
<5	856.567	0.000	856.567	1.33
5 - 10	2365.052	35.580	2400.632	4.97
10 - 15	8744.266	1312.270	10056.536	18.50
15 - 20	11122.514	1043.920	12166.434	35.70
20 - 25	8715.236	1327.336	10042.572	49.20
25 - 30	10487.377	5679.286	16166.663	65.50
30 - 35	6686.744	1447.612	8134.356	75.80
35 - 40	2779.246	418.080	3197.326	80.10
40 - 45	3112.913	465.765	3578.678	84.90
45 - 50	2877.610	614.230	3491840	89.40
50 - 55	2278.762	453.370	2732.132	92.90
≥55	4584.054	817.320	5401.374	100.00
Total	64610.341	13614.769	78225.110	-

Note: Updated list of plantations as by 1992 was not obtained from the following Ranges, *viz.*, Nagarampara, Sholayar, Shenthuruny and Aralam

3.2. Stocking

The frequency distribution of the stocking ratio based on basal area ha^{-1} is given in Table 3. Plantations having a stocking ratio between 0.9 and 1.1 were taken as fully stocked.

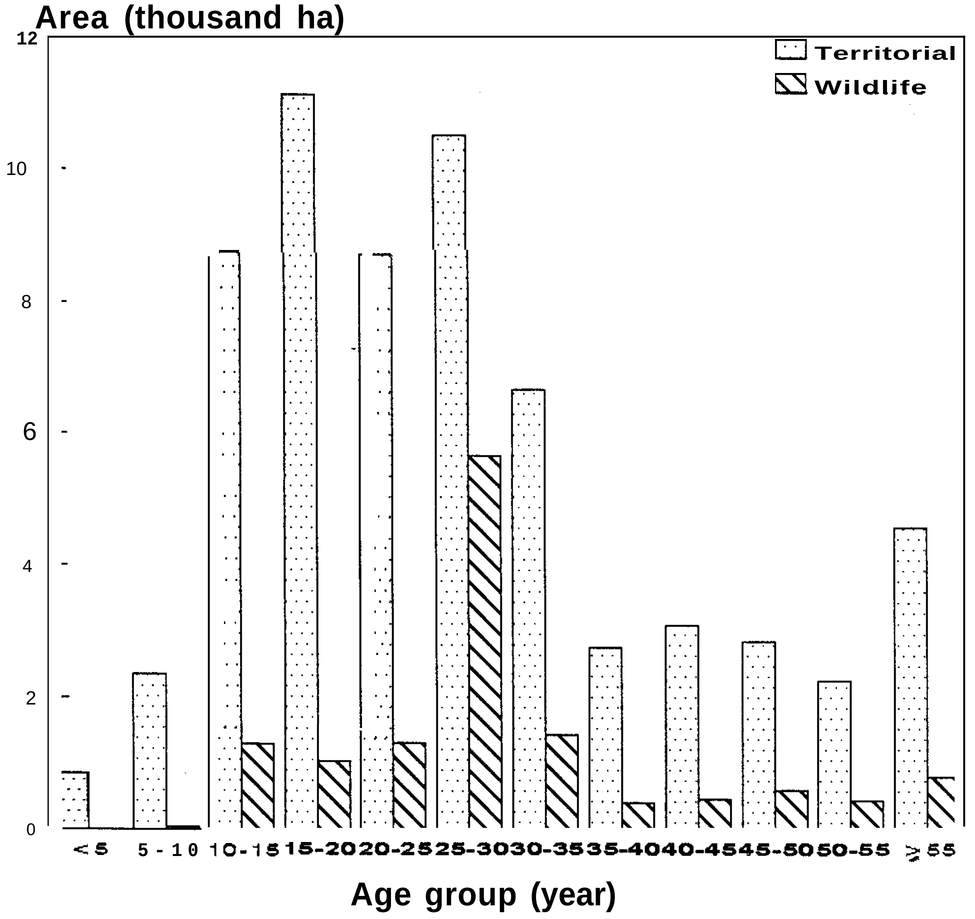

Figure 1. Age structure of teak plantations in Kerala as on 1992

Considering teak alone, based on basal area, nearly 19 per cent of the plantation area was fully stocked, 36 per cent understocked and 45 per cent overstocked (Table 4). Overstocking at least in some places was found to be due to the nonadherence to the prescribed thinning schedule rather than better growth. When the presence of miscellaneous species was taken into account, the degree of understocking lessened as can be expected.

Table 3. Frequency distribution of stocking ratio based on basal area and number of trees ha^{-1}

Stocking ratio class	Frequency based on basal area	
	Teak	Teak and others
0.3 - 0.5	7	2
0.5 - 0.7	17	8
0.7 - 0.9	35	20
0.9 - 1.1	31	35
1.1 - 1.3	34	28
1.3 - 1.5	22	27
1.5 - 1.7	11	24
1.7 - 1.9	2	6
1.9 - 2.1	2	7
2.1 - 2.3	1	2
2.3 - 2.5	1	2
2.5 - 2.7	0	2
> 2.7	0	0
Total*	163	163

* Excludes plots in plantations less than 5 years of age.

The variation in the stocking pattern over broad age groups is also discernible from Table 4. With respect to the basal area of teak alone, the stocking pattern did not show significant differences over age groups. Considering the growth of miscellaneous species in terms of basal area, overstocking was more prevalent in older plantations.

The composition of teak stands based on basal area and number of trees arc given in Tables 5 and 6. There is a gradual though not systematic increase in the proportion of stand basal area occupied by miscellaneous species. The fact that this is more due to the ingrowth rather than survivor growth is indicated by the increase in the proportion of miscellaneous species by number of trees over years. However, considering the range of proportion of teak by number of trees, there are plantations in the older age groups wherein the proportion of teak is as low as 0.10. This happens mostly in the case of plantations situated away from human settlements. Undergrowth in plantations accessible areas is mostly disturbed by human interference.

Table 4. Variation in the stocking pattern over age groups

Age group (Year)	Stocking status based on basal area	Proportion of area in different stocking classes	
		Teak	Teak and others
< 20	Understocked Fully stocked Overstocked	0.44 0.12 0.44	0.35 0.19 0.46
20-40	Understocked Fully stocked Overstocked	0.28 0.18 0.54	0.08 0.18 0.74
≥40	Understocked Fully stocked Overstocked	0.38 0.25 0..37	0.17 0.27 0.56
Overall	Understocked Fully stocked Overstocked	0.36 0.19 0.45	0.18 0.22 0.60

Table 5. Composition of teak stands based on basal area

Age group (years)	Proportion of basal area		Range of proportion of teak
	Teak	Others	
5 - 10	0.92	0.08	0.48 - 1.00
10 - 15	0.97	0.03	0.88 - 1.00
15 - 20	0.91	0.09	0.63 - 1.00
20 - 25	0.86	0.14	0.42 - 1.00
25 -30	0.92	0.08	0.45 - 1.00
30 - 35	0.85	0.15	0.38 - 1.00
35 - 40	0.85	0.15	0.47 - 1.00
40 - 45	0.79	0.21	0.34 - 1.00
45 - 50	0.81	0.19	0.48 - 1.00
50 - 55	0.82	0.18	0.38 - 1.00
≥55	0.80	0.20	0.29 - 1.00

Table 6. Composition of teak stands based on number of trees

Age group (Years)	Proportion of number of trees		Range of proportion of teak
	Teak	Others	
5 - 10	0.98	0.02	0.94 - 1.00
10 - 15	0.97	0.03	0.91 - 1.00
15 - 20	0.91	0.09	0.64 - 1.00
20 - 25	0.83	0.17	0.36 - 1.00
25 - 30	0.90	0.10	0.44 - 1.00
30 - 35	0.83	0.17	0.61 - 1.00
35 - 40	0.78	0.22	0.41 - 1.00
40 - 45	0.76	0.24	0.34 - 1.00
45 - 50	0.68	0.32	0.10 - 1.00
50 - 55	0.72	0.28	0.30 - 1.00
≥55	0.74	0.26	0.21 - 1.00

3.3. Site quality distribution

The estimates of the proportion of area in different site quality classes tabulated by the age groups considered are given in Table 7. There is a predominance of I1 and III site quality classes compared to other site quality classes. The chi-square test showed significance at P = 0.05 indicating the dependence of site quality levels on age groups. There is a marked absence of higher site quality levels in older plantations. On the other hand, young plantations mostly belonged to higher site quality levels. The reason for this trend is not very clear from the present data set and this observation may require further confirmation. A major impediment in drawing any inference on the causative factors was the lack of information on the stage of rotation of the individual plantations considered for the study.

Table 7. Proportion of number of plots in different site quality classes by age groups

Age group (years)	Site quality class				Total
	I	II	III	IV	
< 10	0.91	0.09	0.00	0.00	1.00
10 - 20	0.11	0.89	0.00	0.00	1.00
20 - 30	0.06	0.48	0.46	0.00	1.00
30 - 40	0.00	0.11	0.89	0.00	1.00
40 - 50	0.00	0.13	0.77	0.10	1.00
≥50	0.00	0.27	0.57	0.16	1.00
Overall	0.09	0.48	0.41	0.02	1.00

The mean site index worked out to approximately 24 m. This happens to nearly coincide with the midpoint of the range of site indices considered in the yield table for teak (Anonymous, 1970). It is a soothing fact that though the above yield table pertains to the national level, the range of site quality levels of the yield table is more or less centrally placed with respect to the performance of teak in Kerala. Moreover the overall site quality distribution for the plantations included in the survey was found to fit well with the normal distribution. This means that most of the plantations in the population are expected to lie in II and III site quality classes and extreme cases of I and IV are likely to be rare. This pertains to the overall site quality distribution for Kerala and does not preclude regional variation in the pattern.

The site quality distribution observed in different Circles is indicated in Table 8. The chi-square test showed significant differences in the site quality distribution over Circles. Olavakkod Circle has a slight edge over other Circles by having more area under site quality II when compared to others. The rest of the Circles showed more or less similar pattern. The effect of these differences are reflected in the corresponding expected mean yield given in Table 8. Olavakkod Circle has shown the maximum yield. The State level figure is 351 m^3 ha^{-1} for 'total yield at 60 years and 177 m^3 ha^{-1} for 'final yield' at the same age. These values for the mean expected yields are to be interpreted with caution. The values are based on the site quality distribution of the entire set of plantations including both young and old, currently existing. Naturally, this value will be applicable for plantations under full stocking for a full rotation period in the future, under the assumption of constancy of site productivity over time.

Table 8. Proportion of number of plots in different site quality classes by Circles

Circle	Site quality class				Expected yield at 60 years (m^3 ha^{-1})
	I	II	III	IV	
Northern	0.155	0.317	0.500	0.038	346.4
Central	0.014	0.521	0.465	0.000	337.8
Olavakkod	0.112	0.705	0.183	0.000	396.2
High Range	0.047	0.376	0.577	0.000	325.8
Southern	0.129	0.428	0.373	0.070	349.0
Overall	0.087	0.482	0.405	0.026	350.9

A more realistic estimate of the current yield levels that can be realized will be that based on the site quality distribution of the area having stands around rotation age. The expected final yield at 60 years under full stocking based on the site quality distribution of area with stands of age 50 years and above was 139 m^3 ha^{-1}. However, the total yield cannot be worked out this way as the thinning yield comes from stands below 40 years.

3.4. Stand dynamics

The list of permanent sample plots established in different parts of the State is given in Table 9. The status of these plots with respect to age, site quality class, stocking and other features at the first and second measurements are also indicated in Table 9.

3.5. Optimum thinning schedule

The results of the simulation trial for working out the optimum thinning schedule are reported in Table 10. The results indicate that there is no need of any thinning in the first two stages followed by maximum removal at 30 and 42 years. This was the case when either silvicultural or mechanical thinnings were carried out before 12 years. Volume is maximized without carrying out any thinning in the four stages but with reduced diameter at final stages.

The consequences of avoiding two thinnings between 12 and 30 years (Table l0), with silvicultural thinning before 12 years-are examined in Figures 2, 3, 4 in comparison with the standard schedule based on yield table for teak. In both cases, the volume predictions were made through equations (l), (2) and (3). As can be seen from Figure 2, the reduction in number of trees under the standard schedule in each site quality class proceeds as per the yield table for teak. Comparative values in respect of the optimum thinning schedule are also given in Figure 2. The changes in the crop diameter under optimum and standard thinning schedules are depicted in Figure 3. Even when two thinnings are avoided, the diameter growth remained unaffected. The larger sized trees when harvested in later stages, resulted in increased volume as shown in Figure 4 . A gross comparison in terms of volume, of the three schedules viz., (i) optimum schedule with silvicultural thinning prior to 12 years (ii) optimum schedule with mechanical thinning prior to 12 years (iii) standard schedule as per yield table, are provided in Figure 5. The total volume inclusive of yield from thinning and final felling under optimum thinning schedule is much higher compared to other schedules. The fact that the increased volume is realized purely through optimal stand density management and is not through any additional inputs like fertilizers is impressive. The advantage of carrying out mechanical thinning prior to 12 years is evident only in site quality class I. In lower site quality classes, this option was on par or worse than the standard schedule. The above results points to the need for re-examining the present thinning schedule for teak in the State and also calls for further physical experimentation with the optimum and standard thinning schedules on year old stands.

Table 9. List of permanent sample plots established in teak plantations

Sl No.	Division	Range	Year planted	Name of the plantation
1	Chalakudy	Pariyaram	1984	Vettukuzhy
2	Kannur	Kasarkode	1946	Parappa
3	Konni	Konni	1946	Inchappara
4	Kothamangalam	Kothamangalam	1963	Thadikulam
5	Kothamangalam	Thodupuzha	1956	Valiayakandam
6	Kothamangalam	Kothamangalam	1973	Charupura
7	Kottayam	Ayyappankovil	1967	Ayyappankovil
8	Kottayam	Ayyappankovil	1941	Kallar
9	Kozhikkode	Peruvannamuzhi	1951	Panikkottoor
10	Malayattor	Kodanad	1968	Perumthode
11	Mannarkad	Mannarkad	1960	Panakadan
12	Mannarkad	Mannarkad	1934	Melekalam
13	Mannarkad	Attappady	1960	Pottickal
14	Munnar	Neryamangalam	1952	Neryamangalam
15	Nilambur North	Vazhikkadavu	1979	Kariam Vettilakkolli
16	Nilambur North	Nilambur	1952	Valluvasseri
17	Nilambur North	Vazhikkadavu	1977	Punchakkolli
18	Nilambur South	Karulai	1974	Nedumkayam
19	Nilambur South	Karulai	1949	Churulippotti
20	North Wynad	Chedalath	1978	Bhoodanam
21	Punalur	Anchal	1948	Kadamankadu
22	Ranni	Vadasserikara	1967	Padayanippara
23	Ranni	Ranni	1984	Pampavalley
24	South Wynad	Chedalath	1978	Ciyambam
25	Thenmala	Aryankavu	1990	Edappalayam
26	Thenmala	Aryankavu	1938	Edappalayam
27	Trichur	Machad	1953	Palakkathadom
28	Trichur	Machad	1942	Pulippurum
29	Trichur	Machad	1937	Elanad
30	Trichur	Peechi	1965	Kuthiran
31	Trichur	Peechi	1958	Pothundy
32	Trichur	Machad	1943	Pattanikkad
33	Trivandrum	Kulathupuzha	1940	Mylamoodu
34	Vazhachal	Vazhachal	1971	Choozhimedu
35	Vazhachal	Vazhachal	1990	Vazhacha1
36	Wynad(W.L)	Tholpetti	1953	Camp Road

Table 9. Cont...

Sl. No.	Name of the plantation	Plot sze (m x m)	Date of Establishment	Age (yr)	SQ class	Date of re-measurement
I	Vettukuzhy	50 X 50	09.03.93	8	I	13.02.97
2	Parappa	50 X 50	10.04.93	46	4	17.04.97
3	Inchappara	50 X 50	24.03.93	47	2	23.03.97
4	Thadikulam	50 X 50	23.02.94	31	3	05.04.97
5	Valiayakandam	50 X 50	14.03.94	38	2	07.04.97
6	Charupara	50 X 50	25.02.94	21	2	04.04.97
7	Ayyappankovil	50 X 50	05.03.94	27	3	10.04.97
8	Kallar	50 X 50	07.03.94	53	3	09.04.97
9	Panikkottoor	50 X 50	27.03.94	43	3	19.04.97
10	Perumthode	50 X 50	17.03.94	25	2	14.02.97
11	Panakadan	50 X 50	24.03.93	33	2	I2.03.97
12	Melekalam	50 X 50	26.03.93	59	2	13.03.97
13	Pottickal	50 X 50	27.01.94	34	2	29.04.97
14	Neryamangalam	50 X 50	27.02.94	42	2	06.04.97
15	Kariam Vettilakkolli	50 X 50	11.02.94	15	2	08.02.97
16	Valluvasseri	50 X 50	03.04.93	41	3	03.02.97
17	Punchakkolli	50 X 50	09.02.94	17	2	04.02.97
18	Nedumkayam	50 X 50	27.03.93	19	2	07.02.97
19	Churulippotti	50 X 50	21.02.93	45	2	06.02.97
20	Bhoodanam	50 X 50	20.04.93	15	2	26.03.97
21	Kadamankadu	50 X 50	10.03.93	45	4	22.02.97
22	Padayanippara	50 X 50	27.03.93	25	3	21.03.97
23	Pampavalley	20 X 20	15.02.94	10	1	18.03.97
24	Ciyambam	50 X 50	26.03.94	16	2	25.03.97
25	Edappalayam	20 X 20	14.02.94	4	NA	19.02.97
26	Edappalayam	50 X 50	13.03.93	55	2	18.02.97
27	Palakkathadom	50 X 50	18.03.93	40	3	28.01.97
28	Pulippuram	50 X 50	18.03.93	51	3	29.01.97
29	Elanad	50 X 50	16.03.93	56	3	30.01.97
30	Kuthiran	50 X 50	01.04.93	28	2	24.01.97
31	Pothundy	51 X51	31.03.93	34	3	22.01.97
32	Pattanikkad	50 X 50	03.05.93	50	3	27.01.97
33	Mylamoodu	50 X 50	14.02.94	54	4	20.02.97
34	Choozhimedu	50 X 50	05.03.93	21	3	11.02.97
35	Vazhachal	50 X 50	06.04.93	3	NA	12.02.97
36	Camp Road	50 X 50	22.04.93	40	2	27.03.97

Note : NA = Not assessed because of young age; DE = Damaged by

Table 9. Cont...

s1. No.	Basal area at first meas. (m^2ha^{-1})	Basal area at second meas. (m2ha-1)	Stocking at first meas. ($no.ha^{-1}$)	Stocking at second meas. ($no.ha^{-1}$)	Site index at first meas. (m)	Site index at second meas. (m)
1	11.43	8.52	1408	384	36.4	29.9
2	6.04	5.70	356	256	14.6	14.8
3	8.22	10.11	92	84	24.1	25.9
4	9.99	11.13	292	288	18.2	18.5
5	15.63	17.88	176	184	23.7	24.0
6	14.08	15.27	716	640	20.6	20.5
7	11.66	13.34	524	492	15.8	16.3
8	16.28	16.74	376	340	16.8	17.2
9	15.57	15.09	272	264	30.9	30.4
10	18.09	17.89	372	336	25.4	24.6
11	17.30	18.92	272	272	21.4	21.7
12	15.62	16.09	104	104	27.6	27.7
13	29.92	33.46	336	336	25.8	26.6
14	22.20	22.68	188	180	26.9	27.0
15	5.42	4.77	320	248	20.8	19.1
16	11.59	11.20	208	196	22.1	21.9
17	5.67	6.4 1	468	408	19.2	19.1
18	7.43	8.00	400	324	21.3	20.0
19	18.48	20.30	268	216	26.4	26.6
20	9.78	13.25	616	620	17.3	17.3
21	8.33	8.69	332	316	17.6	17.7
22	7.79	8.36	408	392	15.8	15.7
23	5.92	9.44	625	625	18.9	19.9
24	13.92	17.03	1044	860	20.8	20.8
25	4.14	10.88	2725	1200	48.1	26.4
26	20.13	22.18	160	160	23.8	24.5
27	11.24	12.17	208	216	20.1	20.5
28	11.41	11.92	168	164	21.6	21.9
29	14.47	14.99	144	144	25.9	26.1
30	14.77	10.58	400	176	20.5	21.9
31	10.84	10.82	184	169	21.3	22.1
32	10.68	11.49	124	124	24.4	25.1
33	8.58	7.95	280	204	15.3	15.9
34	6.25	6.85	360	280	18.2	17.9
35	3.34	4.68	1948	1172	0.0	0.0
36	15.21	13.85	128	100	22.9	23.7

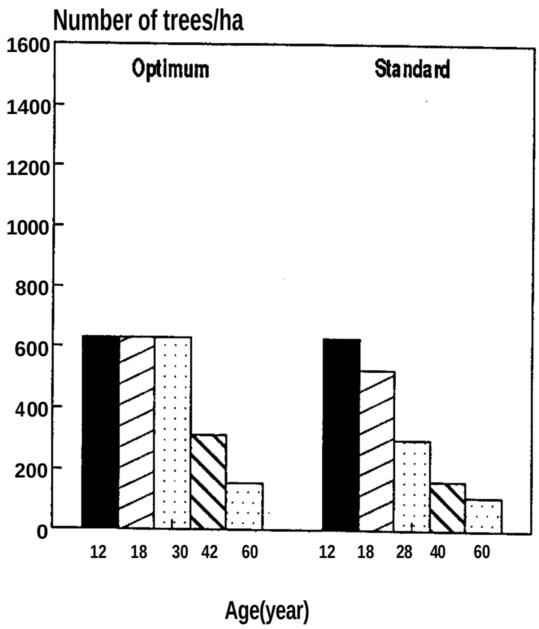

Figure 2a. Site Quality I

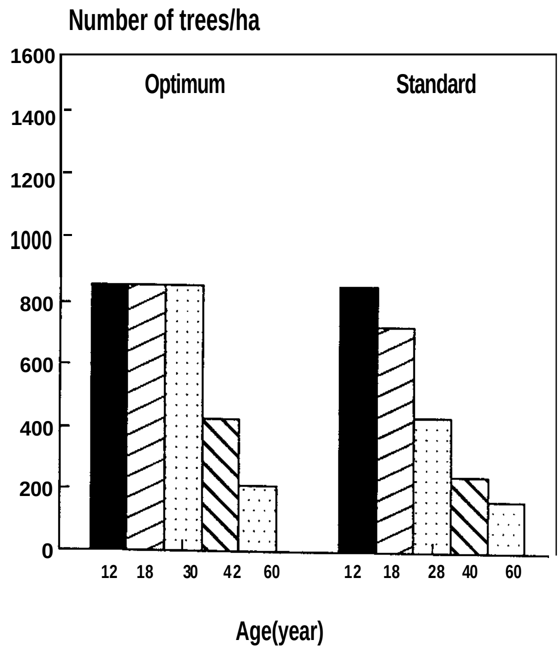

Figure 2b. Site quality II

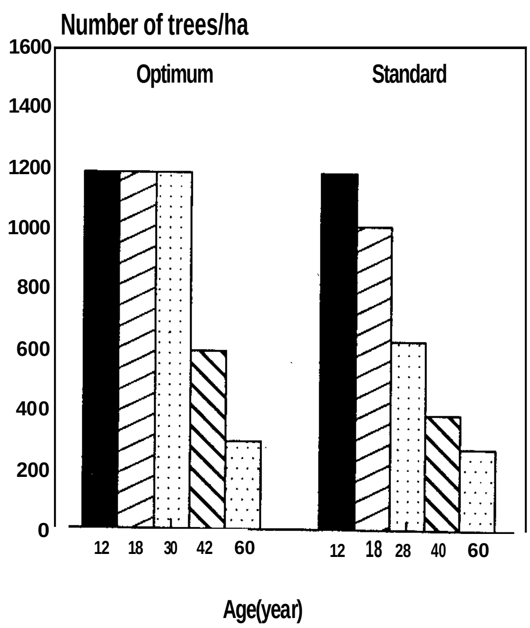

Figure 2c. Site Quality III

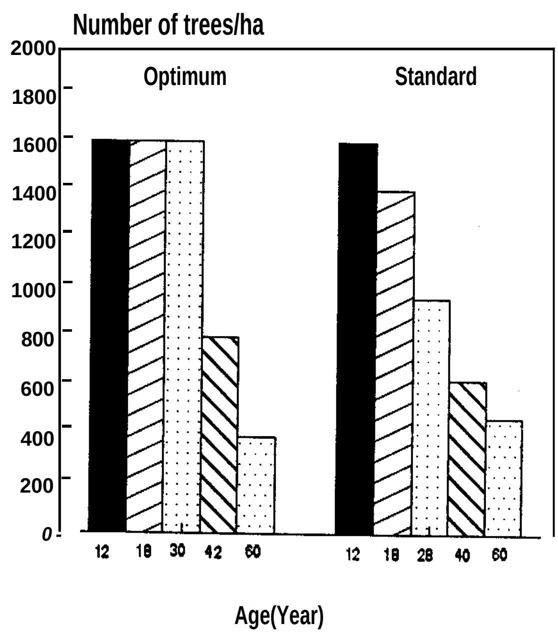

Figure 2d. Site Quality IV

Figure 2: Reduction in number of trees under optimum and standard thinning schedules for different site quality classes

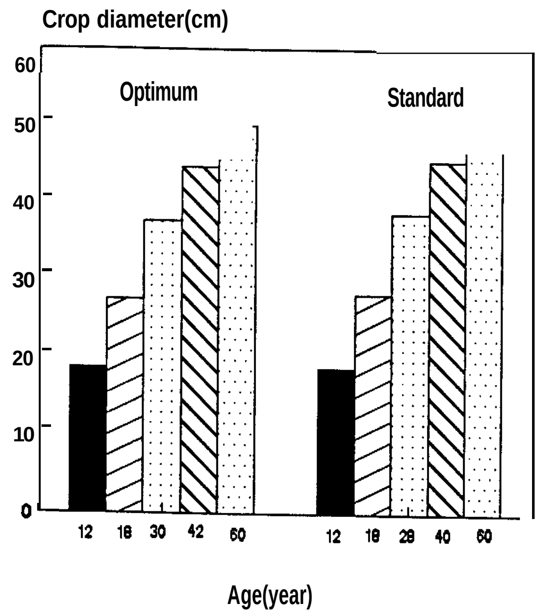

Figure 3a. Site Quality I

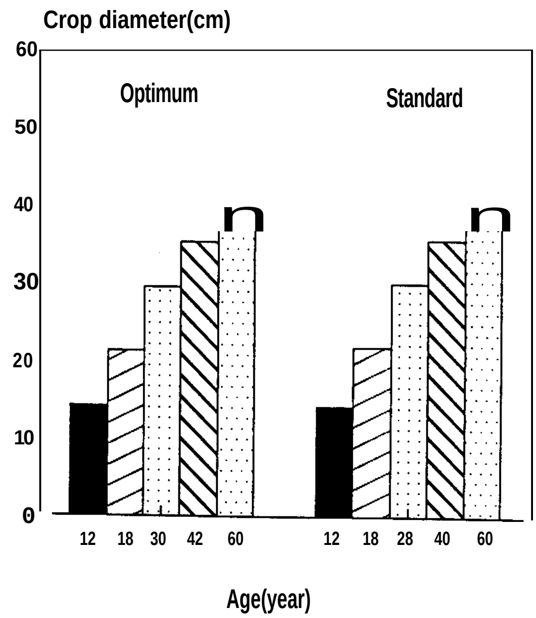

Figure 3b. Site Quality II

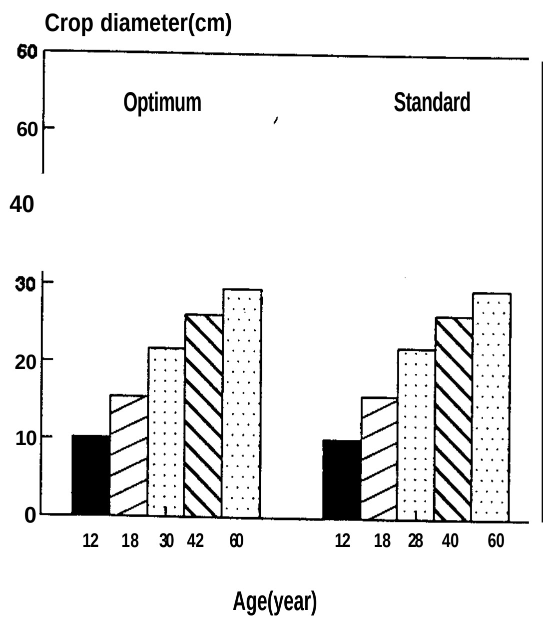

Figure 3c.Site Quality III

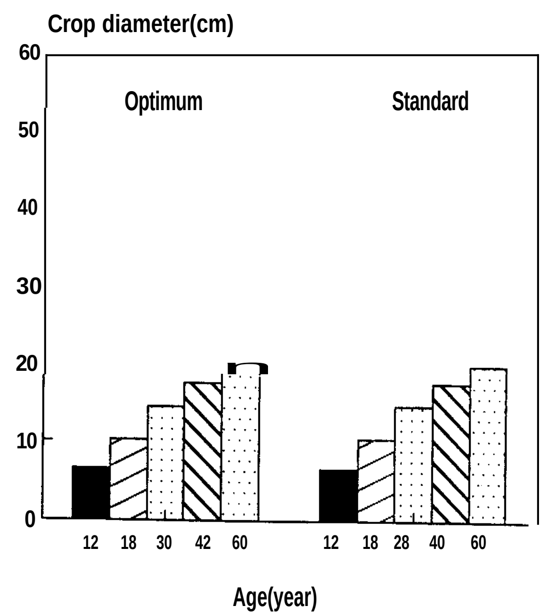

Figure 3d. Site Quality IV

Figure 3: Change in crop diameter of teak under optimum and standard thinning schedules for different site quality classes

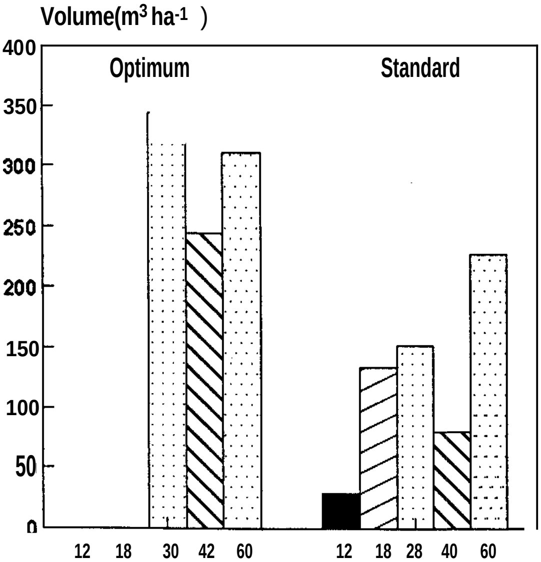

Figure 4a. Site Quality I

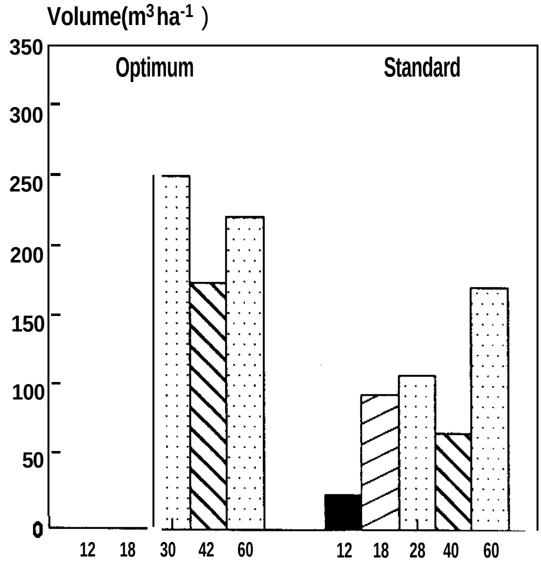

Figure 4b. Site Quality II

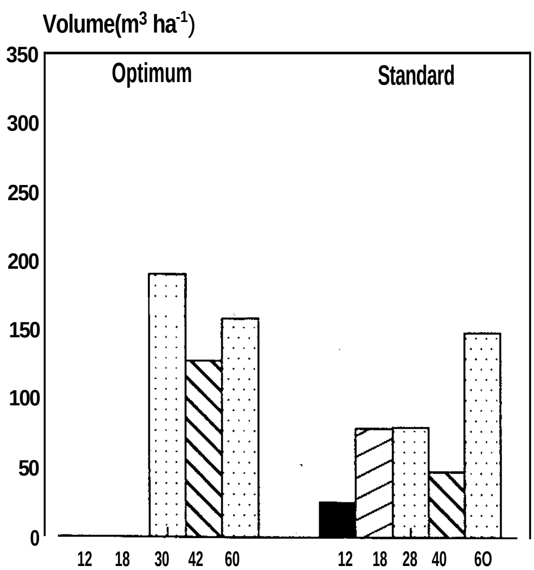

Figure 4c. Site Quality III

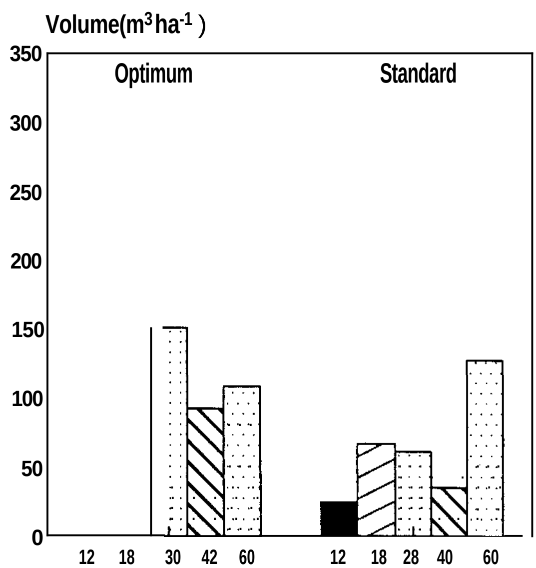

Figure 4d. Site Quality IV

Figure 4: Change in volume of teak under optimum and standard thinning schedules for different site quality classes

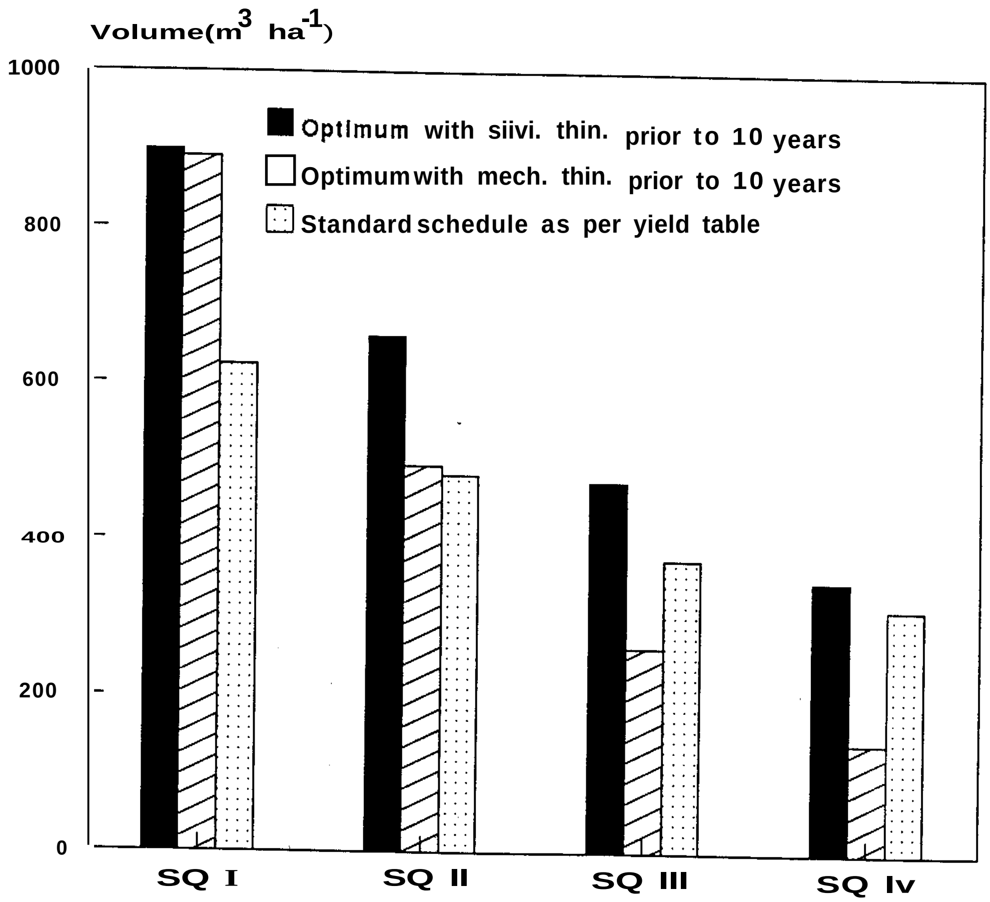

Figure 5: Total yield under optimum and standard thinning schedules for different site quality classes

Table 10. Optimum thinning schedule for teak in different site quality classes

Options	Age at thinning years, Intensity of thinning (%)			
	ST I	ST II	ST III	ST IV
Silvicultural thinning below 12 years	(--, 0)	(--, 0)	(30,50)	(42,50)
Mechanical thinning below 12 years	(--, 0)	(--, 0)	(30,50)	(42,50)
Silvicultural thinning below 12 years with no restrictions on tree size	(--, 0)	(--, 0)	(--, 0)	(--, 0)

3.6. Maximum sustainable harvest

The age class distribution of area under teak plantations managed by the Territorial Wing as on 1995 which formed the initial age structure for simulations is given Table 11. The corresponding age class distribution of standard hectares of II/III site quality class is also given in Table 11 and Figure 6. Although five-yearly values are given in Table 11, the area falling under individual years was used in the computations. Only the area having stands younger than 100 years was considered for the simulations which came to 71782 ha. The yield figures used in the simulations are reported in Table 12.

Table 11. Age structure of teak plantations belonging to the Territorial Wing as of 1995 and the corresponding area under standard area (II/III site quality class)

Age group (years)	Actual area (ha)	Standard II/III area (ha)	Cumulative % of standard II/III area (%)
<5	3313.590	3710.026	5.15
5-10	1202.909	1346.823	7.02
10-15	4586.035	5052.659	14.04
15-20	13447.596	13540.454	32.85
20-25	10204.237	11004.445	48.13
25-30	9972.213	9949.231	61.95
30-35	11163.124	9661.484	75.37
35-40	5513.590	5200.138	82.59
40-45	3174.189	2641.302	86.26
45-50	3330.793	3182.890	90.68
50-55	2888.493	2518.723	94.18
55-60	2254.302	2261.919	97.32
60-100	1876.367	1711.595	99.70
2100	240.048	218.969	100.00
Total	73167.486	72000.658	

Figure 6. Age structure of standard area (II/III site class) of teak plantations in Kerala

Table 12. Yield of teak at final felling (timber and smallwood) for II/III site quality class

Age (year)	Yield (m^3ha^{-1})	Age (year)	Yield (m^3ha^{-1})
40	**129.938**	**56**	**153.685**
41	**131.813**	**57**	**154.821**
42	**133.624**	**58**	**155.925**
43	**135.374**	**59**	**156.999**
44	**137.066**	**60**	**158.045**
45	**138.703**	**61**	**159.063**
46	**140.286**	**62**	**160.054**
47	**141.819**	**63**	**161.020**
48	**143.304**	**64**	**161.961**
49	**144.743**	**65**	**162.879**
50	**146.138**	**66**	**163.773**
51	**147.491**	**67**	**164.646**
52	**148.804**	**68**	**165.497**
53	**150.078**	**69**	**166.328**
54	**151.315**	**70**	**167.139**
55	**152.517**	**>70**	**167.139**

After repeated simulations, the age structure reported above was found to sustain an yield level of 1,40,000 m^3 annually, inclusive of timber and smallwood under a rotation age of 50 years. The plantations reached a stable age class distribution after 91 years. The total area of 71,782 ha under the Territorial Wing got redistributed in 80 age classes almost equally. However, retaining the stands much older than the rotation age is not desirable and so the reason for the above state of affairs was looked into. An examination of the initial age structure showed that, going from the oldest age class to lower age classes, there is a sudden upward shift in the area from 30-34 years onwards. The plantations below 35 years of age initially will qualify for final felling after about 15 years and so a provision was made to review the target yield after about 15 years. After a few trials it was found that the sustained yield level can be raised to 2,00,000 m^3 after 14 years from the start. The stable age class distribution was achieved after 161 years. At the terminal stage, the total area of 71,782 ha of the Territorial Wing got redistributed in 52 age classes starting form -1 to 50 years with around 1348 ha in each age class. The area in -1 age class is taken as area felled in the current year to be planted the next year. Similarly, the area in 0 age class is taken as currently planted area.

The simulations with 60 years as the rotation age showed a sustained yield level of 83,000 m^3 annually, inclusive of timber and smallwood. The plantations reached a stable age class distribution in 159 years. The total area of 71,782 ha under the Territorial Wing got redistributed in 141 age classes almost equally. Since retaining the stands much older than the rotation age is not desirable, the target yield was changed after about *25* years. After a few trials it was found that the sustained yield level can be raised to 1,75,000 m^3 after 24 years from the start. The stable age class distribution was achieved after I56 years. At the terminal stage, the total area of 71,782 ha of the Territorial Wing got redistributed in 62 age classes starting form -1 to 60 years with around 1092 ha in each age class.

As a practical strategy, it is good to know the extent of plantations to be felled every year to meet the target yield. Such an output is given in Table 13 which shows the area to be subjected to felling for the next 60 years to realize the target yield under rotation age of 50 as well as 60 years. The annual cut required in terms of the percentage of total area is less than 2 per cent which looks reasonable. The area to be felled in a particular year to realize the target yield as shown in Table 13, may have to be obtained from plantations of different ages. For the purpose of illustration, an expanded statement for the first 5 years of harvesting for rotation age of 60 years is given in Table 14 wherein, the age and extent of the plantations to be cut are indicated. The geographical locations of the plantations of any age-group can be obtained readily from the database for the forest plantations in the State. The teak plantation area currently felled annually or the out-turn from final felling were not directly available for comparison. A compilation made from the Administration Reports of the Kerala Forest Department which is indicative of the above features is reported in Table 15. The area clearfelled centered around 212 ha and the harvest varied around 19,122 m^3 of timber and smallwood (inclusive of yield from thinning). Although the out-turn of timber as reported in the Administration Reports excludes yield of poles and billets, comparison of the current levels of harvest with the maximum sustained yield indicates that the annually felled area has to be raised considerably to meet the target yield. However, this can be done without any apprehension provided sufficient measures are taken to retain the site productivity over time.

The effects of bringing the teak plantation to normality in one rotation period are discernible from Figures 6 and 7. When the rotation age was kept at 50 years, the yield levels varied from 2,24,613 m^3 to 1,94,006 m^3 in the first 50 years and stabilized at 2,01,731 m3 after 50 years. The lowest harvesting age to be followed in any year came down to 46 years in the first 50 years. With a rotation age of 60 years, the expected yicld from the Territorial Wing varied between 1,91,301m^3 and 1,66,437 m^3 in the first 60 years and stabilized at 1,84,065 m^3 after 60 years. The lowest harvesting age in any year to be followed was 48 years.

Some general comments are in order here. The yield levels quoted in the above set of results are expected figures as per the prediction equation used in the simulation runs and their realization in the field shall depend on the validity of the prediction equation. The yield prediction equation used was estimated based on observations on standing volume from around 1200 sample plots through out the State. Although there is nothing much to doubt about the validity of this equation, disparity with the actually realized yield at the field could arise due to a number of factors like differences in stocking. presence of defective trees nonadherence to standard definitions of timber and smallwood ctc. Similarly, although the conversion strategies seem justified in terms of the total area available, the expected yield figures are subject to the validity of the yield prediction used in the simulation.

Table 13. Area to be felled for the next sixty years to obtain maximum sustainable harvest

Rotation age 50				Rotation age 60			
fear	Area to be felled (ha)	Final yield State total) (m^3)	Per cent area to be felled (%)	Year	Area to be felled (ha)	Final yield (State total) (m^3)	Per cent area to be felled (%)
1	849.4	140000	1.18	1	499.9	83000	0.70
2	876.0	140000	1.22	2	508.8	83000	0.71
3	882.8	140000	1.23	3	516.7	83000	0.72
4	887.8	140000	1.24	4	517.5	83000	0.72
5	894.6	140000	1.25	5	517.6	83000	0.72
6	902.6	140000	1.26	6	518.2	83000	0.72
7	906.2	140000	1.26	7	518.0	83000	0.72
8	908.8	140000	1.27	8	519.5	83000	0.72
9	912.4	140000	1.27	9	520.6	83000	0.73
10	914.9	140000	1.27	10	521.5	83000	0.73
11	917.7	140000	1.28	11	521.3	83000	0.73
12	925.0	140000	1.29	12	520.2	83000	0.72
13	928.9	140000	1.29	13	520.0	83000	0.72
14	935.0	140000	1.30	14	519.0	83000	0.72
15	1341.9	200000	1.87	15	518.6	83000	0.72
16	1350.6	200000	1.88	16	518.5	83000	0.72
17	1355.3	200000	1.89	17	517.8	83000	0.72
18	1348.7	200000	1.88	18	516.5	83000	0.72
19	1347.9	200000	1.88	19	516.4	83000	0.72
20	1346.8	200000	1.88	20	517.5	83000	0.72
21	1344.1	200000	1.87	21	516.7	83000	0.72
22	1338.6	200000	1.86	22	516.2	83000	0.72
23	1333.9	200000	1.86	23	516.1	83000	0.72
24	1332.6	200000	1.86	24	516.0	83000	0.72
25	1323.6	200000	1.84	25	1089.7	175000	1.52
26	1321.7	200000	1.84	26	1091.2	175000	1.52
27	1315.9	200000	1.83	27	1095.0	175000	1.53
28	1311.3	200000	1.83	28	1093.4	175000	1.52
29	1310.7	200000	1.83	29	1088.9	175000	1.52
30	1301.4	200000	1.81	30	1086.8	175000	1.51

Table 13. cont...

Rotation age 50				Rotation age 60			
Year	Area to be felled (ha)	Final yield (State total) (m^3)	Per cent area to be felled (%)	Year	Area to be felled (ha)	Final yield (State total) (m^3)	Per cent area to be felled (%)
31	1301.4	200000	1.81	31	1086.8	175000	1.51
32	1299.3	200000	1.81	32	1084.6	175000	1.51
33	1298.2	200000	1.81	33	1080.5	175000	1.51
34	1291.8	200000	1.80	34	1077.7	175000	1.50
35	1290.3	200000	1.80	35	1074.4	175000	1.50
36	1285.1	200000	1.79	36	1073.1	175000	1.49
37	1282.7	200000	1.79	37	1068.6	175000	1.49
38	1275.3	200000	1.78	38	1068.6	175000	1.49
39	1273.9	200000	1.77	39	1062.9	175000	1.48
40	1269.9	200000	1.77	40	1062.1	175000	1.48
41	1266.1	200000	1.76	41	1057.4	175000	1.47
42	1265.5	200000	1.76	42	1057.4	175000	1.47
43	1257.4	200000	1.75	43	1052.1	175000	1.47
44	1253.1	200000	1.75	44	1049.4	175000	1.46
45	1249.6	200000	1.74	45	1047.0	175000	1.46
46	1242.1	200000	1.73	46	1047.0	175000	1.46
47	1241.0	200000	1.73	47	1047.0	175000	1.46
48	1234.9	200000	1.72	48	1047.0	175000	1.46
49	1231.5	200000	1.72	49	1047.0	175000	1.46
50	1227.9	200000	1.71	50	1047.0	175000	1.46
51	1224.4	200000	1.71	51	1047.0	175000	1.46
52	1222.3	200000	1.70	52	1047.0	175000	1.46
53	1221.2	200000	1.70	53	1047.0	175000	1.46
54	1220.0	200000	1.70	54	1047.0	175000	1.46
55	1220.9	200000	1.70	55	1047.0	175000	1.46
56	1224.4	200000	1.71	56	1047.0	175000	1.46
57	1243.1	200000	1.73	57	1047.0	175000	1.46
58	1269.0	200000	1.77	58	1047.0	175000	1.46
59	1277.3	200000	1.78	59	1047.0	175000	1.46
60	1274.6	200000	1.78	60	1047.0	175000	1.46

Table 14. Area to be felled from different age classes for the next 5 years to obtain the target yield under rotation age of 60 years

Year	Age of plantation (Year)	Area to be felled (ha)
1	86	4.431
1	85	0
1	84	0
1	83	0
1	82	0
1	81	0
1	80	28.806
1	79	0
1	78	0
1	77	22.476
1	76	17.037
1	75	4.105
1	74	13.155
1	73	1.844
1	72	11.330
1	71	50.781
1	70	28.606
1	69	80.181
1	68	121.705
1	67	115.442
2	68	65.900
2	67	88.911
2	66	97.195
2	65	60.240
2	64	86.171
2	63	110.351
3	64	20.473
3	63	276.989
3	62	219.197
4	63	186.269
4	62	331.182
5	63	156.68
5	62	360.347

Table 15. Teak plantation area annually felled and the out-turn

Year	Area excluded during the year (ha)	Out-turn (m^3)
1984 - 85	214.5	21819
1985 - 86	138.0	14051
1986 - 87	370.3	16252
1987 - 88	183.9	19189
1988 - 89	122.5	8062
1989 - 90	107.5	24719
1990 - 91	116.3	15514
1991 - 92	251.4	19753
1992 - 93	402.7	32738

Note : Area excluded in a year is taken as indicative of the area felled in a year. The out-turn of wood (timber and smallwood in round) excludes yield of poles and billets.

Source: Annual Administration Reports of the Kerala Forest Department.

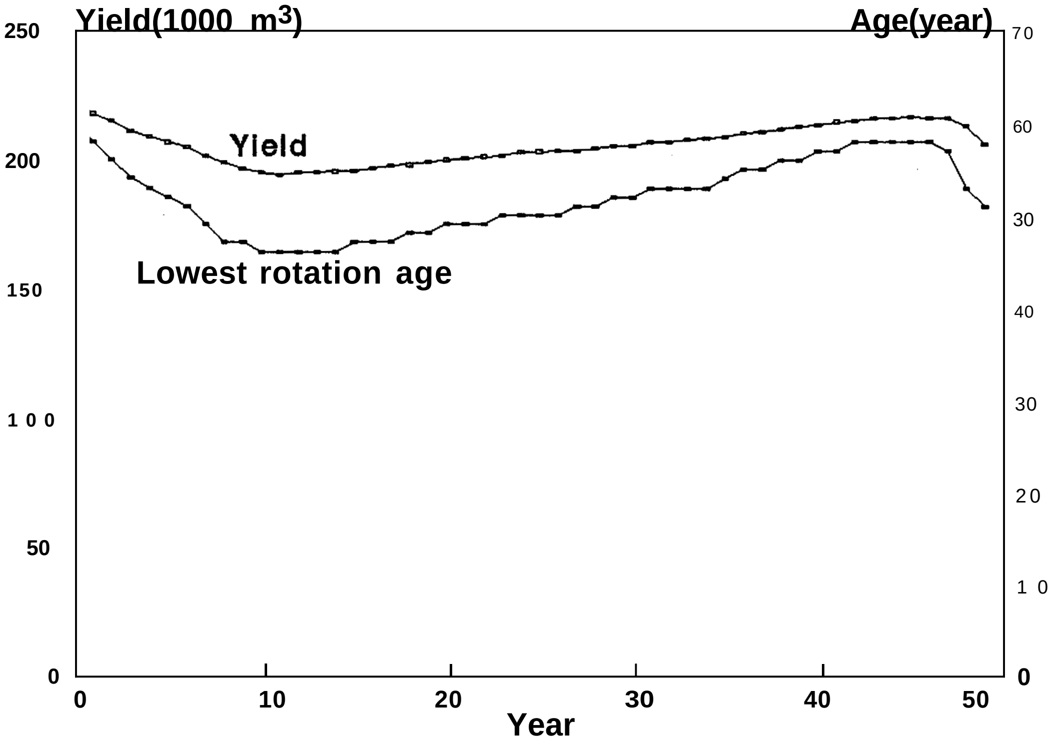

Figure 7. Expected yield pattern while attaining normality in 50 years

Figure 8. Expected yield pattern while attaining normality in 60 years

4. CONCLUSIONS

A study on the status of teak plantations in Kerala revealed that nearly 60 per cent of the plantations are overstocked. Overstocking was mostly due to delayed thinning or natural regeneration of miscellaneous species responding to empty space in older plantations.

The observed site quality distribution indicated site quality class II and III being predominant among the plantations, the percentage of area belonging to these classes being 48 and 41 respectively. There was a marked absence of higher site quality levels in older plantations.

Efforts made to work out an optimum thinning schedule for teak based on computer simulation indicated that two silvicultural thinnings in practice after 10 years of planting teak are unnecessary. Even when two thinnings are avoided, the diameter growth remained unaffected. The larger sized trees when harvested in later stages, resulted in increased overall volume. The above results points to the need for re-examining the present thinning schedule for teak in the State and also calls for further physical experimentation with the optimum and standard thinning schedules on 10 year-old teak stands.

Investigations on the maximum sustained yield from teak plantations in the State indicated that with the existing land base, the current harvest levels can be increased manifold without depleting the resources in any manner. However, sufficient measures are to be taken to retain the current productivity levels of the plantations over lime.Efforts to bring the plantations to normality in one rotation period would require bringing down the rotation age to as low as 46 years for a few years initially.

REFERENCES

Anonymous, 1970. Growth and Yield Statistics of Common Indian Timber Species. Forest Research Institute and Colleges, Dehra Dun : 257-281.

Anonymous, 1997. Productivity of teak and eucalypt plantations in Kcrala. KFRI Consultancy Report. Kerala Forest Research Institute, Peechi, Kerala. 68 p.

Chaturvedi, A. N. 1973. General Standard Volume Tables and Height-Diameter Relationship for Teak (*Tectona grandis*). Indian Forest Rccords (NS). Silviculture, Vol. 12, No. 8, Manager of Publications, Delhi. 8 p.

Chaturvedi, A. N. and Khanna, L. S. 1982. Forest Mensuration. International Book Distributors, Dehra Dun. 406 p.

Clutter, J. L., Fortson, J. C., Pienaar, L. V., Brister, G. H. and Bailey, R. I., 1983. Timber Management : A Quantitative Approach. John Wiley & Sons. New York. 333 p.

Jayaraman, K. and Rugmini, P. 1993. Variation in the productivity of teak plantations in Kerala. Proc. Fifth Science Congress, January 1993, Kottayam. pp. 179- 181.

Nair, N. R. 1971. Provisional Volume Tables for the Forest Trees of Kcrala. Kerala Forest Department. 41 p.