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DEMONSTRATION – CUM – RESEARCH ON MULTI–TIER FORESTRY THROUGH OPERATIONS RESEARCH

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ABSTRACT

The potential of **multi-tier forestry** as a powerful tool for the **ecorestoration** of degraded forest areas lying close to human habitation was successfully demonstrated through a 2.17 ha experimental plot established in a degraded forest area at Kerala Forest Research Institute, Peechi. Various operations were carried out to convert this degraded site of moist deciduous forest into a multi-tier forest which is ecologically sound, economically viable, and socially relevant, capable of meeting multifarious needs of local people on a **sustainable** basis through **intensive multiple use**. The study also revealed the effectiveness of multi-tier forestry in overall productivity enhancement as well as promotion and conservation of **biodiversity** of the site and adjoining ecosystem.

Complexity of the problem necessitated the use of **Operations Research** approach, which looks at various aspects of the problem under study with a holistic perspective from multi-disciplinary and trans-disciplinary angles. The nature of multi-tier forest to be developed, operations to be carried out, problems involved in planning and implementation, and strategies for tackling these problems were also studied.

Within three years after initiation of study, number of plants in the plot increased 25 times, 45% of which was through natural regeneration. Total number of species increased from 15 to 163. Number of plants per hectare in different height classes 0-2 m, 2-10 m, 10-20 m, and above 20 m increased from 10, 325, 58, and 3 to 8709, 1218, 86 and 6 respectively. During third year, there was a yield of 4.52 tonnes of fuel wood, 3.3 tonnes of green manure, 1.67 tonnes of fodder, 1.27 tonnes of small timber, 0.438 tonnes of teak leaves (packing materials) and 0.249 tonnes of materials of medicinal importance per hectare. Various activities generated 696 man-days ha^{-1} yr^{-1} of labour in the form of partial employment. Of this, women constituted 65%. Through various goods and services 255 families were benefited.

Overall cost per hectare incurred in first three years of establishment when adjusted to the current year was only Rs.18, 900/-. Wages of 128 man-days ha^{-1} yr^{-1} towards costs of various cultural operations were saved through participation of local people. An amount

of Rs. 769/- per hectare was realised through supply of various materials produced from the plot on subsidised rates during third year.

During the subsequent six years of consolidation, local people collected an average of 4.5 tonnes of green manure, 14.6 tonnes of fodder, 9.16 tonnes of fuel wood, 2.56 tonnes of small timber, 1.28 tonnes of medicinal produces, 3.85 tonnes of teak leaves,155 bamboo culms, 25 rattan stems ha^{-1} yr^{-1}. The value of these produces came to Rs. 13,033/- ha^{-1} yr^{-1} at local rates. The activities also generated labour of 1095 man-days ha^{-1} yr^{-1}. There was a steady overall increase in growing stock and various benefits during this period. Cash flow obtained by considering the cost of establishment and the value of the materials realised revealed a positive net cumulative benefit in the 6^{th} year and an amount of Rs.54,741/- in the 10^{th} year, thus demonstrating the potential of the practice from economic perspective.

Transformation of existing vegetation into multi-tier forests by regeneration and selective harvesting; choice of species and package of practices that can supplement and complement the eco-system of the influence zone; development of a multi-species permanent local nursery to meet the requirement of the site and adjoining eco-system on a continuous basis; **participatory forest management** involving local people of the influence zone to minimize biotic pressure, to reduce operational cost and to ensure the full utilization of various produces; and **decentralized planning** and execution coupled with efficient coordination and control at different levels of management, were the major management strategies identified for successful implementation of multi-tier forestry. The potential management tools identified to help in decision making on multi-tier forestry were (i) **stock mapping system** for site evaluation, (ii) a **continuous inventory system** for assessment of needs and potentials of people in influence zone, (iii) a **silvicultural knowledge base** which can provide information on different species and silvicultural management techniques and (iv) a set of **modeling tools** for integrating the above three for decision making. With suitable illustrations and examples, the study highlighted scope of utilising various computer-aided management tools such as **Data base technology**, **Geographic Information System**, and **Operations Research** for developing them.

Key-words: multi-tier forestry, ecorestoration, sustainability, intensive multiple use, bio-diversity, Operations Research, participatory forest management, decentralized planning, stock mapping system, continuous inventory system, silvicultural knowledge base, modeling tools, Data base technology, Geographic Information System.

1. INTRODUCTION

Existence of large stretches of degraded forests as an interface between natural forests and human settlements is a common occurrence in the tropics, particularly in the thickly populated third world countries (CSE 1986; Davidson, 1982; Hallworth, 1982; Poore and Sayer, 1987; Spears, 1985;). The local people depend heavily on these forests for various forest-based needs and due to excessive biotic pressure these forests are getting depleted in quality and quantity. Development of appropriate forestry practices ensuring maximum production and utilization in a sustainable manner is very important for enabling these forests to carry out their various ecological, social and economic functions.

Intensive multiple use has been suggested by many resource planners as one of the most viable and even inevitable practice for the sustainable management of scarce forest resources in the tropics (Allen, 1986; Arnold, 1983; Bare and Field, 1987; Bell, 1976; Davis and Johnson, 1987; Gong, 1992; Leuchner, 1990; Nair *et al*, 1984). In a thickly populated, land hungry state like Kerala, where most of the forests lie in close proximity to human habitations, this is particularly true (FAO 1984). The local people depend heavily on these forests for fodder, fuel wood, green manure, small timber, various materials of daily use such as bamboo, rattans, honey, different products of medicinal value, food and varied forms of labour. They also depend on these forests for their many intangible requirements such as soil and water conservation and pollution control. Often the demands on these forests far exceed their current potential making them more and more degraded. The only option available is to develop appropriate forestry system in which intensive multiple use can be adopted on a sustainable basis.

With the vegetation structure and management practices currently being followed, there are serious constraints in adopting sustainable intensive multiple use in most of the existing forest plantations and natural forests of Kerala (Nair, 1980; Nair *et al*, 1984). Due to less number of species and more or less uniform nature of management practices followed, it is

difficult to adopt multiple use forestry in existing forest plantations (monoculture or mixture). In case of natural forests, factors such as incompatibility of species with the needs of local population, poor stocking and skewed size class distribution cause serious limitations in practicing sustainable intensive multiple use forestry.

Multi-tier forests are forests comprising various plant species, grass, herbs, shrubs, climbers and trees of varying heights mixed together, occupying various layers above and below ground eco-system. Such a system developed appropriately by incorporating species and package of management practices suited to the site conditions and local needs are likely to be more suitable for intensive multiple use than natural forests and plantations.

Though much has been discussed about the merits of multi-tier forests developed by simulating tropical rain forests (Lasco, 1988; Maydell, 1991), literature on systematic efforts to develop such forests is lacking. Most of the reported studies were concerned with multiple cropping system as practised in agriculture and agroforestry, consisting of mostly domesticated plant species (Bandolin and Fisher, 1991; Nair and Sreedharan, 1986; Nair, 1987; Nair and Dagar, 1991; Pierre, 1991). Other similar studies were mainly on forest areas where agriculture crops were raised along with forestry crops (Inoue and Lahjie, 1990; Lasco, 1988; Peck, 1983; Remmers and De Koeijer, 1992). Kerala is well known for multi-tier cropping system in its home gardens with 10 to 15 forest tree species existing as combinations (Chacko, 1991; Nair *et al*, 1986;). Most of the plantations are monocultures and the rest, which are mixed, consist of, at the most, 5 or 6 species in a set (Kerala Forest Department, 1990; Nair *et al*, 1980). The performance of mixed plantations in the state was also not up to the expectations (Chacko, 1991; FAO, 1984). This was the case with 'vanarashmi plantations' (plantations in which forest and agricultural crops like pepper were mixed) and 'heterogeneous plantations' (mixed plantations involving species such as, *Tectona grandis* L.f and *Bombax ceiba* L.) of Kerala Forest Department (Nair, 1980). Survey of literature revealed a dearth of information regarding success of multi-aged, mixed forest plantations involving large number of species. Performance of natural forests managed under

traditional silvicultural systems was also not satisfactory. The practice of selection felling, a harvesting system that envisages harvesting of trees which are silviculturally available from such forests, though scientifically sound, was a failure due to management problems and was stopped in Kerala (Balasubramanyan, 1984; Karunakaran, 1992).

Though multi-aged mixed forests were theoretically very promising from ecological and economic angles due to optimal utilisation of available land, the increased number of species, age classes and the variety of package of practices required make their design, development and management complex. Thus it was necessary to conduct studies for developing appropriate management strategies for multi-tier forestry.

The Kerala Forest Department, in 1989, under a World Bank supported social forestry programme entrusted Kerala Forest Research Institute the task of establishing a demonstration plot on "multi-tier forestry" by optimal utilisation of available know how and resources. A demonstration plot was thus established in an area of 2.17 ha. at Kerala Forest Research Institute Campus at Peechi. Though this project was completed in 1992, observations on various aspects connected with development of the plot were continued. The findings are highlighted in this report.

2. MATERIALS AND METHODS

2.1 MATERIALS

When compared to monoculture plantations, multi-tier forestry offers large number of options with regard to species suitable for a site and also within the site. The trade-offs associated with site conditions and uses of different species also vary considerably. Increase in number of species results in increase in number of management options viz., in choice of species, regeneration techniques, nursery management, pattern of arrangement of species in space and time, various stand management practices including pest and disease control and other protection measures, harvest scheduling, in geometric or exponential proportions. Long gestation period involved in knowing response of different management practices in the system, makes evaluation of different options difficult. Effect of external factors, such as influence of neighbouring community, complicate the issue further. Due to inter-linkage between components involved, as well as high trade-off connected with different management options available, successful establishment of multi-tier forest requires considerable efforts involving lot of trial and error methods. Thus, development of a multi-tier forest poses complex problems in the design, establishment and management.

Operations Research (OR) provides powerful tools to handle such complex management problems in a systematic manner (Ackoff and Sasieni, 1968; Hwang and Mazud, 1979; Makarav *et al*, 1982; Saaty, 1959; Taha, 1976; Zeleny, 1974). This approach looks at the system under study with a holistic perspective from multi-disciplinary and trans-disciplinary angles. For easy handling, a model of the system is created and used for the study. Through this model, the different components of the system and their inter-relationships are studied with the help of system analysis from individual and overall perspective. The results are then integrated to arrive at solutions satisfactory from an overall perspective. The solutions arrived at in this manner are then verified and modified by analysing the performance of the system in achieving the desired goals through actual implementation of these solutions in the real life problem.

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Problem formulation, model development, deriving solution to the problem from the model, testing and refinement of the solution through implementation of solutions to the problem under study, are the major phases of any Operations Research project and these processes are repeated till satisfactory results are obtained (Hiller and Lieberman, 1974). (Fig.1).

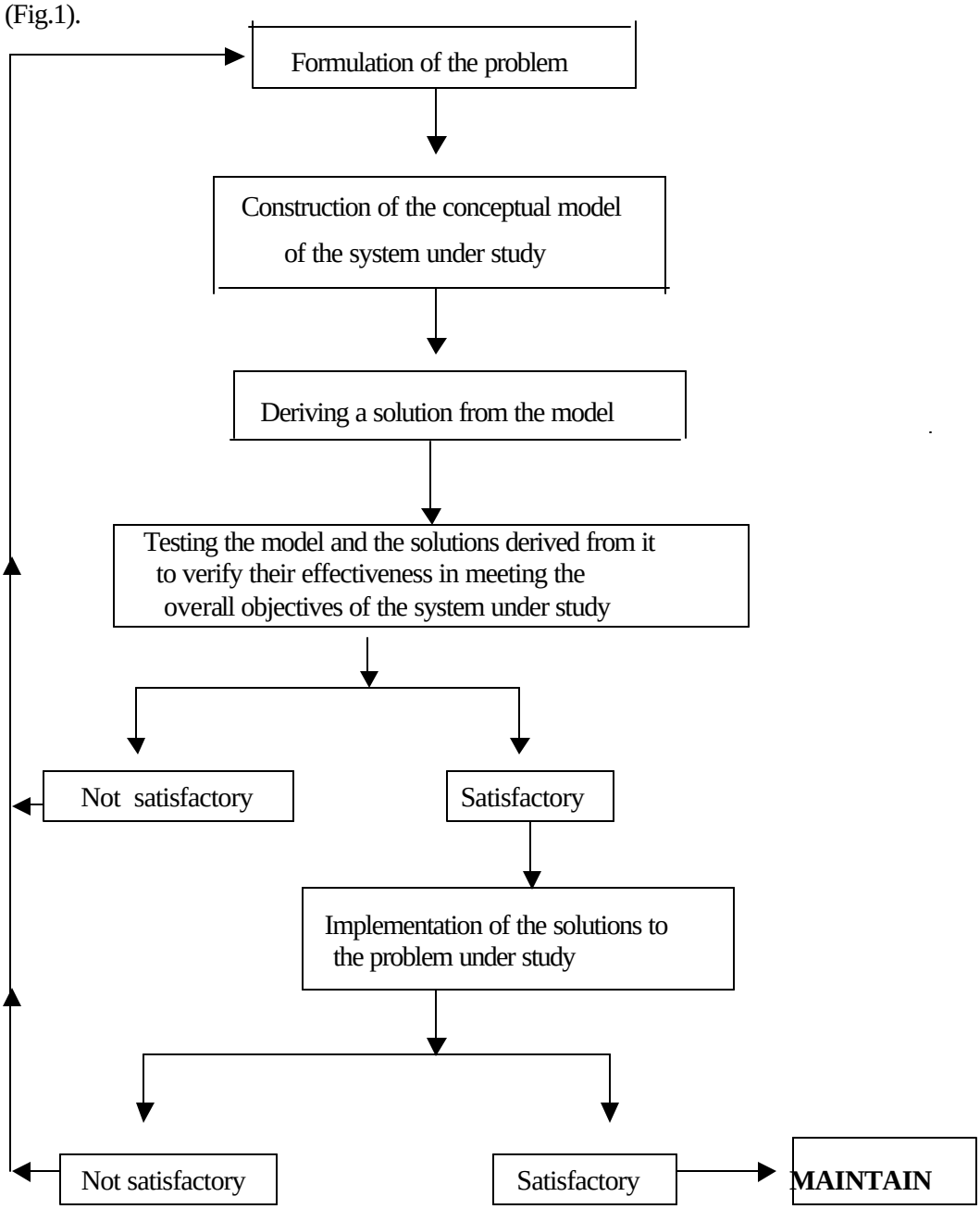


Fig.1.Schematic diagram showing different phases of an Operations Research Project

Operation Research approach is increasingly used in complex forest management problems (Bare *et al*, 1984; Bare and Field, 1987; Dress and Field, 1985; Mendoza and Sprouse, 1987; Rustagi, 1973). Some of the earlier applications of OR in forestry cover areas such as land use planning, yield regulation, thinning, enterprise planning, regulation of species composition, wildlife management and timber production (Adams and Elk, 1974; Amidon and Akin, 1968; Duerr, 1971; Fornstad, 1971; Hofle, 1971; Jackson, 1971; Kostov, 1971; Naslund, 1969; Novotny, 1971; Risvand, 1971; Rustagi, 1973; Sayers, 1971; Wardle, 1965; Wardle, 1971). Use of OR in choice of species (Ban, 1985; Huang, 1985); in land use planning (Bell, 1976; Davies and Johnson, 1987; Dykstra, 1984); for multiple use forestry (Arp and Lavigne, 1982; Mendoza *et al*, 1987); and for thinning and yield regulation (Chen *et al*, 1980; Filius and Dul, 1991; Leuschner, 1990; Martin and Ek, 1981) are well documented. Due to large computing requirements, till recently, only developed countries having sophisticated computing facilities have used its application. However, the advent of low cost but powerful microcomputers has helped to widen the use of these techniques to third world countries. With the availability of technologies such as, Geographic Information System for spatial analysis, Satellite remote sensing for quicker and cheaper spatial data acquisition, and Knowledge based Expert System technologies for handling large body of knowledge available, the power of these tools have enhanced considerably (Arnoff, 1989; Datta and Bandyopadhyay, 1993; Davis and Nanniga, 1985; Eastman, 1992; Eastman, 1994; Fedra *et al*, 1987; Fedra, 1993; Lam and Swayne, 1991; Parent and Church, 1989).

In this study, the task involved was to transform the given site to a multi-tier forest comprising vegetation which is most suited to site conditions and needs of the people, particularly local population, within the shortest time possible and with minimal cost, making use of available know-how and resources. An understanding of the nature of forest and the objectives for which it is to be developed, along with the processes involved, is required for this purpose. This involves assessment of existing vegetation, forest utilisation and management practices, climate, topography, soil, and needs and potentials of neighbouring population. Information on different species, their site requirements, growth and yield, utilisation potential and silvicultural management practices are also essential. Success of multi-tier forest depends on optimum matching of

micro-site conditions at individual plant level with the species and management practices over space and time, which vary considerably when compared to monoculture plantations.

2.2METHODS

Development of a mathematical or abstract model is the common practise in an OR project. However, as in case of many semi-structured problems, because of the complexity and lack of information with regard to the nature of multi-tier forestry and the factors governing, there was difficulty in formulating such a model. So, to begin with, based on conventional knowledge, a mental image of a multi-tier forest was conceived as a model and various activities required to transform the given site to the multi-tier forest as conceived was initiated. Modification to the mental image was made based on field response of the operations undertaken and additional information gathered from other forestry practice. This process was repeated a number of times during the study to concretise the nature of multi-tier forest and operations required for developing such a forest.

The following guiding principles were identified and adopted in the development of this model of a multi-tier forest.

(ii) Vegetation should contain trees of varying heights, shrubs, herbs, climbers, creepers and grass. There should be sufficient representation to each of these components in the proposed multi-tier forest.

(iii) Species chosen have to be forestry species, which are capable of meeting various needs of the local population. Introduction of domesticated plant species that can be easily grown in the neighbouring homesteads need to be kept to the minimum. Local species or species which are found in similar forest types should be given preference.

(iv) To promote bio-diversity as well as to ensure multiple use, opportunity should be given to grow maximum number of species in the multi-tier forestry site within the limitations of logistical constraints.

(v) To facilitate large-scale implementation, practices that are simple and low cost should be given preference.

(vi) The species chosen at individual plant level should match the micro site condition.

(vii) To enable sufficient growing space among plants of diverse nature, following spacing pattern was conceived for an ideal multi-tier forest:

Table 1. Thumb rule for spacing in different tier classes in multi-tier forestry:

Tier class	**Height category**	**Spacing**
Tier I	20-40 m(large sized trees)	12 m
Tier II	10-20m(medium sized trees)	8 m
Tier III	2-10 m(small sized trees)	4 m
Tier IV	Shrubs	2 m
Tier V	Herbs, climbers, creepers and grass	No specific spacing

The recursive steps that were adopted in the development of a multi-tier forest in the study area are given in Fig. 2.

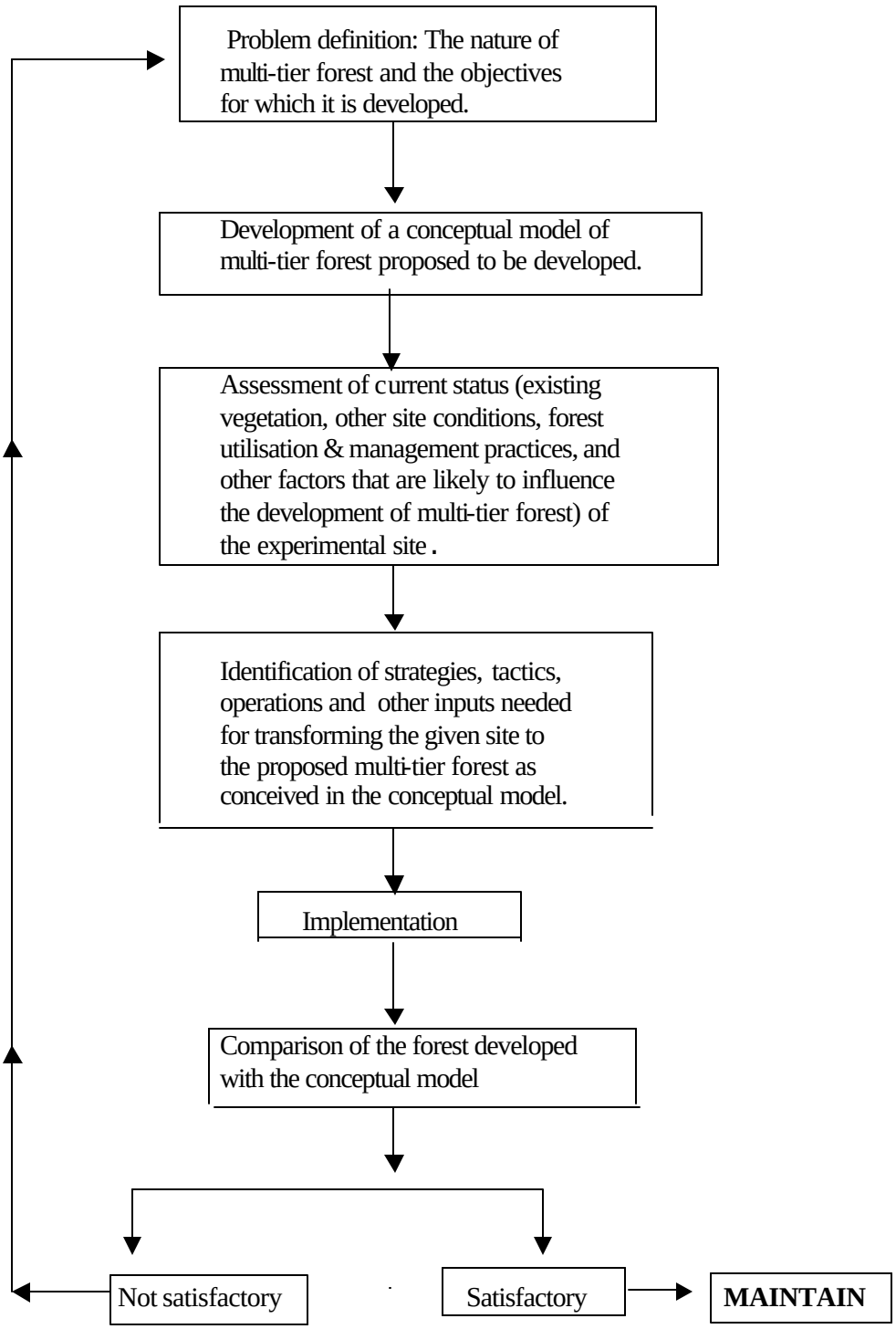


Fig. **2** Various steps adopted in the development of multi-tier forest

The major components influencing the successful development of multi-tier forest as revealed by the preliminary systems analysis is shown in Fig. 3. The interactive and dynamic nature of the components, as detailed in Fig. 4, makes it difficult to complete the study on one aspect and then to proceed to the next. So, the approach adopted was to initiate activities which are necessary for transforming the given area into the multi-tier forest of required nature based on available information and then refine these activities taking into consideration the information gathered on interacting components subsequently.

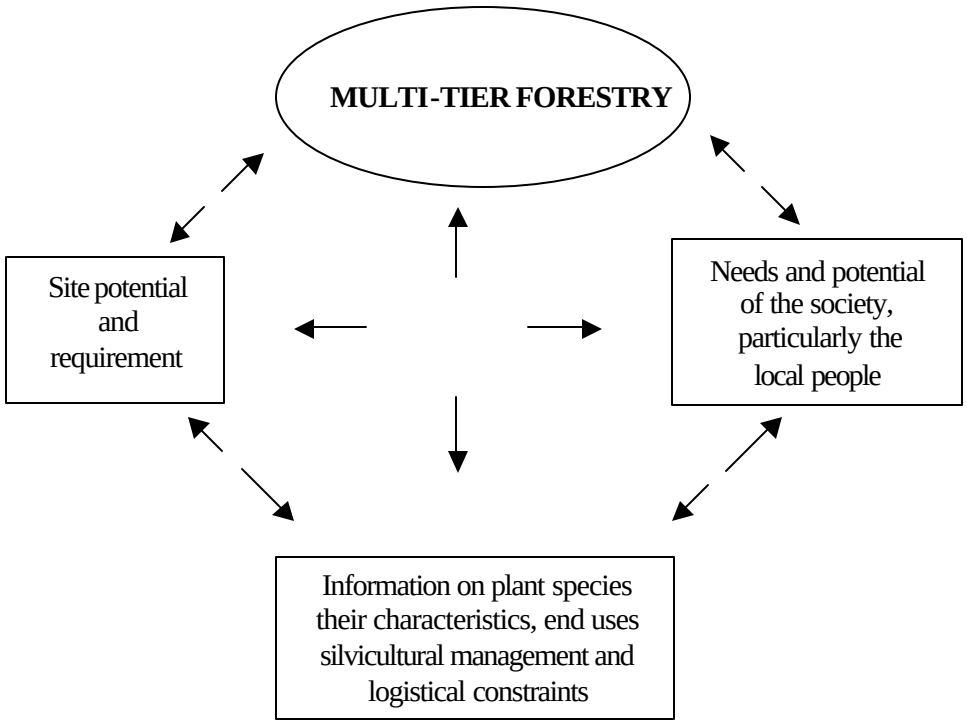


Fig. 3 Schematic diagram showing the interacting components on multi-tier forestry.

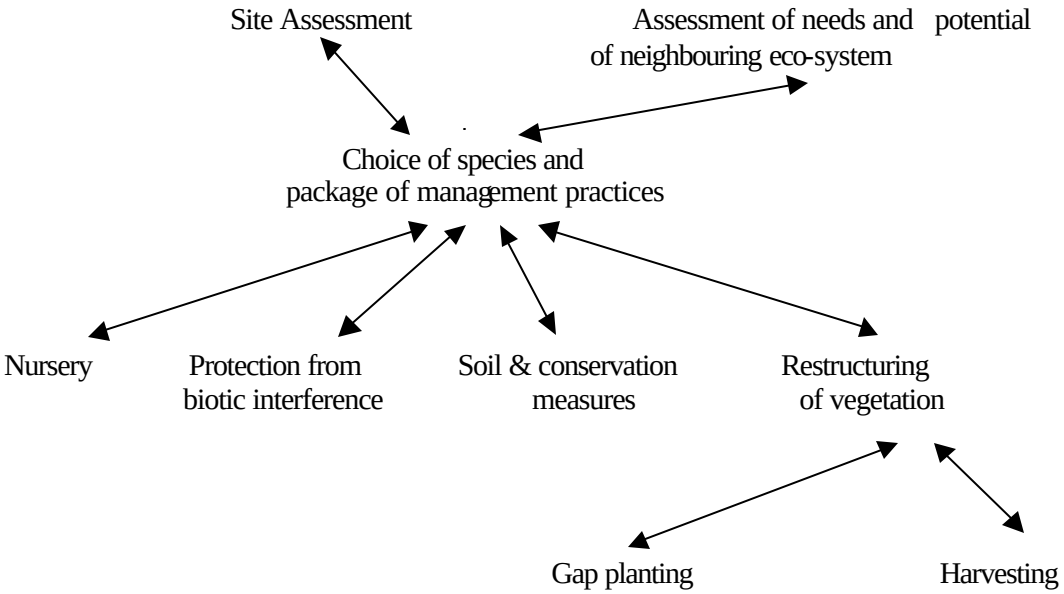


Fig. 4 Schematic diagram showing interactive and dynamic nature of components of a multi-tier forest.

The major operations identified in the effective transformation of a given area into a multi-tier forest are site assessment, identification of influence zone and assessment of needs and potentials of local population and stand modification. The procedures adopted in these operations are detailed below.

2.2.1 Site Assessment

When compared to other afforestation/ planting practices, multi-tier forestry demands micro-level assessment of the site to a greater extent on a continuous basis. Due to involvement of variety of species with differing characteristics, micro-level information of the site at individual plant level is often required to decide the spatial and temporal arrangement of plant species, regeneration techniques, planting design, soil and water conservation methods, cultural practices, maintenance, thinning, yield regulation and harvesting. No standard methods are available to collect this information. Standardisation

of suitable procedures for multi-tier forestry is a time consuming task involving lot of experimentation. So, to start with, the site assessment was carried out using the conventional procedure followed in any afforestation programme such as field survey, review of various published and unpublished records and local enquiry. In this manner, maximum possible information on macro and micro-site conditions that are required for development of multi-tier forestry were gathered. The forest department records, past working plans, and weather data of the area available with KFRI were the records studied. Exhaustive enumeration of existing vegetation was carried out using standard stock mapping procedure (Chaturvedi and Khanna, 1994). Assessment of site on various required parameters on a repetitive basis using the above mentioned approaches so as to modify the site in the desired manner. Subsequently, an effort was also made to evolve a stock mapping procedure to evaluate site condition at micro and macro levels. The method devised and employed in the study are given below.

Stock mapping procedures: In multi-tier forestry, because of involvement of plants of multi-species, uneven-aged characteristics grown through natural and artificial regeneration, there was no fixed spacing pattern between plants. So, as in the case of regeneration and stock mapping surveys in natural forests, the entire site was divided into grids of appropriate size (Fig.5). As trees of smallest height category, 2-10m height, were to be provided with a tentative spacing of 4m.(Table1), to enable effective spatial representation of distribution of plants, a grid size of 4mx4m was chosen to be ideal for stock mapping.

These grids were located for field measurement by marking them in the field and also with the help of measuring ropes suitably marked for the purpose. To facilitate collection of data on various parameters pertaining to plants as well as site features suitable proformae were used (proforma 1,2 &3; appendix 1).

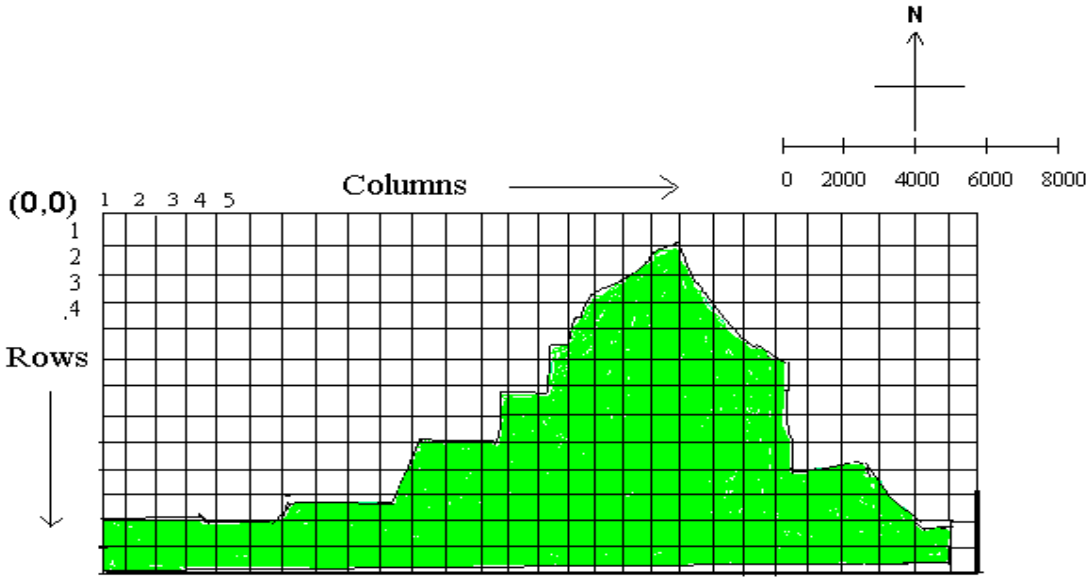


Fig. 5 Stock mapping system for multi-tier forestry - spatial arrangement

Computerisation and processing of data: Stock mapping involves considerable amount of data. Handling of this data by manual methods was cumbersome, time-consuming, labour intensive and prohibitively costly. This was sorted by computerising the data with the help of data base management packages such as Dbase & FoxPro. A sample copy of computerised database files is given in file format 1, appendix 2. The various stock mapped data arranged in such database files provided all information required on stand. This was used for effective monitoring as well as for deciding various management decisions. A computer program in FoxPro used for getting desired spatial information on vegetation from the stock-mapped database is given in program 1, appendix 4. The spatial display of desired parameters was made by converting this stock-mapped data into GIS formats using GIS software IDRISI and ARC/INFO.

2.2.2 Assessment of needs and potentials of local population

The first task was to decide the extent of area influencing the site (influence zone). The influence zone is a dynamic concept and depends on the nature of resources available within the site, the size of the site and the needs and potentials of the people. There was no standard method available to identify the influence zone. So, the alternative was to demarcate the area based on a reconnaissance survey as probable influence zone. Various methods are available for carrying out surveys in such a situation (Huxely, 1987; Maydell, 1991; Muller and Scherr, 1990; Raintree, 1987). The methods available include Diagnosis and Design, Rapid Rural Appraisal, Census and Statistical Survey based on sampling. Each of these methods has got its own advantages and limitations and no method has been found to be fool proof. An appropriate method best suited to the specific situation had to be evolved.

In the present case, assessment of need and potential of local population were carried out by an integrated approach involving five different methods.

(i) A reconnaissance survey to get a first time view of extent of influence zone as well as requirement of local population.

(ii) A complete enumeration survey covering households in the influence zone identified through reconnaissance survey: The survey was conducted using proforma 4 (Appendix 1).

(iii) A detailed sample survey of households in the influence zone: 25% households were sampled. Samples were selected through simple random sampling. The survey was conducted using proforma 5 (Appendix 1).

(iv) Repeated interaction and information exchange with the stakeholders involved.

(v) Continuous monitoring of the benefits and beneficiaries using proforma 6 and 7 (Appendix 1)

The survey data were summarised with the help of appropriate database management Software Dbase and FoxPro. Sample copies of computerised data formats used are given in file format 2, 3, 4 and 5 (Appendix 2).

2.2.3 Stand modification

An evaluation of the needs and potentials of the site and the influence zone revealed the following as important tasks in transforming the given degraded forest area into a multi-tier forest.

(i) Providing compatible conditions for growth and development of existing vegetation.

(ii) Creating conditions for promoting natural regeneration.

(iii) Equipping the present site to fully utilise the site conditions and potentials available in the neighbouring ecosystem by gradual restructuring of vegetation to make it compatible to site conditions and needs of local population.

A number of methods are available in forestry and agriculture for achieving the above mentioned objectives. (Binkley and Gardina, 1998; Brunig, 1983; Champion and Seth, 1968; Evans, 1982; Ghosh, 1977; Govindankutty and Alavikutti, 1988; KFD, 1996; Khanna, 1984; Maithani, 1988; NWDB, 1987; Odum, 1969; Smith, 1962; Solanki and Tiwari, 1988). However, in the case of multi-tier forestry, when compared to other forestry practices options available are quite large and the trade-off also vary considerably. So the task involved was to choose appropriate set of methods which are suited to the situation and implement them with necessary modification. Through trial and error, a number of methods were tried in the study area. To ensure success, the method has to be simple and easy to implement, cost effective, eco-friendly and efficient. Efforts were made to identify and test various methods through actual implementation.

The following six major approaches were identified as important tasks in multi-tier forestry development.

(i) Reduction of biotic interference and to minimise the harmful effects.

(ii) Enhancement of productive potential of the site through soil and water conservation.

(iii) Choice of species suitable to site conditions and local needs.

(iv) Restructuring the existing vegetation to achieve multi-tier forestry structure.

(v) Ensuring availability of quality planting stock on a continuous basis for planting in the site as well as for supply to local people through a permanent multi-species nursery.

(vi) Reduction of establishment cost and efficient utilisation of various yields from multi-tier forestry.

2.2.3.1 Reduction of biotic interference

Though the site as well as the locality factors such as topography, forest type, geology, soil and climatic conditions were congenial for developing a multi-tier forest suitable for intensive multiple use, the forest was in a degraded condition due to excessive biotic pressures. The local people were using the area for meeting various day to day requirements and activities such as, uncontrolled cutting of trees for fuel wood and small timber; lopping for green manure and fodder, sweeping the floor for litter collection, cattle grazing and lighting of fire for various purposes. This has also resulted in making the area barren and in turn susceptible for unregulated water run off and heavy soil erosion, thus making the land with shallow soils and exposed rocks. Warding of harmful biotic interference was thus identified as one of the important pre-requisites for restoring the ecosystem to its potential. However, taking into consideration the nature of biotic pressure, it was extremely difficult to totally prevent it. Moreover, for the benefit of the forest, it was found sufficient to control and minimise the harmful effects of biotic activity.

A number of methods were available for preventing biotic interference. It was observed that, no measure when implemented in isolation was sufficient to meet the challenge. For example, barbed wire fence or individual watch and ward was not sufficient in preventing the uncontrolled entry of local people into the forest area. Frequent damage to the barbed wire fence made its maintenance prohibitively costly and thus ineffective. This was the case with posting of watchers also. Measures such as involvement of local people or social fencing, planting trees in the households could be achieved only gradually and could be carried out successfully only after creating the necessary environment. However, these measures were found to be quite effective when implemented in a phased manner. It

was found that for successful implementation, a close supervision by a technical forestry officer with expertise is an imperative necessity for achieving the desired results.

The following methods when employed in a systematic and integrated manner were found to be effective in reducing biotic pressures.

(i) Existing barbed wire fences, which were damaged by men and cattle, were repaired and strengthened.

(ii) Regular watcher-cum-workers were engaged in sufficient number for watch and ward purposes. They were also entrusted with execution of various forestry activities to be carried out in the site.

(iii) Measures were initiated to strengthen the barbed wire fence by establishing a live hedge inside the plot adjacent to barbed wire fence. Multi-purpose species such as *Bougainvillaea*, *Lawsonia*, *Erythrina*, *Gliricidia*, bamboo, canes, *Agave*, different species of *Opuntias*, *Ceasalpinia sappan*, *Hibiscus rosa-sinensis* and *Adhatoda vasica* were planted along fence in appropriate designs as live hedge (Fig. 6)

Fig. 6 Reduction of biotic pressure: Live hedge.

(iv) Efforts were initiated to change the attitude of apathy and mistrust prevailing among the local population by creating awareness about the importance of afforestation work and the consequent benefits they derive and by showing

interest to understand their problems and needs. These encouraged participation and involvement of local people (Fig. 7).

Fig. 7 Reduction of biotic pressure: Interaction with local people.

(v) Gradual involvement of local people in various plantation development and management activities such as maintenance and harvesting was encouraged.

(vi) The duties of watcher-cum-labourers were gradually transformed to that of extension workers. Their services were utilised for training and supervision of various plantation development and management activities including supervision of the harvest of different materials in a regulated and systematic manner.

(vii) Modelling the plantation through appropriate silvicultural management interventions such as, introduction of suitable species, regulation of harvesting, improved utilisation of various produces were undertaken to change the nature of the forest to a healthy, viable and sustainable multi-tier forest.

(viii) Promotion of measures such as, planting of appropriate species in their home gardens, effective utilisation of available forest based resources and encouragement for utilising alternative resources were carried out simultaneously. This was achieved by creating awareness through informal interaction with the local people and also through use of display of appropriate boards giving appropriate messages in English and local language (Fig.8).

Planting stock of suitable species were provided to the local people for encouraging tree planting.

Fig. 8 Creation of awareness: Display board hig hlighting activities of the study.

2.2.3.2 Soil and water conservation measures

Prevention of surface water runoff, retention of rainwater during dry season, enrichment of soil fertility by erosion control and through recycling of organic material and fixing of nitrogen from atmosphere and soil were identified to be the thrust areas for improvement of the site. The following measures were identified and implemented in the study area:

(i) Retention walls were erected using rubble stones available within the site in two sensitive locations along the boundary to prevent sliding of land (Fig.9).

Fig. 9 Soil conservation: Retention walls to prevent soil erosion.

(ii) Gullies wherever seen were plugged using locally available rubble stone and brushwood.

(iii) A large number of pits were dug during the first year so as to obstruct surface water run off and act as catch pits. They served as small traps for topsoil and organic matter that eroded from upper regions. These pits were used for planting in subsequent years.

(iv) Contour planting in the slopes with suitable species was carried out. Multi-purpose species such as Agave, Pineapple, Subabul, Aloe, Vetiver were planted in specific designs such as staggered planting to suit various micro level field features (Fig.10).

(v) Pits inwardly tilted to the uphill side of the slopes were dug in sloppy areas, whereas along flat terrain, saucer shaped pits were chosen, so as to conserve as much water as possible

(vi) Leaf mulching and stone packing were carried out for drought sensitive plants just before summer.

(vii) Thinning and pruning, grass cutting and green manure collection were carried out in a regulated manner to prevent the unnecessary exposure of land.

Fig. 10 Soil and water conservation: Contour planting with Vetiver and leaf mulching.

(viii) While harvesting, a good amount of plant residue was deliberately left behind at the site. This acted as leaf mulch as well as organic material for enhancing the soil fertility as well as for efficient nutrient cycling.

(ix) A number of nitrogen fixing species were introduced so as to fix the atmospheric nitrogen.

(x) Under storey species such as herbs, shrubs and grasses were introduced to provide adequate ground cover to regulate surface water flow. Most of these species belong to medicinal plant category so that these can serve dual purpose (Fig.11).

2.2.3.3 Selection of plant species

Green manure, fuel wood, fodder, small timber (poles for banana support and other household requirements), bamboo and plants of medicinal importance were major needs of local people. These were kept in mind while selecting species for planting in the experimental plot. As there is lot of scope for growing many herbs, shrubs and climbers

as ground storey vegetation, plants belonging to these categories having different end-uses were also considered for planting.

Fig. 11 Selection of multi-purpose under storey species for soil cover.

Following site specific features were found to be of significance in the design of multi-tier forest:

(i) Species with soil binding capacity were identified for planting along slopes to check erosion.

(ii) Plant species, which prefer more water, were selected for areas close to canal, depressions and gullies.

(iii) Shade loving plants were chosen for locations under dense canopy (Fig. 12).

(iv) Shallow rooted plants were identified for rocky areas.

(v) Drought enduring species were planted in drier and open/exposed areas.

(vi) Species with smaller crown were chosen for planting along the boundaries to avoid disturbance to neighbouring households.

(vii) Wind hardy species were planted as wind breaks.

(viii) Species with nitrogen fixing characteristics were selected to facilitate soil enrichment.

(xi) Suitable species were selected as live hedge to serve as a permanent measure of

protection to augment existing barbed wire fence.

(x) Plant species of aesthetic value were chosen for planting along roadside.

Fig. 12 Shade loving plants under dense canopy

To enable effective selection of species, information on various aspects such as vegetative characteristics, site requirements, growth and yield, uses and package of management practices of different species were gathered from multiple data sources such as literature, unpublished records and knowledge available with different people. This was computerised as a silvicultural knowledge base for easy retrieval.

2.2.3.4 Restructuring the vegetation

To ensure maximum possible output in a sustainable manner, it was necessary to have an optimal stocking of different plant species of differing growth characteristics (age, height, girth, crown and volume) and end uses.

Following methods were identified and employed in the study area:

(i) Selective harvesting of plants – While harvesting, plants that were silviculturaly available or required depending on space/light requirements were given preference. So also plants, which were not required to be harvested on silvicultural considerations, were harvested only when absolutely needed otherwise.

(ii) Planting of suitable species in appropriate locations considering the growth requirements, micro-site conditions and harvesting potentials.

(iii) Promoting natural regeneration – Natural regeneration was found to be easier and cheaper than planting. Hence, wherever possible, natural regeneration was promoted and planting was adopted only when absolutely essential.

(iv) Tier classification and spacing of vegetation – As both natural and artificial regeneration is employed simultaneously, it was difficult to adopt a specific spacing pattern. However, while planting or harvesting, spacing requirement of plants available at the site has to be considered to avoid wastage. To facilitate this, the plants available in the plot were classified based on their potential height into different tiers (Refer Table1).

(v) Harvesting of plant produce from the site – In addition to silvicultural availability, the market demand and requirements of the local people were the other main considerations.

(vi) Cultural operations such as, canopy manipulation, pruning and branch cutting – These activities were identified to be essentia l for optimal growth of the under storey vegetation and general health of the stand. The local population also used these plant produces as green manure, fodder, fuel wood and small timber (Fig.13)

Fig. 13 Canopy manipulation.

The stand structure was modified by controlling the various stand parameters such as stocking, species composition, basal area, stand volume and crown area. Actual and potential height (the height a plant would have achieved at the time of maturity) were the major controlling parameters with respect to which these stand parameters were regulated.

2.2.3.5 Multi-species permanent nursery

Good planting stock is necessary, not only for planting purposes but also to supply to local population. This is essential as planting of suitable species in households situated in the vicinity need to go hand in hand with multi-tier forestry activities so as to reduce the pressure on the forest. To provide planting stock on a sustainable basis, the following measures were identified and employed.

(i) Collection and storage of required seeds and other planting stock from different locations/different agencies.

(ii) Establishment of a multi-species nursery (Fig. 14)

.**Fig. 14** Multi-species nursery.

2.2.3.6 Cost reduction and efficient utilisation of plant produce

In multi-tier forestry, when compared to other forestry practices, the quantum of labour required for various operations such as, nursery, site preparation, pitting and planting, weeding, soil working, plantation maintenance, thinning and harvesting, are quite high. Also marketing of variety of produces is also a problem. During the study it was found that involving local people could easily solve these problems. The local people were ready to carry on the work connected with grass cutting, weeding, thinning, branch pruning and canopy manipulation, as it will provide them employment as well as the necessary material required for their daily subsistence (Fig.15&16). These, apart from solving problem of labour availability, also provided an opportunity to involve local people in protection as well as in other management operations. At the same time, these provided the local people substantial scope for enhancing their living standard through generation of employment as well as resources, which are essential for their livelihood. Thus, involvement of local people in the activity was found to be a necessary and essential aspect of successful and sustainable multi-tier forestry development.

Fig. 15 Participation of local women in activities in the site.

Fig. 16 Cost efficient utilisation of harvested materials from the site.

The procedures employed on the above six major operations were evaluated and integrated in a repetitive basis to achieve the desired goal. The results of these operations are reflected in stand dynamics.

3. RESULTS

The findings of the various operations as detailed earlier are summarised in this section.

3.1 Site assessment

The area selected for the study lies at $10^0$32'N and $76^0$20'E of Thrissur Forest Division, Peechi Forest Range, Vilangannur hill reserve (Fig.17). This is under lease to KFRI from the Kerala State Forest Department. The site is situated at the top of a micro watershed. The Peechi-Thrissur road runs along the southern boundary. There are house compounds adjoining the study area

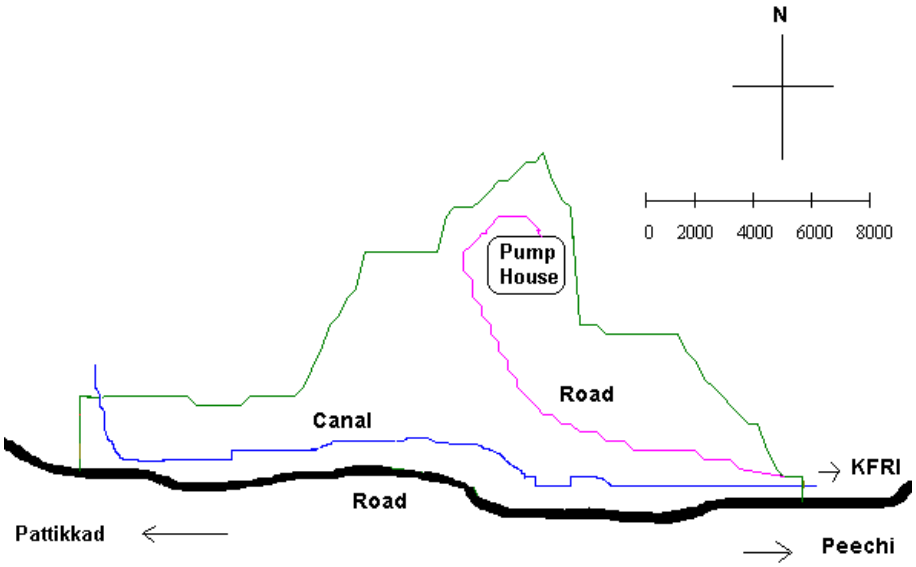


Fig.17 Location map of the study area on multi-tier forestry (prepared using GIS)

Originally this was a part of the Peechi forest area supporting moist deciduous forest, rich in economically important plant species such as teak, rosewood, Xylia, Terminalias, bamboo and canes. Local enquiry and search of Forest Department records revealed that with the passage of time there was encroachment of the forest by the settlers, who had

come from various parts of state for construction of the Peechi dam. This led to the depletion and degradation of the rich forest. In 1945-46, teak planting was tried but failed. Due to heavy biotic interference such as, illicit removal of trees, overgrazing, litter collection, unscientific lopping of trees for green manure, and frequent fire, the land became highly degraded supporting only some unhealthy teak coppice growth and a few miscellaneous species. Though the land was taken over by KFRI in 1975, improvement was minimal due to the heavy pressures from local population, who were using the land for meeting their requirements such as, fuel wood collection, grazing etc. There was an attempt in 1984 to improve the forest by thinning unhealthy coppice growth. In 1987, a few mahogany saplings were also planted.

The experimental plot is at an elevation of 100m msl. There is an altitudinal variation of about 30m. within the 2.17 ha area. Except for a small portion, where the terrain is flat, the area consists of moderate to steep slope (30-60º slope). The aspect is southern to south western. Soil is lateritic and predominantly barren with practically no litter or
humus over the ground at the time of initiation of the study in 1989. The soil is also shallow with high amount of granite rocks (Fig. 18). The pH of the soil is 5.44 and gravel content 31.6%.

Fig. 18 Site assessment: Rocky terrain with a water hole in Region II of the site.

Weather data of the area for the past 10 years available at KFRI was processed to obtain necessary information. Average annual rainfall ranges from 2700mm to 3500mm and number of rainy days per annum varies from 75 to 100 (with more than 10mm rainfall/day). The area receives two monsoons, southwest and northeast. On an average, monthly rainfall exceeds 500mm during June to September and more than 70% of the rain occurs during this period. The site is susceptible to heavy wind during January-February. The mean minimum and maximum temperature varies from 18^0 to 40^0C, the average temperature being 29ºC. March to May are hottest months. The area is highly humid with an average monthly relative humidity ranging from 70% to almost 100% during rainy season (July-September). (Source: Weather data - KFRI)

A narrow irrigation canal passes through the valley region of the study area in which there is water during summer when the local irrigation department opens the Peechi reservoir main irrigation canal. This canal also collects water from other part of the site and act as a drainage canal during rainy season. Due to soil erosion, this canal was found to be partially obliterated at the start of the study, thus incapable of serving its purpose. There is also a pump house which stores water for the entire KFRI campus at the top of the hilly region of the site.

The original vegetation type of the site is moist-deciduous (Champion and Seth, 1968; Chandrashekaran, 1960). The area, at the beginning of the study existed as a degraded forest. Weeds such as *Lantana* and *Eupatorium* were the main constituents of lower stratum. The existing vegetation status was stock mapped, using conventional methods (Table 2). 97% of the vegetation in the area constituted of two species, teak (86%) and mahogany (11%). 84% of the trees were with less than 10m. height. 73.4% of the plants were teak coppice growth belonging to 2-10m height classes. The height class distributions are given in Fig.19, which again highlight the poor regeneration status and imbalance in size-class distribution. Majority of the trees were unhealthy, crooked and malformed (82%) due to unregulated cutting of fuel wood and poles and removal of leaves. Natural regeneration in the plot was very poor and the number of plants below 2m height was only 2.4%.

Table 2. Vegetation status in the area of 2.17ha. at the commencement of the study in 1989. (Height class distribution)

Species name	Height class in meters				
	0-2	**2-10**	**10-20**	**20-40**	**Total**
Swietenia mahogany (L.) Jacq.	0	67	27	0	94
Pterocarpus marsupium Roxb.	1	0	3	0	4
Albizia odoratissima (L.f.) Benth.	0	0	0	1	1
Albizia procera (Roxb.) Benth.	0	0	1	0	1
Xylia xylocarpa (Roxb.) Taub.	0	0	1	0	1
Bauhinia racemosa Lamk.	0	0	1	0	1
Alstonia scholaris (L.) R. Br.	0	0	1	0	1
Tectona grandis L. f.	19	633	84	4	740
Bombax ceiba L.	1	0	4	1	6
Emblica officinalis Gaertn.	0	0	2	0	2
Delonix regia (Boj. Ex Hook.)	0	2	1	0	3
Ailanthus triphysa (Dennst.) Alston	0	2	0	0	2
Ficus exasperata Vahl	0	0	1	0	1
Trema orientalis (L.) Blume	0	1	0	0	1
Total	21	705	126	6	858

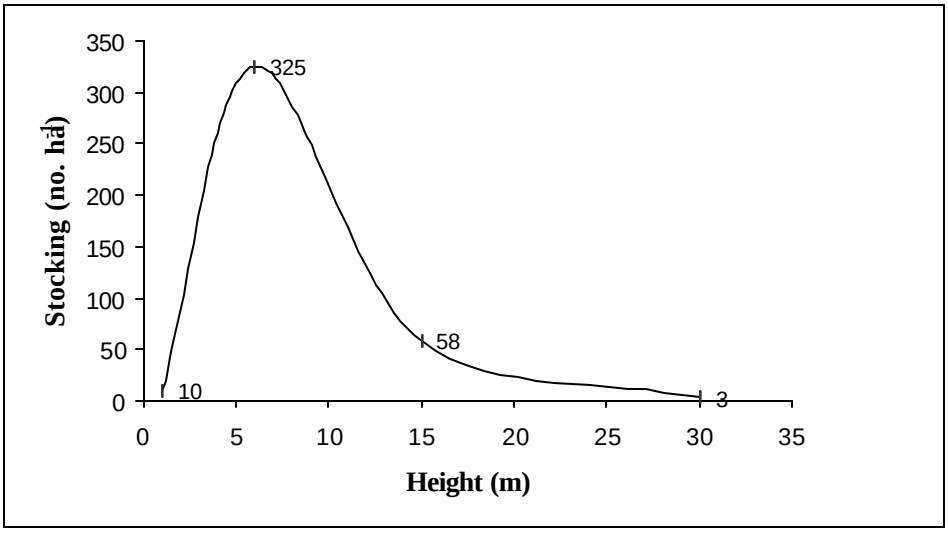
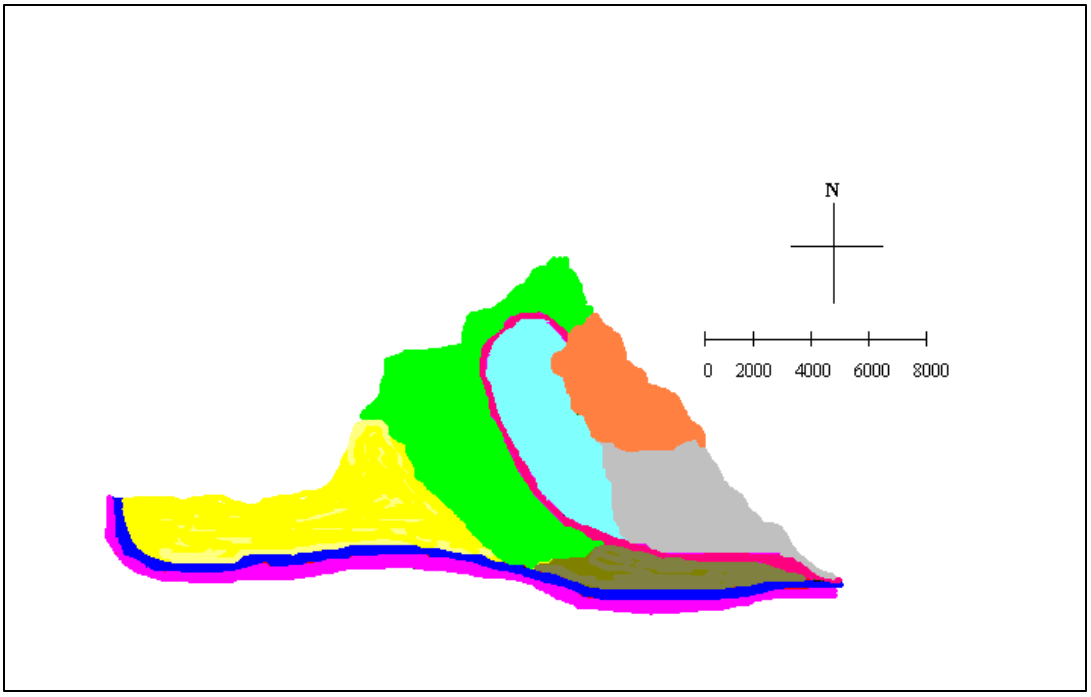


Fig. 19 Height class distribution of plants in the beginning of the study

Based on terrain conditions, slope, aspect, status of vegetation and proximity to human habitation, the study site was divided into 6 regions for specific treatment (Fig.20).



AREA BETWEEN CANAL AND ROAD (FENCE PLANTS WITH AESTHETIC VALUE)

CANAL

PLANE OPEN AREA (WITH SPARSE VEGETATION)

SLOPPY AREA WITH VEGETATION (WESTERN AND NORTHERN ASPECT)

ROAD

ROCKY AREA SPARSE VEGETATION (WESTERN ASPECT WITH MODERATE SLOPE)

MODERATE SLOPE SPARSE VEGETATION (SOUTHERN ASPECT)

PUMP HOUSE COMPOUND

SPARSE VEGETATION - STEEP SLOPE (SOUTHERN ASPECT)

Fig. 20 Study area**:** treatment map (prepared using GIS)

Region I: A linear strip of 5m width between Peechi-Thrissur road and the irrigation canal running east to west of the entire site constituting 11% of the site area: This is the valley terrain of the site. Vegetation was sparse. Situated adjoining to the road, the location had significant aesthetic importance. The area was more susceptible to cattle grazing as it was nearer to the fence and road.

Region II: Flat terrain with sparse vegetation situated to the north of the canal accounting for 25% of the total area: This is a continuation of the valley region of the site. The soil is shallow (about 60cm), the ground stratum consisting more of rocks than soil.

Region III: Slope between Region II and pump house road comprising 21% of total area: This region on the western aspect of the plot has fairly dense vegetation, consisting of teak coppices and mahogany trees. The slope here is 45°.

Region IV: Area between canal and pump house road constituting 16% of the total area: This region has moderate slope of 30^0-40^0 gradient with sparse vegetation on the southeastern side.

Region V: Rocky area between pump house and pump house road consisting of 7% of the total area: Situated on western aspect, the undulating terrain and steep slope of 40° -50° has a very sparse vegetation.

Region VI: Eastern side of the plot between pump house and pump house road comprising 20% of total area: The steep slope of 45° -60° falling on the southern aspect of the plot has rocky terrain and possessed only sparse vegetation.

The changes in the site monitored through repetitive site evaluation is provided in the section on stand dynamics and socio-economic benefits

3.2 Assessment of influence zone

An area of one km radius from the site was identified as the influence zone. The broad details about the households, people, cattle and vegetation are given in Table 3.

Table 3 Details of the Socio-economic-vegetal survey carried out in the immediate influence zone.

Parameters	Nos.
Number of households	97
Total extent of households Number of persons	82 acre (33 ha.) 437
Number of labourers	83
Number of women	225
Number of cattle	83
Number of forest plant species (i.e., those not considered as agricultural/horticultural species)	28
Total number of woody species (forest and non forest)	33
Total number of plant species (forest and non forest)	53

The distribution of total number of plants under different species in the influence zone is given in Table 4. Classification of this vegetation based on their potential use is given in Table 5.

As the landholding of individual households was very low, the local people had to depend on the forest areas for various basic needs (Fig.21). They prefer to use their land basically for producing materials of economic importance, which will provide them food and revenue for their livelihood. Of the households surveyed, 35% families had only less than 10 cents, 49% with less than 50 cents 33% between 0.5 to 2 acre and 18% families with more than 2 acres of land. The biggest landholding was 6 acres. Eight cows were maintained in households having less than 10 cents and 28 cows in households with less than 50 cents. Of the households surveyed, 96%, mainly those with small land holdings, preferred small trees, 28% wanted fodder trees and grasses, while all were interested in growing plants of medicinal value in their homesteads.

Fig. 21 Assessment of influence zone: Households with low landholdings

Table 4 Distribution of total number of plants under different species in the 97 households

Name of plants	Total number
(a) Cash crops	
Coconut	1941
Arecanut	3481
Pepper	2046
Cashew	575
Rubber	2500
Coffee	18
(b) Fruit bearing plants	
Jack tree	220
Mango	267
Banana	2398
Tamarind	21
Annona (Atha)	38
Papaya	76
Amla (Nelli)	4
(c) Other trees	
Semal	71
Maharukh (Perumaram)	267
Bamboo	8
Gliricidia	408
(d) Miscellaneous	811
Total	15150

Table 5 Distribution of plants in the 97 households based on their potential use.

Use	No. of plants	Percentage to the total no. of plants
Food	7744	51
Medicinal Industrial	2264 6674	15 44
Cottage industries	172	1
Fuel wood	10214	67
Fodder	3621	24
Small timber	6181	41
Green manure	1451	10
Construction	3342	22
Pulp	970	6
Plywood	70	1
Packing case	392	3
Match wood	348	2

The response of people for not preferring forest trees for planting in their homesteads is given in Table 6.

Table 6 Reasons given by people for not preferring forest tree species for planting.

Reasons	%
No land for planting Importance to other crops	28 32
Not profitable	28
Unfavourable laws for harvesting trees	96
Long duration for harvesting tree crops	68

The requirement of forest produces for the local population within the influence zone are summarised in Table 7.

Table 7. Needs of the local population within the influence zone.

Item	Requirement	Quantity required/year
Fuel wood	8 kg/family/day	283.24 tonne
Fodder	30 kg/cattle/day	886.95 tonne
Green manure	100 kg/coconut (3 bundles of about 35 kg)/year	192.22 tonne
Small timber (Poles of 3m length)	As banana tree support: 2398 Other uses : 970 (10 number of poles/family/year	3368 nos.
Employment requirement	93 labourers (300 days/year) =27900 225 women (needing partial employment for 300 days, 25% of the days time) =16875	44775 (days of man/women labour)

Note: 1. A cattle is expressed in cow unit. The fodder requirement of one buffalo or two goats is assumed to be equal to that of one cow.

2. The requirement of green manure for three aeronaut or banana plants is assumed to be equal to that of one coconut palm.

The need assessment made through various above-mentioned methods also brought out the following additional information.

(1) People belonging to 8-10 families staying within 4 to 5 km away from the site travel regularly a distance of 10 to 15 km to collect fuel wood from interior forest area. Every day, each person collects about 40-50 kg of fuel wood and sells the same to households and hotels (Fig.22).

(2) About 10-15 families living in the neighbourhood of 2 km distance from the plot, depend on forest areas for collection of medicinal plants. They often go deep into the forest (sometimes about 20 km) to get these materials and supply them to local manufacturing units dealing in Ayurvedic medicines (indigenous Indian system of medicine) or to vendors in the nearby town.

(3) About 15-20 women staying in the influence zone collect green manure, litter and fodder from the study plot and adjoining regions and supply these to farmers. Each individual often collects 6-8 bundles of 30-40 kg each every day, especially during the months when there is no other source of labour. They supply these materials to households within a radius of about 4 to 5 km.

(4) About 8 families in the immediate influence zone depend on forests for bamboo. They often travel more than 15-20 km every day to get the raw materials. They make baskets and mats and supply the same to local households.

(5) Members of about 4 or 5 families outside the influence zone collect teak leaves from the teak plantations and these are sold to the local shop keepers and fish merchants as wrapping material. On an average a shopkeeper requires about 8-10 kg/day. One kg consists of about 30-40 leaves.

Fig. 22 Assessment of influence zone: Demand for fuel wood.

The people involved in these activities were doing this for their subsistence. They get only labour charges as income from these activities.

Thus, it was found that there is considerable demand for materials such as, fodder, green manure, fuel wood, small timber, raw materials for cottage industries and plant materials of medicinal value. Significant labour force, particularly partial labour among women, was easily available.

In addition to providing various information required, activities connected with the need assessment also helped in having more interaction and exchange of ideas with local people, which in turn helped in getting their goodwill, support and participation in the activity.

3.3 Stand dynamics

Stand structure over time with respect to various stand parameters such as number of plants, species, natural and artificial regeneration, basal area, volume, crown area and crown volume indicates the progress of the stand in attaining multi-tier structure and optimising the ecosystem. Change in vegetation with respect to potential use, materials realised and cash flow from the study area after initiation of the experiment highlights socio- economic benefits and productive potential of the system.

3.3.1 Stand dynamics with respect to number of plants.

The change in number of plants is one of the major indicators of stand dynamics. The stand dynamics in terms of stocking under actual height and potential height were as follows:

Stocking with respect to actual and potential height

Table 8 Distribution of plant ha^{-1} in the study area based on actual height

Height Class (m)	Period		
	1989(initial)	1992 (3rd yr.)	1999 (10th yr.)
0-2	10	8709	8996
2-10	325	1218	3093
10-20	58	86	177
20-40	3	6	18
Total	396	10019	12284

Table9 Percentage distribution of plants in the study area based on actual height

Height Class (m)	Period		
	1989 (initial)	1992 (3rd yr.)	1999 (10th yr.)
0-2	2.4	86.9	73.2
2-10	82.1	12.1	25.2
10-20	14.8	0.9	1.4
20-40	0.7	0.1	0.2
Total	100	100	100

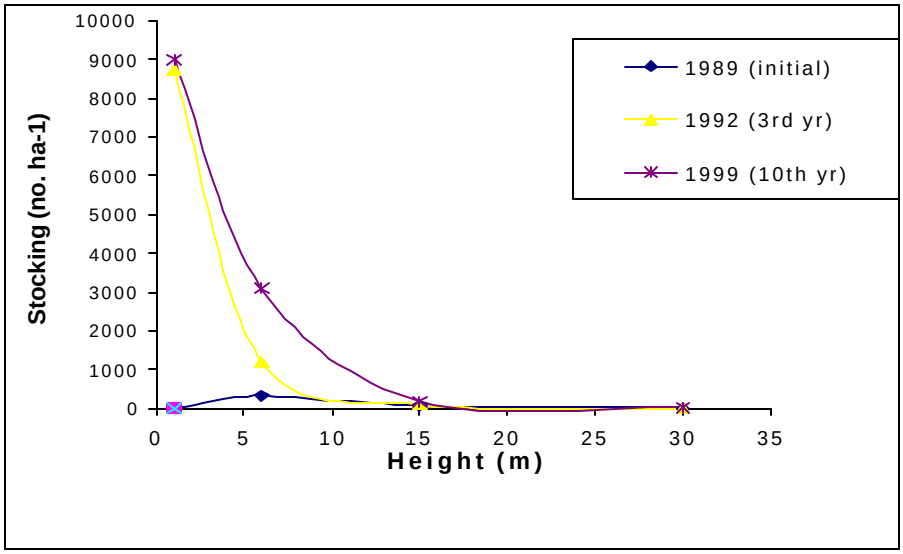


Fig. 23 Distribution of plants ha^{-1} in the study area based on actual height

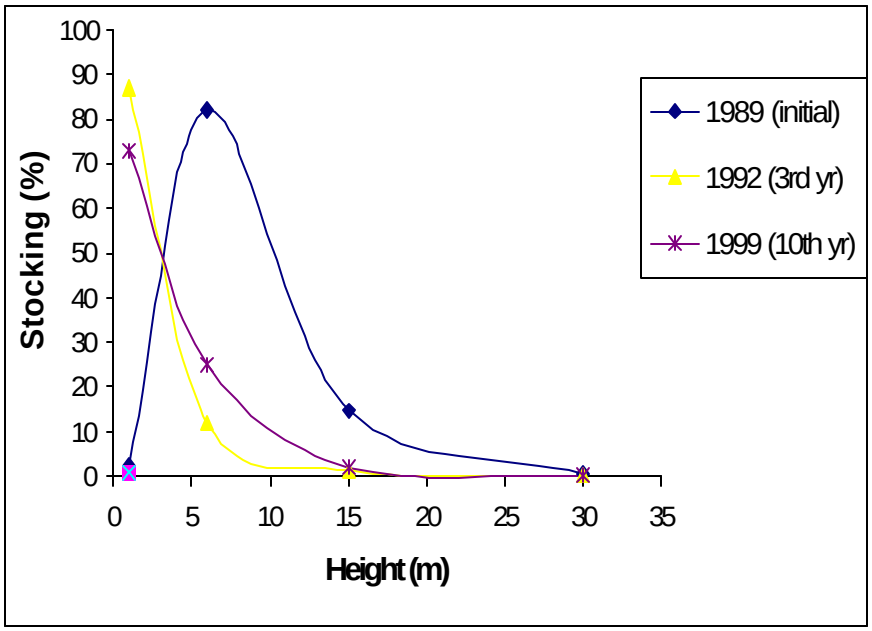


Fig. 24 Percentage distribution of plants in the study area based on actual height

The tables and graphs reveal progress towards normality in stocking. At the time of

initiation of work for establishing the plot, stocking was extremely poor with only 396 plants ha^{-1}. Within 3 years of initiation of the study, stocking has increased to 10019 plants ha^{-1} and by 10^{th} year, it was 12284. Initially regeneration was also very poor, as reflected by number of plants in 0-2m height class (2.4% of total vegetation). The entire vegetation was concentrated mostly in the 2-10m height class (82.1%). This trend had changed after the initiation of the study. Within 3 years after the commencement of the work, number of plants belonging to 0-2m height classes changed from 10 to 8709 indicating very high amount of regeneration. The number of plants in the next height class 2-10m also increased from 325 to 1218, showing high regeneration and growth potential of the site. This also reflected effectiveness of various measures carried out for reducing biotic interference, for enhancing productive potential of the site through in situ soil and moisture conservation. The inverted 'J' shaped curve in the 3^{rd} and 10^{th} years pronounces the progress towards normality of the forest. Another important aspect was change in number of plants belonging to different potential height (tier) classes. Figures 25 and 26 clearly bring out the trend.

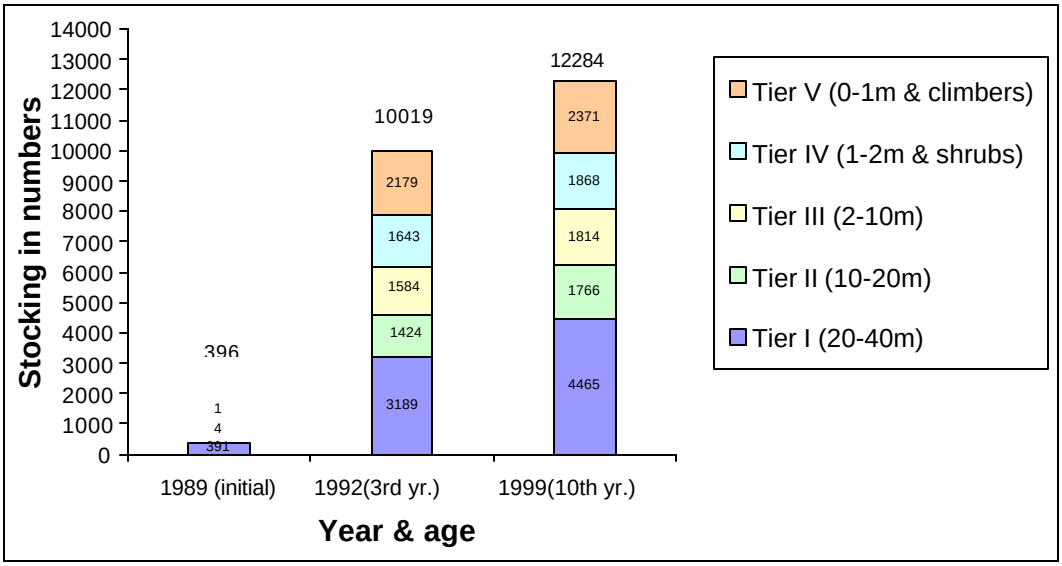


Fig 25 Distribution of plants ha^{-1} in the study area based on potential height

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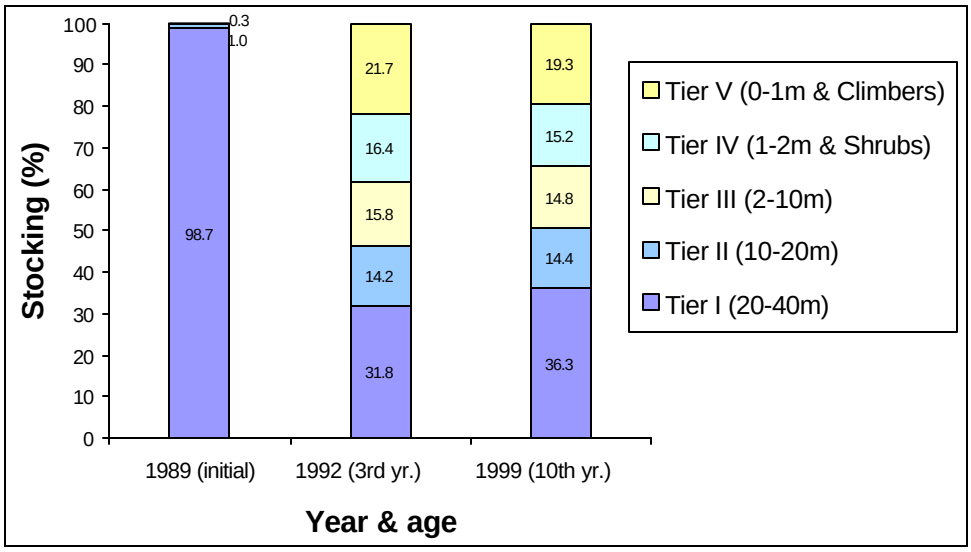

Fig 26 Percentage distribution of plants in the study area based on potential height

There is a steady increase in number of plants under each tier. However, the number of plants is maximum in top canopy species, trees having potential height of 20-40m indicating the need for intervention by introducing plants belonging to other categories. The skewed distribution of plants in different categories necessitated restructuring vegetation through judicious regeneration and harvesting strategies to ensure even distribution.

Percentage distribution highlights progress of stand towards normality in stocking in different tier classes. In the initial stage, 98.7% of trees were of top canopy species and in other tier categories there was insignificant representation. However in ten years, the percentage stocking in top canopy species came down to 36.3% and balance distributed among other tier categories.

Changes in stocking due to natural regeneration and planting

As already mentioned, number of plants in the area was regulated through planting and natural regeneration. Changes in this respect are given in table 10 and figure 27. By 10^{th} year, out of the total number of plants, 45% were through natural regeneration. The

progress towards even distribution of plants under both actual and potential height categories was visible.

Table 10 Distribution of plants ha^{-1} in the study area based on nature of regeneration & potential height

Class (m)	1989 (initial)			1992 (3rd yr.)			1999 (10th yr.)		
	Planted	Natural	Total	Planted	Natural	Total	Planted	Natural	Total
Tier I (20-40)	44	347	391	748	2441	3189	817	3648	4465
Tier II (10-20)	0	4	4	1099	325	1424	1127	639	1766
Tier III(2-10)	0	1	1	949	635	1584	1029	785	1814
Tier IV (shrubs)	0	0	0	1226	417	1643	1394	474	1868
Tier V (herbs, climbers, creepers	0	0	0	1512	667	2179	2284	87	2371
Total	44	352	396	5534	4485	10019	6651	5633	12284

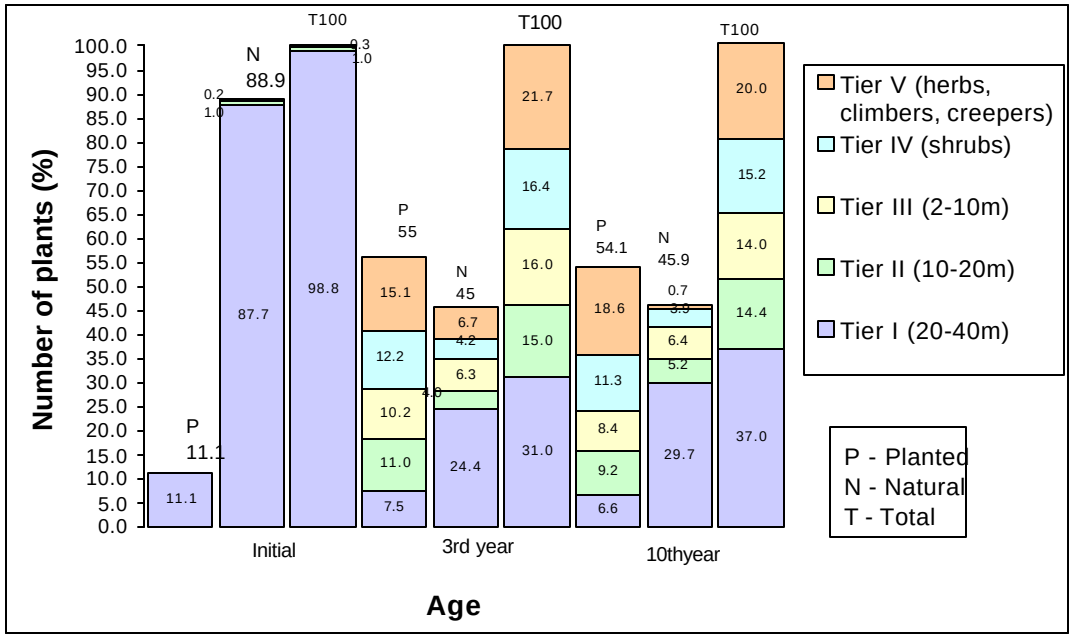

Fig 27 Distribution of plants (in %) in the study area based on nature of regeneration & potential height

3.3.2 Stand dynamics with respect to species composition

The stand dynamics with respect to species composition are given in figures 28 to 30 and tables11 to13.

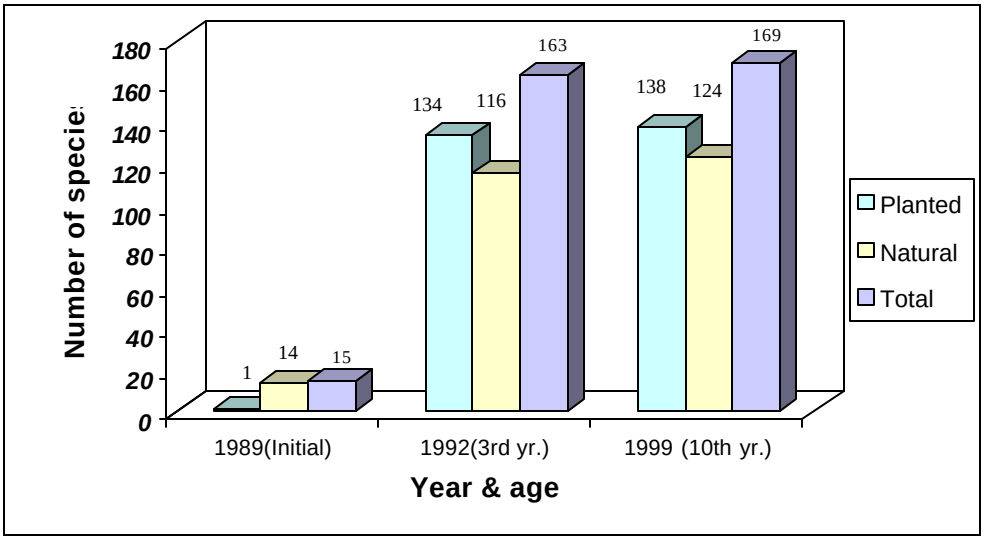

Fig 28 Number of plant species in the study area based on nature of regeneration.

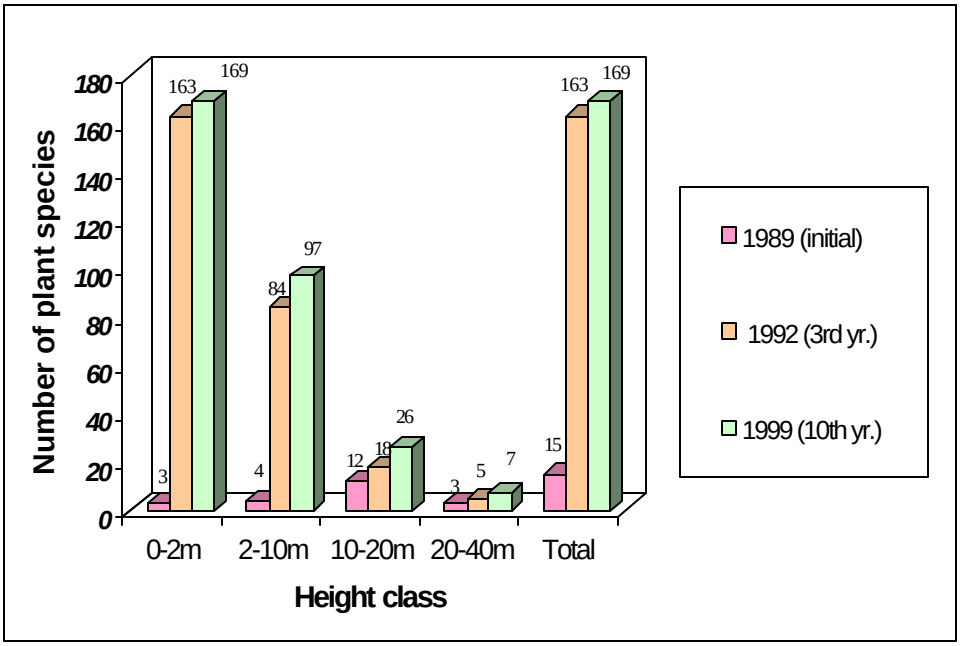

Fig 29 Distribution of plant species in the study area based on actual height.

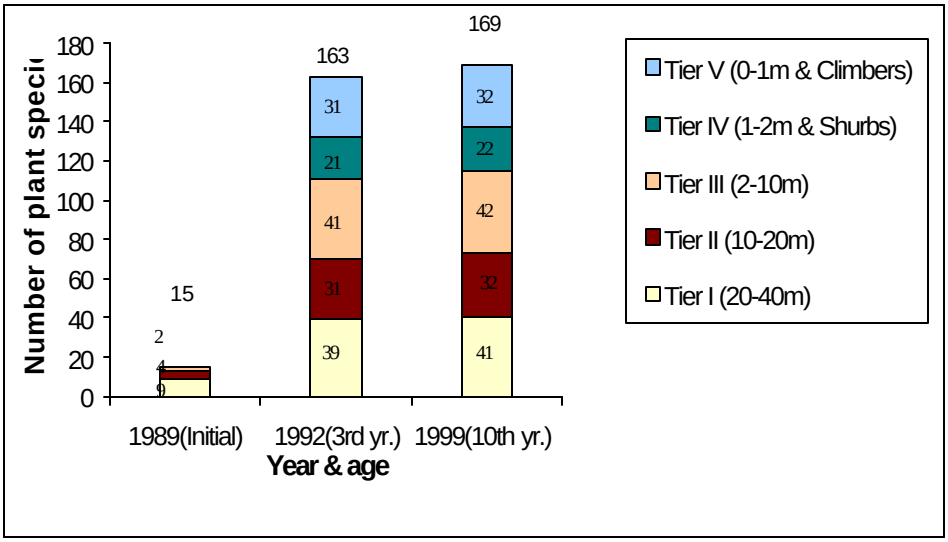

Fig 30 Distribution of plant species in the study area based on potential height.

Table 11 Distribution of major tree species in the study area

Name of species	1989	1992	1999
Artocarpus hirsutus Lam.		*	*
Syzygium cumini (L.) Skeels		*	*
Strychnos nux vomica L.		*	*
Vateria indica L.		*	*
Swietenia mahagoni (L.) Jacq.	*	*	*
Pterocarpus marsupium Roxb.	*	*	*
Terminalia paniculata Roth		*	*
Albizia lebbeck (L.) Willd.		*	*
Albizia odoratissima (L. f.) Benth	*	*	*
Hopea parviflora Bedd.		*	*
Diospyros melanoxylon Roxb.		*	*
Xylia xylocarpa (Roxb.) Taub.	*	*	*
Casuarina equisetifolia L.		*	*
Lagerstroemia microcarpa Wight		*	*
Terminalia bellirica (Gaertn.) Roxb.		*	*
Alstonia scholaris (L.) R. Br.	*	*	*
Hydnocarpus pentandra (Bunch.-Ham.) Oken		*	*
Adenanthera pavonina L.		*	*
Tectona grandis L. f.	*	*	*
Bombax ceiba L.	*	*	*
Grewia tiliifolia Vahl		*	*
Bridelia retusa (L.) Spreng.		*	*
Hymenodictyon orixense (Roxb.) Mabber.		*	*

Name of species	1989	1992	1999
Dalbergia latifolia Roxb.		*	*
Chukrasia tabularis A. Juss.			*
Leucaena leucocephala (Lam.) de Wit		*	*
Ceiba pentandra (L.) Gaertn.		*	*
Oroxylum indicum (L.) Benth. Ex Kurz			*
Pongamia pinnata (L.) Pierre		*	*
Garcinia gummi-gutta (L.) Robs.		*	*
Pterocarpus santalinus Buch.-Ham ex Wall.		*	*
Azadirachta indica A. Juss.		*	*
Cassia fistula L.		*	*
Emblica officinalis Gaertn.	*	*	*
Lagerstroemia reginae Roxb.		*	*
Acacia auriculiformis A. Cunn. ex Benth		*	*
Delonix regia (Boj. ex Hook.) Rafin.	*	*	*
Cleistanthus collinus (Roxb.) Benth. ex Hook. f.		*	*
Ailanthus triphysa (Dennst.) Alston	*	*	*
Carallia brachiata (Lour.) Merr.		*	*
Macaranga peltata (Roxb.) Muell.-Arg.		*	*
Bauhinia racemosa Lamk.	*	*	*
Annona reticulata L.		*	*
Terminalia catappa L.		*	*
Wrightia tinctoria (Roxb.) R. Br.		*	*
Acacia catechu (L.f.) Willd.		*	*
Santalum album L.		*	*
Psidium guajava L.		*	*
Aegle marmelos (L.) Correa		*	*
Caesalpinia sappan L.		*	*
Trema orientalis (L.) Blume	*	*	*

Table 12 Major bamboo, reeds and canes in the study area

Name of species	1989	1992	1999
Bambusa bambos **(L.)** Voss		*	*
Bambusa vulgaris Nees		*	*
Dendrocalamus strictus (Roxb.) Nees		*	*
Bambusa balcooa Roxb.		*	*
Bambusa nutans Wall ex Munro		*	*
Bambusa polymorpha Munro		*	*
Dendrocalamus hamiltonii Nees & Arn. ex Munro		*	*
Ochlandra tranvancorica Benth. ex Gamble		*	*
Calamus thwaitesii Becc. & Hook. f.		*	*
Calamus hookerianus Becc.		*	*
Calamus viminalis Willd.		*	*

Table 13 Major shrubs, herbs, climbers and grasses in the study area

Name of species	1989	1992	1999
Erythrina indica Lam.		*	*
Gliricidia maculata L.		*	*
Cinnamomum verum Presl.		*	*
Adhatoda vasica Nees		*	*
Ixora coccinea L.		*	*
Hibiscus rosa-sinensis L.		*	*
Lawsonia alba Lamk.		*	*
Bougainvillaea spectabilis Willd.		*	*
Sida rhombifolia L.		*	*
Plumbago indica L.		*	*
Agave sisalana Perrine ex Englem. *Aloe vera* (L.) Burm. f.		* *	* *
Curcuma aromatica Salisb.		*	*
Ananas comosus (L.) Merr.		*	*
Asparagus racemosus Willd.		*	*
Piper longum L.		*	*
Vetiveria zizanioides (L.) Nash		*	*

Within 3 years, there was substantial increase in total number of plants from 15 to 163. As the operations in the experimental plot progressed, the distribution of species among actual and potential height classes had become more even when compared to the initial period highlighting the trend towards multi-storied and multi-species structure. A perusal of the tables reveals the diversity of species that has occupied the study area during ten years through natural regeneration and planting.

3.3.3 Stand dynamics with respect to basal area

The stand structure in terms of basal area modified with respect to height and potential height classes is given in table 14 and figures 31 to 33. There has been steady increase in stand basal area from a total of 7.83 m^2 to 33.4 m^2 in 10 years. The progress towards normality in the structure of the forest with respect to actual and potential height was visible.

Table 14 Stand basal area ha $^{-1}$ (m^2) in the study site based on actual height

Height class(m)	Period		
	1989 (initial)	1992 (3rd yr.)	1999 (10th yr.)
0-2	0.03	4.33	5.51
2-10	3.88	8.07	17.74
10-20	3.18	4.45	6.98
20-40	0.74	1.27	3.17
Total	7.83	18.12	33.40

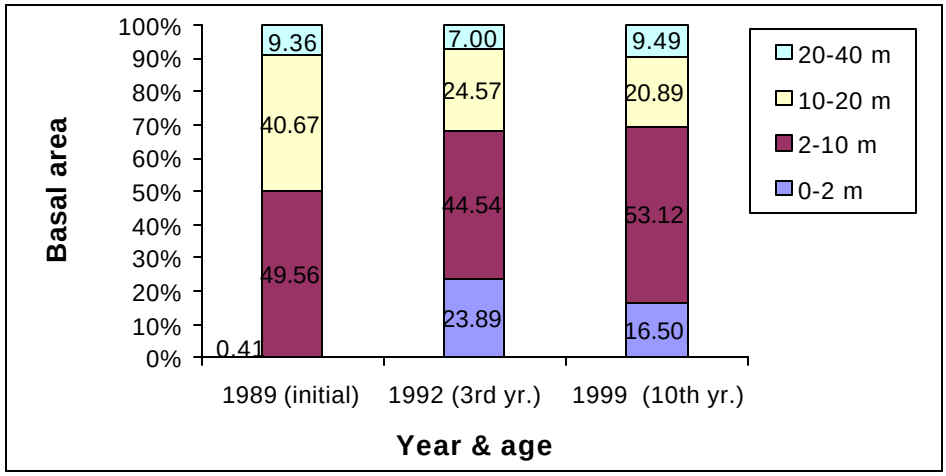

Fig 31 Stand basal area (%) in the study site based on actual height.

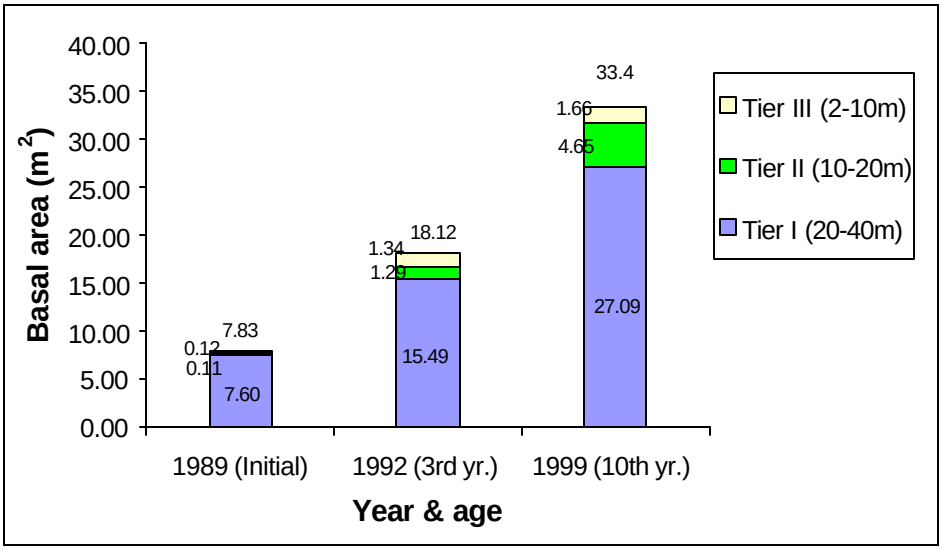

Fig 32 Distribution of basal area ha. $^{-1}$ (m^2) in the study area based on potential height.

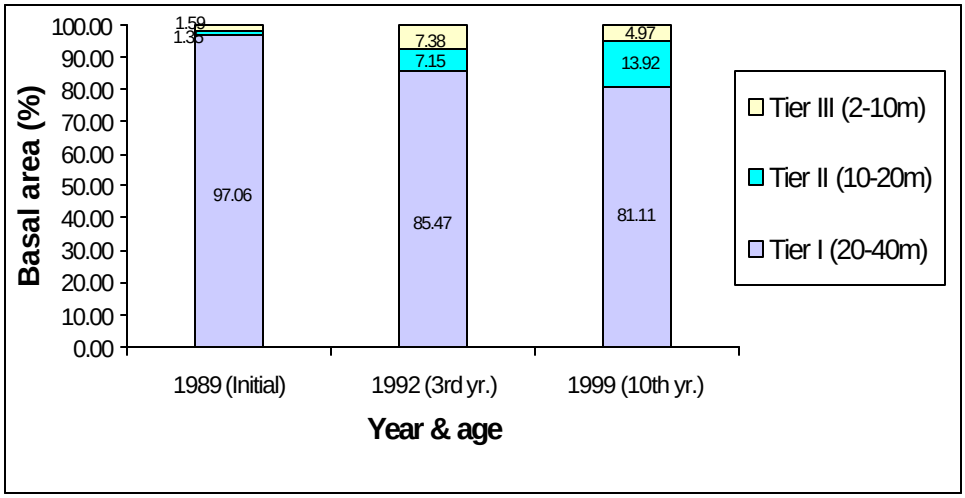

Fig 33 Percentage distribution of basal area (m^2) in the study area based on potential height.

3.3.4 Stand dynamics with respect to stand volume

The stand modifications based on stand volume with respect to actual and potential height are reflected in figures 34 to 37.

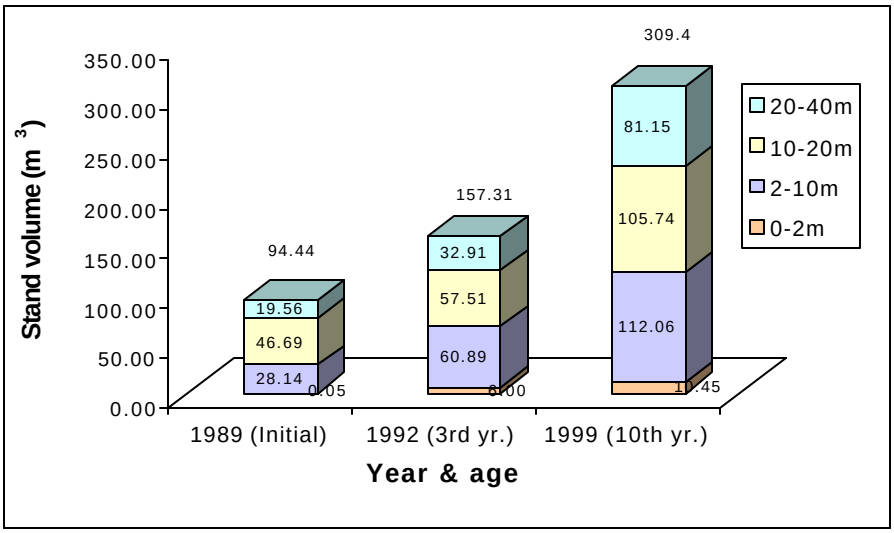

Fig 34 Stand volume (m^3) ha^{-1} in the study area based on actual height.

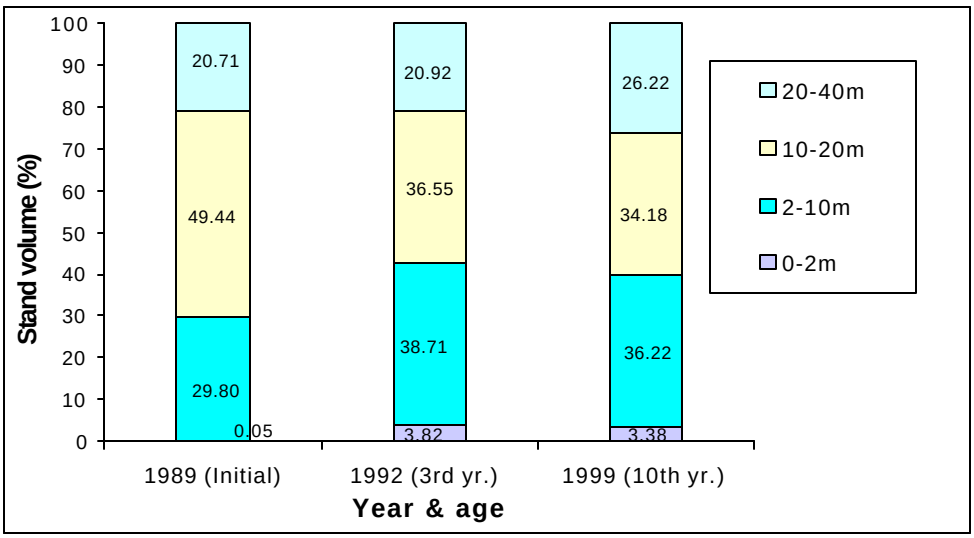

Fig 35 Stand volume (%) in the study area based on actual height.

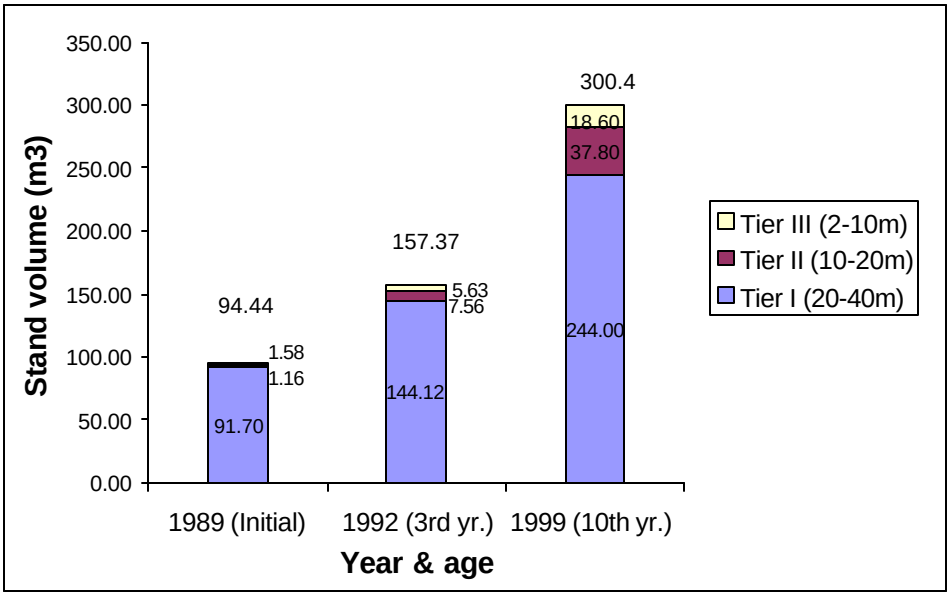

Fig 36 Stand volume (m^3) ha^{-1} in the study area based on potential height

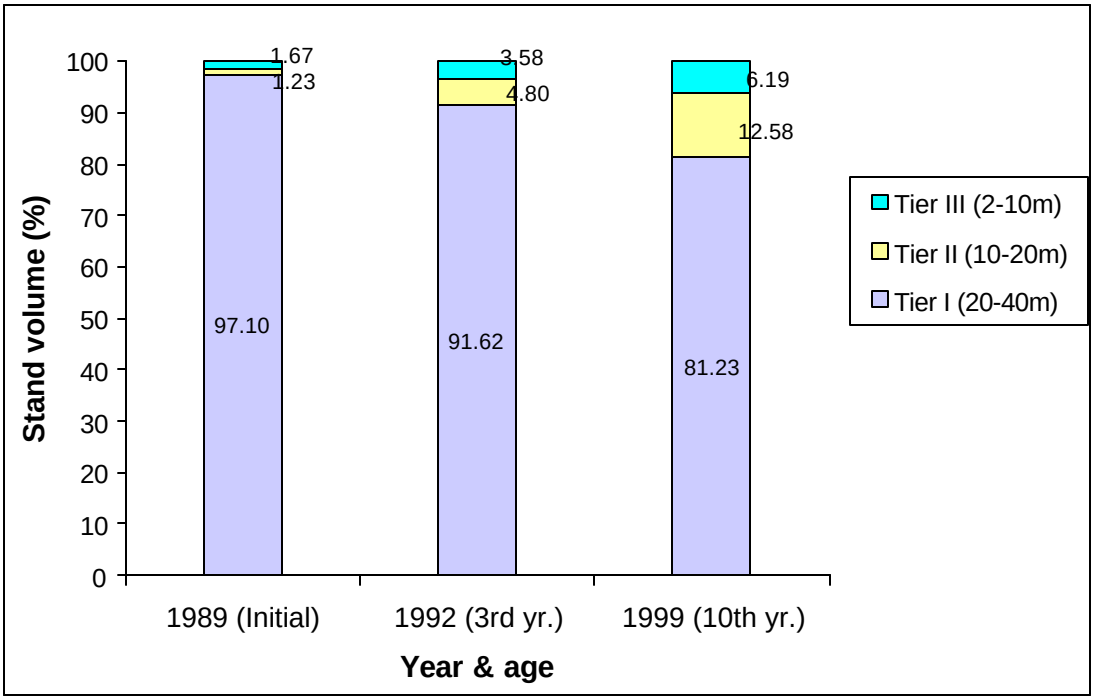

Fig 37 Distribution of stand volume in the study area based on potential height

The stand volume has increased from 94.44 m^3 to 309.4 m^3 in 10 years of the study. Progress towards even structure was also seen from these figures.

3.3.5 Stand dynamics with respect to Crown area

The change in crown area affected is given in table 15 and figures 38 to 40.

Table 15 Crown area ha^{-1} (m^2) in the study site based on actual height.

Height class (m)	Period		
	1989 (initial)	1992 (3rd yr.)	1999 (10th yr.)
0-2	1.90	2547.91	3099.71
2-10	2033.13	3317.44	4445.19
10-20	1373.84	1902.95	2216.14
20-40	158.27	409.23	917.94
Total	3567.14	8177.53	10678.98

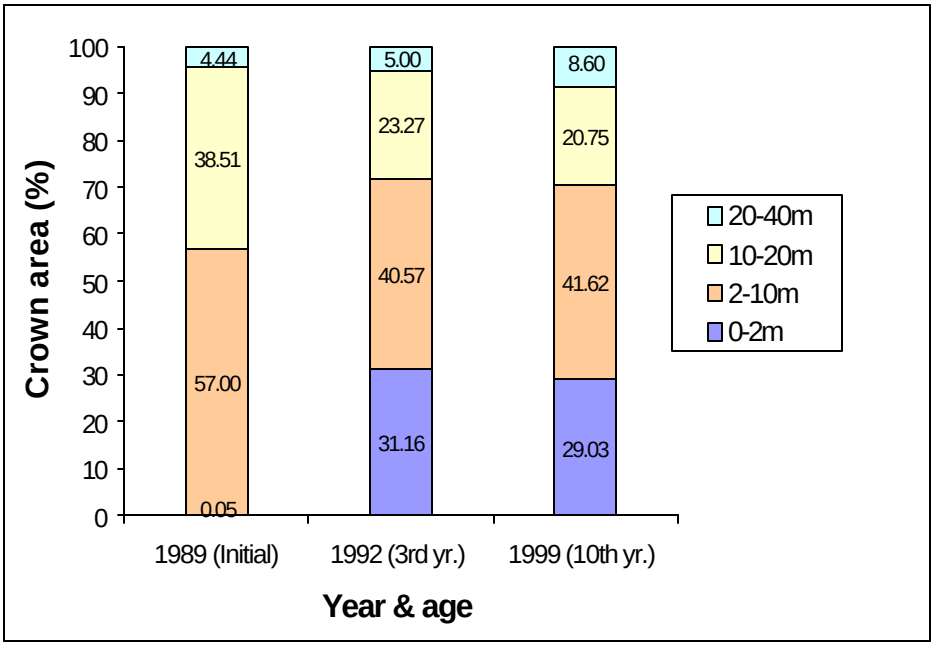

Fig 38 Percentage distribution of Crown area in the study site based on actual height.

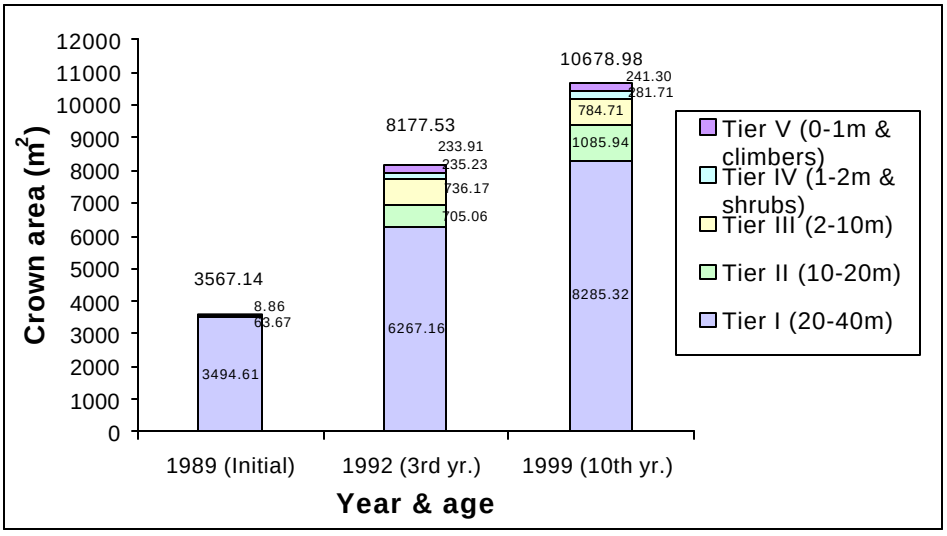

Fig 39 Distribution of crown area ha^{-1} in the study area based on potential height

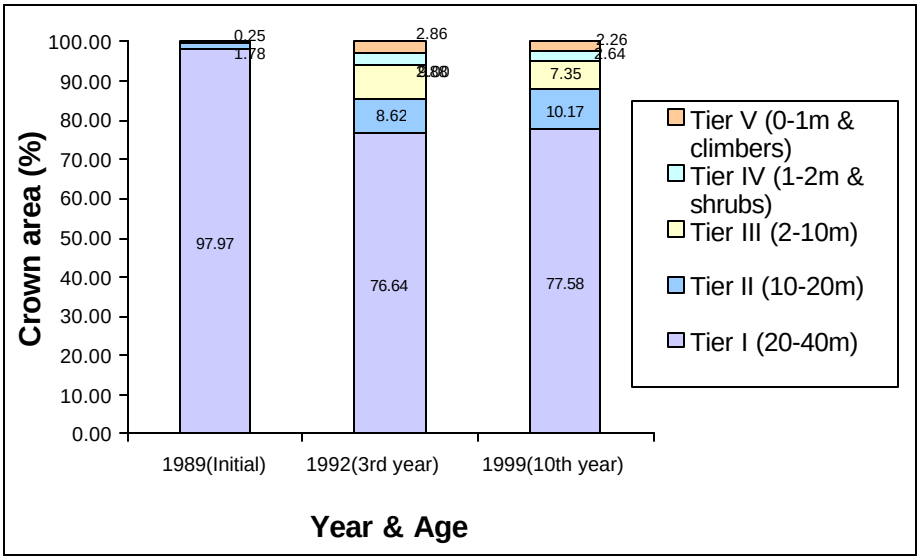

Fig 40 Percentage distribution of Crown area in the study area based on potential height

Crown area increased from 3567.14 m2 to 10678.98 m2 in 10 years. The distribution of crown area under actual and potential height categories have become more even when compared to initial period. The trends highlights the effectiveness of the operations carried out and the synergistic response of different species under a multi-tier forest environment.

3.4 Ecological, economic and social benefits

The overall ecological, economic and social benefits are summarised in tables 16 to 19. Improvement in stand structure in terms of parameters such as number of plants, species, natural regeneration and planting, basal area, volume and crown area are provided in Table 16. Stocking is much higher when compared to various forestry plantations (maximum of 2500 plants ha^{-1} with a spacing of 2mx2m and 10,000 plants ha^{-1}). Increase in number of species from 15 to 169 shows the tremendous potential of multi-tier forestry in promoting plant diversity and in turn bio-diversity. The fact that 45% of the regeneration could be achieved mainly through natural means is an indicator of ecological sustainability of the system.

Table 16 Change in status of vegetation in the study area

SL. No.	Parameter	1989 (initial)	1992 (3rd yr.)	1999 (10th yr.)	Increase(in multiples of initial value)
1	Number of plants ha^{-1}	396	10019	12284	31
2	Number of species in the study area of 2.17 ha.	15	163	169	11
3	Number of plants naturally regenerated ha^{-1}	352	4485	5633	16
4	Number of plants planted ha^{-1}	44	5534	6651	151
5	Stand basal area (m^2)ha^{-1}	7.83	18.12	33.4	4
6	Stand volume (m^3)ha^{-1}	94.44	157.31	309.4	3
7	Stand crown area (m2)ha^{-1}	3567.14	8177.53	10678.98	3

The increase in growing stock in terms of stand volume from 94.44 m^3 ha^{-1} to 157.31 m^3 ha^{-1} within three years and 309.4 m^3 ha^{-1} within ten years which comes to a mean annual increment (MAI) of 20.95 m^3 ha^{-1} for three years and 21.5 m^3 ha^{-1} for 10 years respectively shows the success of various operations in rehabilitating a degraded ecosystem. This growing stock is respectively equivalent to that of 8, 9.5 and 29.5-year-old first quality teak plantations. The MAI is almost double to that of a first quality teak plantation. In addition to this, there is an annual removal of 16.59m^3 of fuel wood/small timber. Thus total MAI comes to 38.09m^3 of standing volume. The growing stock of teak (which constitute 29% of the vegetation) in the area has increased from 341 trees ha^{-1} to 2722 trees ha^{-1}. Stand volume of teak has increased from 73.21m^3 ha^{-1} to 140.18m^3 ha^{-1} with MAI of 6.69 m^3 ha^{-1}. The growing stock of teak currently removed annually as fire wood or small timber comes to 7.51m^3 ha^{-1}. Thus average annual increment in teak alone comes to14.10m^3 ha^{-1}. The maximum MAI recorded in a first quality teak plantation is only 12.24m^3 ha^{-1} (All India yield table for Teak). There is three-fold increase in crown area.

Table 17 Distribution of plants in the study area based on use.

Use	No. of plants ha^{-1}		
	1989 (initial)	1992 (3^{rd} yr.)	1999 (10^{th} yr.)
Food	1	267	381
Medicinal	51	5914	6896
Industrial	50	2502	3485
Cottage Industries	3	6295	6964
Fuel wood	387	2959	3325
Fodder	3	3767	4631
Small timber	391	3438	4478
Green manure	47	2039	3564
Construction timber	386	2157	4184
Pulp	4	222	264
Plywood	388	1954	2234
Packing case	3	2106	2458
Match wood	4	660	780
Live hedge	-	654	964
Nitrogen fixing	3	1239	1785

The progress achieved through restructuring vegetation to make it compatible with needs of local population is highlighted in Table 17.Availability of materials suited for a variety of uses demonstrates the scope for utilising multi-tier forestry for intensive multiple use.

The quantum of materials realised and benefits accrued from the study area are summarised in Table 18 which illustrates the utility of this practice for meeting the basic needs of local people. It also highlights the mutual benefits in involving local population in multi-tier forestry activities. The benefits were distributed among 255 families. Women constituted 65% of the beneficiaries.

Table 18 Material realised & benefits accrued through the involvement of the local public from the study area.

Sl. No	Item	+Rate as on 1999 (Amount in rupee unit)	After 3 years		Average of 8th, 9th and 10th year	
			Quantity	Amount	Quantity	Amount
1	Green manure	Rs. 1/- per 10 Kg.	3300 kg ha^{-1} yr^{-1}	330.00	4500 kg ha^{-1} yr^{-1}	450.00
2	Fodder	Rs. 1/- per10 Kg.	1672 kg ha^{-1} yr^{-1}	167.20	14600 kg ha^{-1} yr^{-1}	1460.00
3	Fuel wood	Rs. 1/- per 5 Kg.	4525 kg ha^{-1} yr^{-1}	955.00	9165 kg ha^{-1} yr^{-1} or (*12.968m3 ha^{-1} yr^{-1})	1833.00
4	Small timber	Rs. 20/- per pole	1270 kg ha^{-1} yr^{-1} (127 poles)	2540.00	2560 kg ha^{-1} yr^{-1} (225 poles) (*3.6225m3 ha^{-1} yr^{-1})	4500.00
5	Medicinal produce	Rs. 1/- per Kg.	249 kg ha^{-1} yr^{-1}	249.00	1280 kg ha^{-1} yr^{-1}	1280.00
6	Teak leaves	Rs. 1/- per10 Kg.	438 kg ha^{-1} yr^{-1}	43.80	3850 kg ha^{-1} yr^{-1}	385.00
7	Bamboo	Rs.20/- per bamboo culm	-	0.00	150 nos. ha^{-1} yr^{-1}	3000.00
8	Canes	Rs. 5/- per no.	-	0.00	25 nos. ha^{-1} yr^{-1}	125.00
9	Number of families benefited		255		255	
10	Rural labour generated	Rs. 100/- per day	696 man days$ha^{-1}yr^{-1}$	69600.00	1095 mandays $ha^{-1}yr^{-1}$	109500.00
11	Amount realised by disposal of fuel wood/small timber produced from the plot on a Subsidised rate (Rs.)		Rs. 769.00		The materials were collected by local people free of cost	
12	Amount saved in cost of weeding, harvesting and canopy manipulation in terms of number of man days	Rs. 100/- per day	128 man days ha^{-1} yr^{-1}	12800.00	165 man days ha^{-1} yr^{-1}	16500.00

\+ Rates are fixed for the produce at site and are exclusive of harvesting and transportation cost

* 1tonne=1.415m3 of fire wood/poles (Foresters Companion by A.R. Maslekar, 1977)

Table 19 Cash flow from the study area per hectare since the beginning of experiment. (Rates adjusted to the year 1999 at 6% interest)

Year	Age	Cost (Rs.)	Benefit (Rs.)	Net annual benefit	Cumulative net benefit (Rs.)
1990	1	7,100.00	0.00	(-) 7,100.00	(-) 7,100.00
1991	2	6,300.00	0.00	(-) 6,300.00	(-) 13,400.00
1992	3	5,500.00	4,291.00	(-) 1,209.00	(-) 14,609.00
1993	4	0.00	6,381.00	6,381.00	(-) 8,228.00
1994	5	0.00	7,486.00	7,486.00	(-) 742.00
1995	6	0.00	7,992.00	7,992.00	(+) 7,250.00
1996	7	0.00	8,332.00	8,332.00	(+) 15,582.00
1997	8	0.00	10,665.00	10,665.00	(+) 26,247.00
1998	9	0.00	13,995.00	13,995.00	(+) 40242.00
1999	10	0.00	14,499.00	14,499.00	(+) 54741.00

The cash flow from the study area, given in Table 19, throws light on the sustainability of the system and the immense benefits it can provide in quantitative economic terms. The positive cumulative net benefit from the 6^{th} year after initiation demonstrates the self-sustainability of the system. The analysis of the table revealed that the annual overall income is comparable with any other forestry activity. While computing the overall income, only items 1 to 8 of Table 18 were considered. Non- tangible benefits and benefits to the adjoining ecosystem were not taken into account.

3.5 Prospects of multi-tier forestry as a forestry practice

While establishing the demonstration plot, prospects of multi-tier forestry were examined from three angles:

(i) Potential of multi-tier forestry over natural forests and plantations

(ii) Sites suitable for multi-tier forestry

(iii) Benefits to adjoining ecosystem

Results are discussed below.

3.5.1 Potential of multi-tier forestry over natural forests and plantations

Comparative studies made on multi-tier forestry over plantations and natural forests have revealed its potential on following aspects:

Utilization of existing vegetation: The transition from existing vegetation to multi-tier forest is a gradual and continuing process where no sacrifice of existing vegetation occurred. There is scope for promoting growth of existing vegetation and utilizing various produces such as fodder, fuel wood, green manure and produces of medicinal value by harvesting them through intensive operations. Clear felling or coppice systems, being followed in plantations, removes entire existing vegetation at one stroke to initiate establishment of a new plantation (Davis and Johnson, 1987; Ramprakash and Khanna, 1979; Smith, 1962). Measures adopted for growth and utilization of existing vegetation in natural forest management are less effective when compared to practices envisaged under multi-tier forest.

Utilization of available space: Entire management practices in multi-tier forestry are tuned to optimize use of available space. Only those plants that were absolutely essential to be removed are harvested. Vacant spaces are utilised through regeneration by natural or artificial means with appropriate species or through regulation of yield in terms of various stand parameters such as stocking, number of species, basal area, stand volume, and crown area with respect to actual and potential height classes.

Utilization of resources and potential available in the neighboring ecosystem: The facilities for utilization of manpower and other resources available in neighboring ecosystem is much higher in multi-tier forest when compared to natural forest or plantations. Multi-tier forestry offers tremendous scope for absorbing a high amount of labour. In the experimental plot, an average of 1095 man-days ha^{-1} yr^{-1} (3 man-days ha^{-1} day^{-1}) is required which is much higher than that for the management of natural forest or forest plantations. In plantation forestry, labour is involved only at the time of plantation establishment and during thinning or harvesting stages. (Evans, 1982) The labour involved in the management of a natural forest is also negligible. Since the produces available from multi-tier forest such as fodder, green manure, fuel wood, litter, fruits, produces of medicinal value and raw materials for cottage industries are of greater value to the local people than that of natural forest or plantations, the scope for involvement of local people and their resources are much higher in multi-tier forestry. Moreover, because of the scope for selection of species from a larger spectrum, opportunities for harmonizing vegetation in multi-tier forest with that of neighboring ecosystem are also very high.

Time span involved in getting the yield: Multi-tier forestry is the shortest and quickest forestry practice to get yield. The various produces such as fodder, green manure, fuel wood, small timber, produces of medicinal value and raw materials for cottage industries can be harvested right from the initial stages.

Types of yield obtained: Multi-tier forestry produces a variety of products such as fodder, green manure, fuel wood, poles, small timber and materials for cottage industries such as bamboo, reeds and canes. It also provides timber. As regeneration and harvesting strategies adopted are tailored to maximize production, the overall quantity of materials available from multi-tier forests is much higher when compared to natural forests or plantations.

Social benefits: The various produces obtained from multi-tier forestry such as fodder, green manure, litter, fuel wood, poles, small timber, materials for cottage industries and plant materials of medicinal importance are needed for the day-to-day living of people. Moreover, because of the highly labour intensive nature of multi-tier forestry practices,

people get employment. The targeted beneficiaries are weaker sections of society, mainly rural men and women. In forest plantations or natural forest, due to the management practices followed, the opportunities available for this are much less. Thus, as a forestry practice, multi-tier forestry has got better social appeal.

Sustainability of the practice: The multi-tier forestry practice provides gradual and steady improvement in vegetation in terms of various stand parameters. The various operations are targeted to enhance the site potential. Since only a portion of the increment is harvested, there is a steady increase in total growing stock. As a result of this, there is always sustained or progressive yield from multi-tier forestry.

Scope for site enhancement and ecological up-gradation: The diversity of the practices followed and the species involved were found to provide considerable scope for ecological up-gradation of the area. There was overall enhancement in the quality and quantity of forest as well as the ecological and socioeconomic benefits it can provide to the neighboring ecosystem. As already discussed, in multi-tier forestry, there was substantial increase in stocking, basal area, stand volume and crown cover. There was also increase in the socioeconomic benefits provided from the site. The various materials such as fodder and green manure produced from the site can enhance the productivity of adjoining agricultural ecosystem. Materials useful for cottage industries such as bamboo, reeds and canes, plant materials of medicinal value along with the amount of labour generated enhances overall productivity of the system. Soil fertility, moisture regime and micro climatic conditions can be made to stand in an ideal state for overall production through regulation of appropriate silvicultural operations. This opportunity is much less in the management of natural forests or in plantation forestry.

Economic benefits: Economic benefits from a multi-tier forest are much higher when compared to natural forests or forest plantations. In terms of realizable produces, the cumulative income from the yield from a multi-tier forest, such as fodder, fuel wood, green manure, poles, bamboo, reeds and canes, plant produces of medicinal importance which are realized annually are significant.

Cost of Production: Cost of production in multi-tier forestry is comparable or even lesser when compared to plantation forestry or natural forest management. Expenses for management of multi-tier forest can be met from the income received through various yields.

3.5.2 Sites suitable for practicing for multi-tier forestry

As a forestry practice, multi-tier forestry was found to have these unique characteristics.

(i) Multi-tier forestry is a highly labour-intensive activity and it can be practiced only in sites where availability of labour for these practices is not a problem.

(ii) Multi-tier forestry, apart from timber, yields a variety of produces such as fodder, green manure, fuel wood, small timber, produces suitable for cottage industries and household consumption such as bamboo, reeds, canes and plant materials of medicinal importance. Scope for marketing and utilization of these produces is a pre-requisite for successful multi-tier forestry.

(iii) Multi-tier forestry involves introduction of a large number of plant species of diverse characteristics. This can be viable only in an environment where multiple use forestry is essential. It may not be viable in a system managed exclusively for single use such as timber or industrial raw material. Thus it may not be advisable to practice multi-tier forestry in good plantation sites.

(iv) Since intensive multiple use is the hallmark of multi-tier forestry, attempting this practice in interior natural forest meant exclusively for conservation may not be advisable.

(v) The practice of multi-tier forestry has to be confined to degraded forest areas with heavy biotic interference and demand for produces such as fodder, fuel wood, green manure, small timber, materials for cottage industries and household consumption such as bamboo, reeds, canes and plant materials of medicinal importance.

Thus multi-tier forestry is suited for forest areas in close proximity to human habitations where intensive multiple use is essential. Only those plantation areas that are of low productivity or are likely to suffer from heavy biotic interference are suited for multi-tier

forest. Due to non-availability of labour and difficulty in marketing of various produces, multi-tier forestry cannot be practiced in interior natural forest.

In Kerala, about 49.7% of the natural forest (3886.37 km^2 out of the total natural forest of 7862 km^2.) fall under this category. These areas are degraded forest which are in close proximity to (within 5km radius) human habitations. (Nair *et al*, 1997). Though statistics are not available, the scope for practicing multi-tier forestry in other states is also quite high. This is the case with degraded natural forests of many other third world countries.

3.5.3 Benefits from multi-tier forest area to adjoining ecosystems

Practice of multi-tier forestry can provide the following incidental benefits to the adjoining ecosystems:

Agricultural lands: Practice of multi-tier forestry provides materials such as green manure, fodder, small timber for agricultural use. This also improves soil and water regimes of agricultural lands. Employment opportunity available from multi-tier forestry is helpful to farmers in utilising their labour potential.

Natural forests and forest plantations: Availability of various forest produces from multi-tier forests at a much cheaper rate reduces the biotic pressure on adjoining natural forests and forest plantations. Besides, improved moisture regimes enhances productivity of these areas.

3.6 Problems in planning and implementation of multi-tier forestry

The following major problems were identified in planning and implementation of multi-tier forestry.

Management decisions based on micro-site conditions at individual plant level:

When compared to plantation forestry or other afforestation programmes, in multi-tier forestry management, decision has to be taken at individual plant level taking into consideration micro-site conditions. This was found to be necessary to fully utilise opportunities available for choosing the right species and package of practices. These management decisions have to be taken considering soil characteristics, slope, aspect,

other terrain conditions such as, availability of moisture and nutrients, intensity of biotic pressure, availability of light, nature of other plants in the neighbourhood and possible interaction at individual plant level. This was also the case with all management decisions concerned with spatial and temporal arrangement of plants, regeneration, maintenance and harvesting. In plantation forestry or other forestry practices, because of involvement of less number of species, options available are limited and so decision making is also quite simple.

Attention to needs and potentials of neighbouring ecosystem: As multi-tier forestry is a practice designed for intensive multiple use, its design and management were found to be dependent on various needs and potentials of people living in the influence zone and their habitat. This is not the case in plantation forestry or other forestry practices where choice of species or management practices are not dependent on the needs of local people. Adequate care is required for identifying extent of influence zone, land use practices, habit of the people, their forest based needs and potentials available for development and utilisation of multi-tier forest. As conditions in the influence zone vary over time, in multi-tier forestry decisions have to be based on assessment of needs of local population made on a continuous basis.

Decisions based on wider spectrum of plant species and plant management practices: Taking into consideration diverse demands and site conditions, number of species and management practices required were found to be quite large in multi-tier forestry when compared to conventional plantation forestry or natural forest management. As a result of this, to make judicious decisions on choice of species as well as package of plant management practices, the plantation manager has to handle information such as their silvicultural characteristics, site requirement, growth, yield and use along with other management practices on large number of species.

Decisions based on wider spectrum of site management practices: Manipulation of varied nature at micro site plant level is necessary in multi-tier forestry due to involvement of large number of species managed with different objectives. This requires varied approach to soil and moisture conservation, site improvement, spatial and temporal arrangement of plants, planting methods, control of biotic factors, plantation maintenance

and harvesting within the same site. When compared to other forestry practices, here, options available are quite enormous and judicious choice and implementation require handling of information on varied site management practices.

Need for planting stock of large number of species on a continuous basis: In case of multi-tier forestry, regeneration and harvesting is a continuous activity in the site as well as influence zone. Success of multi-tier forestry will depend on availability of good quality planting stock of desired species in required quantity at appropriate time. Ensuring adequate supply of good quality planting stock of different species of varied characteristics requires careful planning taking into consideration availability of propagates and nursery techniques. As there is increase in number of species involved it is necessary to handle information such as flowering and fruiting seasons, nature of seeds, information on seed collection areas, germination methods and other nursery management techniques on large number of species. Involvement of large number of species also brings problems of scheduling of various activities in the establishment and management of nurseries on a continuous basis. These problems are not so acute for plantation forestry or other afforestation activities where the number of species involved are comparatively less. In such cases the requirement of planting stock is also not to the extent required under multi-tier forestry, as planting is a one-time activity.

Yield regulation and harvest scheduling for diverse forest produces: The materials harvested in a multi-tier forest vary from species to species and within species. The different species produces yield such as fodder, fuel wood, green manure, small timber, raw materials for cottage industries, plant materials of medicinal value and timber. The time and mode of harvest varies considerably between species. This can also vary within species as most of the species can be managed for multiple purposes. The uneven-aged nature of forest, the diverse species characteristics, yield and utilisation potentials complicate harvesting. Harvesting of different produces has to be carried out, taking into consideration silviculture requirements, labour availability and market demand. Thus, harvest scheduling under multi-tier forestry system is highly complex and requires high technical skill in planning and execution.

More intensive management on a continuous basis: Involvement of large number of species of diverse characteristics and end uses necessitates intensive management at various levels starting from design, development and management on a continuous basis. These are not so in the case of plantations, natural forests or other afforestation sites.

High labour requirement on a continuous basis: The intensity of operations involved in multi-tier forestry is enormous when compared to other forestry practices. Aspects such as nursery development, regeneration, site preparation, maintenance and harvesting of varied products require considerable amount of effort of diverse nature.

Difficulty in decision making through integrating a number of related factors over time and space: Successful design of multi-tier forestry requires decision making by integrating factors such as site conditions, neighbouring ecosystem, plant species and their management practices, plantation site management methods and resources and constraints involved. Often this is complex due to the difficulties involved in integrating various factors over time and space. Determination of trade off of various options available is difficult by mental calculations.

Lack of availability of information: Information on species characteristics and package of silvicultural management practices for non-conventional plantation species are lacking on many aspects. Also, information on response of many species and package of practices under multi-tier forestry is not known.

Implementation problems in harvesting of various produces: Harvesting of timber in a multi-species uneven-aged forest without harming the surrounding vegetation is a difficult task. The problem of choice and implementation of harvesting in a selection forest is a debated topic all over the world. Due to logistic problems involved in successful implementation, selection felling has been stopped in natural forests of Kerala. The same problems are more acute in multi-tier forestry as harvesting has to be carried out not only for getting the yield of various produces but also for optimising productivity of the forest.

3.7 Strategies for multi-tier forestry

The following are the strategies identified for successful implementation of multi-tier forestry:

Reduction of biotic pressure for preventing degradation: The first and foremost task in multi-tier forestry is to find out ways and means to reduce biotic pressure causing forest degradation. Excessive pressure on land results from forest fire, cattle grazing, uncontrolled and excessive exploitation of various forest produces, soil erosion and forest degradation. Hence, the strategies chosen have to be aimed at minimising these causes of degradation to the maximum extent possible. The study revealed the integrated use of following operations to be effective in achieving this.

(i) Maintenance and strengthening of existing barbed wire fence/cattle proof trenches/stone walls and deployment of sufficient number of watcher-cum-labourers depending upon requirement for ensuring immediate protection.

(ii) Gradual establishment of live hedge with suitable multi-purpose species to augment barbed wire fence/cattle proof trenches/stone walls and to utilise the area effectively for productive purposes.

(iii) Creation of awareness among local people regarding the importance of afforestation activity for their day-to-day life through informal interactions, discussion and display boards and thus change the attitude of apathy and mistrust prevailing among local people.

(iv) Gradual involvement of local people in various plantation development and management activities including plantation maintenance and harvesting. To begin with, depending upon availability, people can be involved in grass cutting, harvesting of green manure, collection of fuel wood and small timber, harvesting of medicinal produces and other materials of local consumption and thus to create vested interest in local people in protection of the area.

(v) Transformation of duties of watcher-cum-labourers to that of extension workers. Their services can be utilised for training and supervision of various plantation development and management activities by local people.

(vi) Maximising the quantity and quality of various materials produced from the site through restructuring the vegetation, to enhance the capabilities of the site, to carry out its various ecological, economic and social functions by meeting different forest based needs of the people living in the influence zone in a sustainable basis as well as to withstand the biotic pressures.

(vii) Promotion of measures such as, planting of appropriate species in their home-gardens, effective utilisation of available forest based resources and encouragement for utilising alternative resources and energy saving mechanisms by creating awareness, supply of planting stock and other materials and technologies and thus minimise the dependence of the people living in the influence zone on the site.

Soil and moisture conservation for productivity enhancement: Enhancing the productive potential of the site is the next step involved in multi-tier forestry. In this soil and moisture conservation assume paramount importance. Following strategies are identified for the purpose:

(i) Strengthening and maintenance of engineering structures such as, contour bunds, retention walls, trenches and crosscut bunds for plugging gullies wherever available. Erection of suitable structures wherever necessary. However, these should be carried out only where it is absolutely essential since the cost involved in engineering works is high. Also to minimise the cost locally available materials such as rubble stones and brushwood should be used to the maximum extent wherever possible. The feasibility of utilising these structures for reducing biotic pressures also should be explored.

(ii) Diggings of catch pits of appropriate size and shape for obstructing surface water run off and trapping topsoil and organic matter coming from upper regions. These pits can be used for planting in subsequent years. Planting pits should be of appropriate sizes and shapes such as saucer shaped pits, trench and mount pits and v-ditches depending upon requirement so as to conserve as much water as possible.

(iii) Contour planting in the slopes with suitable multi-purpose species such as, Agave, Pineapple, Subabul, Aloe, Vetiver in specific designs such as staggered planting depending upon site conditions to suit various micro level field features.

(iv) Thinning, pruning, grass cutting and green manure collection to be carried out in a regulated manner to prevent unnecessary exposure of land. While harvesting, a good amount of plant residue should be deliberately left behind in the site as leaf mulch and as organic material for enhancing the soil fertility as well as for efficient nutrient cycling. Effective utilisation of cultural practices such as leaf mulching and stone packing in appropriate seasons are also to be carried out.

(v) Introduction of nitrogen fixing species to facilitate fixation of atmospheric nitrogen. Regeneration of under storey species such as herbs, shrubs and grasses for providing adequate ground cover to regulate surface water flow. Use of multi-purpose species for enhancing the overall productivity should be encouraged.

Multi-species permanent nursery for continuous supply of planting stock: Supply of planting stock of suitable species in adequate quantity on a continuous basis required for multi-tier forestry site as well as for households in the influence zone is one of the most important pre-requisites for success of this forestry practice. To facilitate this, a multi-species permanent nursery nearer to the site is required. As multi-tier forestry requires planting stock of varied nature - herbs, shrubs, climbers, creepers, trees of varied height on a continuous basis, this nursery requires better facilities for irrigation when compared to the local temporary nurseries involving a few species established for initiating a conventional plantation or an afforestation/reforestation work. The nursery planned must have facilities for assembling and maintenance of planting stock of various species gathered from other places and raising planting stock of required species in sufficient quantity on a permanent basis. While in the initial stages the planting stock can be supplied on subsidised rates, later the nursery has to support itself on a self-sustainable basis by supplying planting stock on production cost.

Matching of species and management practices with micro site conditions and local needs: Often, the species composition and management practices followed in the site are not compatible either for effectively utilising the site potential or for meeting the demands of local population living in the influence zone. So deliberate attempt is essential to match

species and management practices with site conditions and needs of the local population. To ensure success in multi-tier forestry, when compared to other forestry practices, it is necessary to chose the species and management practices from a wider spectrum based on a thorough evaluation of site conditions, requirement and potential of the influence zone and species and practices available. The species selected should include herbs, shrubs, climbers, creepers, grasses, trees of varied characteristics and end-uses and should meet multifarious ecological, social and economic requirements of the site as well as local needs. In forest areas, species selected should augment those species, which can grow in neighbouring agricultural areas, and for this the concept of landscape ecology should be fully made use of. To minimise cost, natural regeneration of appropriate species has to be promoted to the maximum extent possible. Some of the specific aspects, which require attention in species selection, are:

(i) Multi-purpose plant species capable of meeting the demands of the local population such as, fuel wood, fodder, green manure, litter, small timber, materials for cottage industries and household consumption such as bamboo, reeds and canes, species of medicinal importance needs to be selected. While selecting species, those species that can augment the resources in the influence zone should be given preference.

(ii) Only species that are suited to the site conditions and the influence zone from a landscape level point of view should be selected. While introducing new species in the site it should be ensured that it will not upset the ecological balance. Also produces from the plants should have ready acceptability and market in the influence zone. While choosing the species, their compatibility to micro-site conditions as mentioned below needs specific attention,

(a) Species with root system having soil binding capacity for slopes

(b)Water loving species for areas close to canal, depressions and gullies.

(c)Shade loving plants for locations under dense canopy.

(d) Shallow rooted plants for rocky areas.

(e) Drought enduring species in drier and open/exposed areas.

(f) Species with smaller crown for boundaries to avoid disturbance to neighbouring households.

(g) Wind hardy species as wind breaks.

(h) Species with nitrogen fixing characteristics for soil enrichment.

(i) Suitable species to be selected as live-hedge.

(j) Species of aesthetic value for locations of aesthetic importance.

(iii) While choosing species, to ensure the multi-tier structure and maximum diversity, species having diverse height, girth and crown characteristics need to be selected. Thus, the species chosen should include sufficient number of plants belonging to herbs, shrubs, climbers, creepers, grasses and trees of varied height.

Restructuring of vegetation for maximising benefits: The most crucial aspect of multi-tier forestry is how best the existing vegetation can be transformed into a multi-tier forest through effective restructuring. Judicious use of natural as well as artificial regeneration along with harvesting can be tried in attaining the right spatial and temporal arrangement of plants which are most congenial for growth and development of stand suited to the site conditions and needs of the influence zone. The transformation of existing vegetation through restructuring is possible by suitably regulating the different stand and individual tree parameters over time.

Restructuring of vegetation is possible by suitably regulating stand parameters with respect to actual and potential height. The stand parameters such as number of plants, basal area, species composition, stand volume, and stand crown area can be used for this purpose.

In addition to these, number of plants in the stand have to be regulated based on different uses required to the society particularly to the local people in the influence zone.

Participation and involvement of local people for mutual benefits: As multi-tier forestry is a practice envisaged on intensive multiple use, its success lies essentially on how best the forest developed is useful in such a situation. Most of the produces raised through multi-tier forestry such as fodder, fuel wood, green manure, small timber, materials for cottage industries and household consumption and materials of important medicinal value are required by the local people. At the same time harvesting and marketing of these produces using conventional systems is costly and labour intensive. The cost involved in protecting these resources from biotic pressure is also prohibitively

high. So also, various operations involved in multi-tier forestry are highly labour intensive. Thus, participation and involvement of local people in multi-tier forestry planning and implementation is essential not only for the people but also for the development of forest. However, for getting the desired results, people's participation has to be under technical guidance and close supervision of forestry professionals. Appropriate institutional set-up involving local people and forest department, based on the concept of Joint Forest Management can be developed for management of such multi-tier forests. The need for peoples' involvement and participation in forest management and eco-development is now widely recognised. (Anderson *et al*, 1998; Arnold, 1988; Basu, 1983; Byron and Parz, 1996; CSE, 1986; Chand Basha, 1991; Chandrakanth *et al*, 1990; Colchester, 1996; Davidson, 1982; Dhiman, 1986; Dove, 1992; Gorte, 1999; Green and Barborak, 1987; Hallsworth, 1982; Jordan, 1971; KFD, 1996; Kumar and Kaul, 1996; Mark, 1990; Michaelsen, 1991; Montalembert and Schmithusen, 1993; Pratima and Jattan, 1999; Roy Bhardhan, 1993; Smith *et al*, 1999; Spears, 1985; Steiguer, 1998; Tewari, 1991; Uma Lele *et al*,1994; Williams and Ellefson, 1997). The findings of the present study also support this.

Decentralised planning for efficient and timely decision making: Multi-tier forestry is an activity involving high intensity management. Timely and continuous decisions have to be taken and implemented with regard to planting, maintenance and harvesting of various produces on a day to day basis. Centralised planning is not suited to multi-tier forestry. While only general policy guidelines can be provided at higher levels, most of the decisions pertaining to multi-tier forestry have to be taken at individual plantation level. This calls for appropriate changes in decision making through decentralised planning involving local people.

3.8 Computer aided management tools in multi-tier forestry

Computer aided tools were found to be useful in handling different planning and implementation problems connected with design, development and management of multi-tier forests. They were useful in continuous assessment of site conditions and evaluation of needs and potential of neighbouring ecosystem, which are required for multi-tier forestry. They are also useful in capture, storage, processing and retrieval of information

on species characteristics and their management practices. This is the case with handling of information on varied site management practices. Computer aided tools are also helpful in scheduling of various management operations and evaluating the impact of different decision alternatives. Some of the computer-aided tools successfully used in this study are discussed below.

Stock mapping system for multi-tier forestry: Data base technology and Geographic Information System (GIS) was used in handling site assessment data gathered through different methods at different time points. With the help of appropriate data base management packages such as Dbase and Fox Pro, data bases providing site conditions and status of vegetation at stand and individual plant level for different time periods were created. Using packages such as MS Excel, it was possible to process this data and obtain the required information in the form of tables, graphs and charts. The spatial display of various information was possible using GIS software packages such as IDRISI and ARC/INFO.A few examples of figures thus obtained are shown below (Fig. 41 to 46).

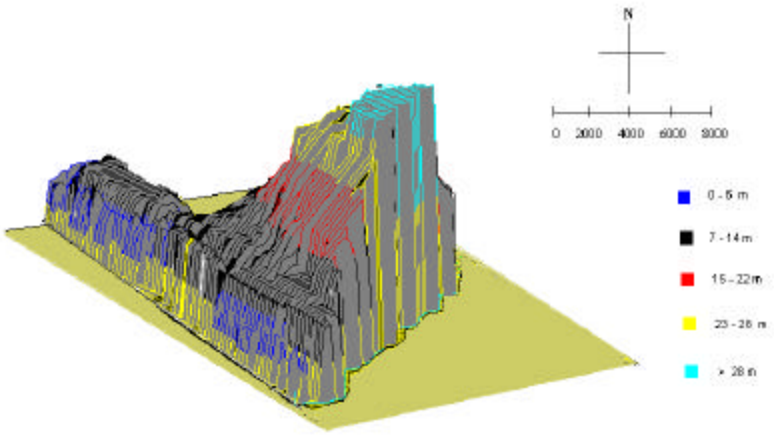

Fig 41 Multi-tier forestry – Study area (a digital terrain model depicting altitudinal variation)

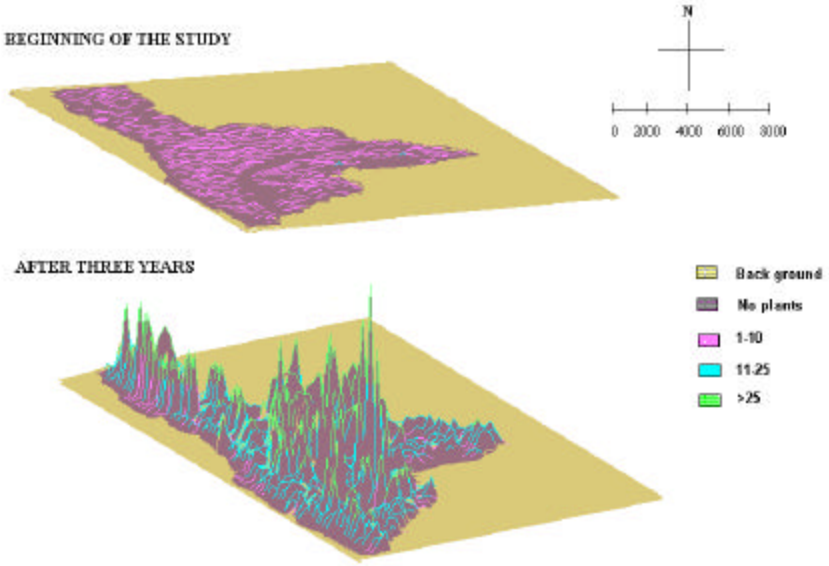

Fig 42 Distribution of number of plants in the study area (a three dimensional perspective view using GIS)

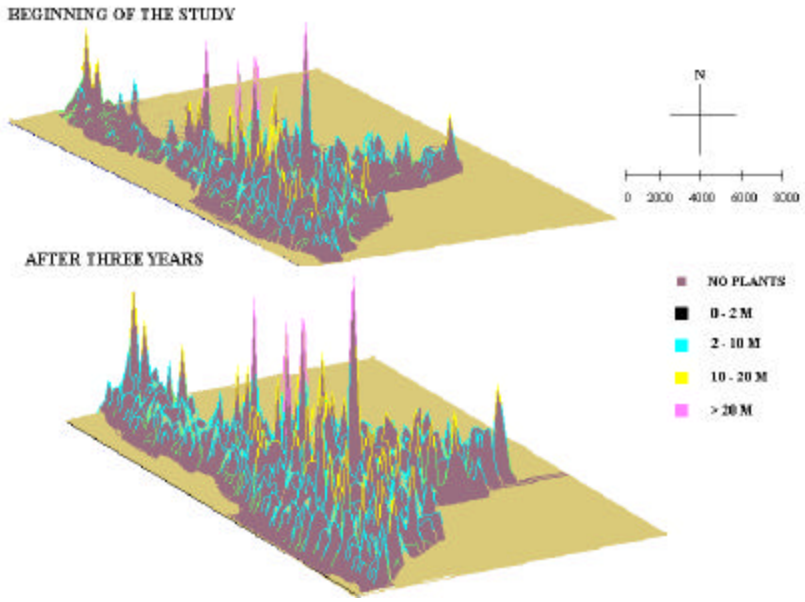

Fig 43 Vegetation status of the study area (a digital elevation model based on height of plants)

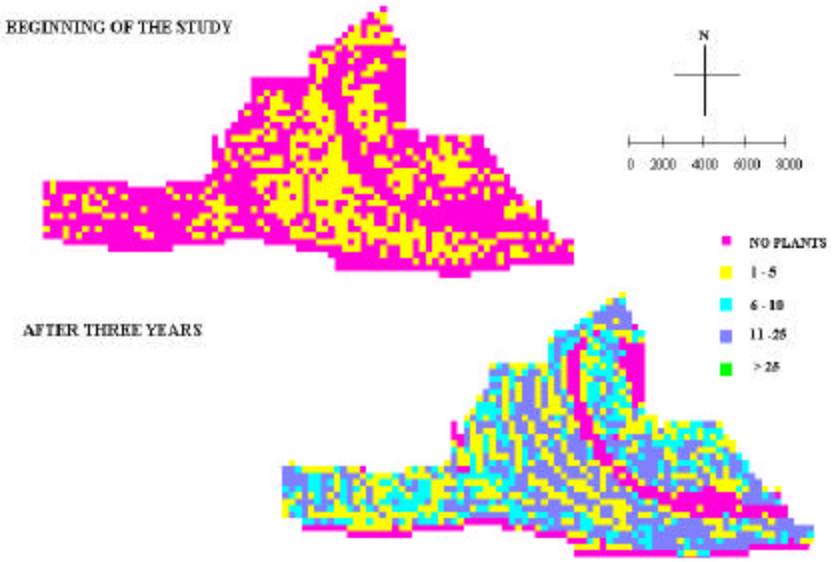

Fig 44 Distribution of plant species in the study area (a map combined through overlay)

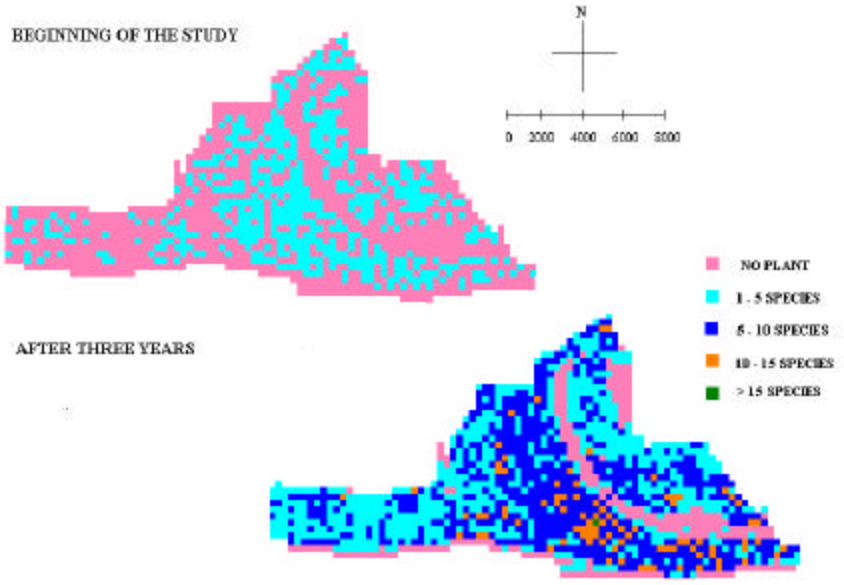

Fig 45 Distribution of number of plants in the study area (a map obtained through overlay)

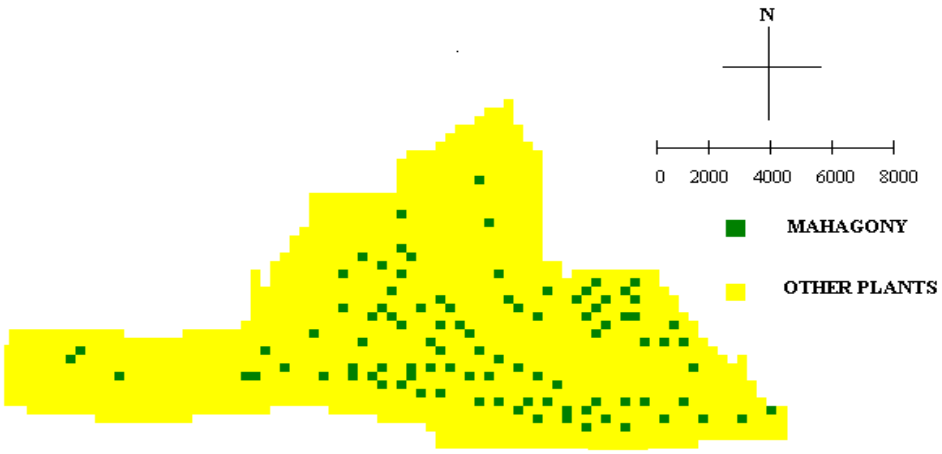

Fig 46 Distribution of Mahogany plants in the study area (a map obtained through overlay)

Silvicultural knowledge base: Computer aided software such as MS Word, MS Excel and Fox Pro were used in storage of various information on species and package of plant management practices. A format devised for the purpose containing various parameters on which information available can be assembled is given in format1, appendix 3 which can be computerised in the form of text files and made readily available with the help of word processing software such as MS Word. A database file arranged similarly for the species *Artocarpus hirsutus* is enclosed in format 2, appendix 3.

Information pertaining to various parameters on different species can be arranged in the form of database files using appropriate database management software such as Dbase, FoxPro or MS access or Oracle. Sample copy of information on height growth of different plant species of different age categories assembled in the form of FoxPro files is given in format 2, appendix 3. Database file formats for arranging information on uses of different plant species are given in format 3, appendix 3. A computer program in FoxPro

for selecting species of required use from the knowledge base is given in computer program 2, appendix 5. A sample output file containing species suitable for live hedge extracted from the knowledge base using this computer program is also given. (Appendix 5)

Similarly information on different site management practices and requirement of labour for various operations can also be assembled from multiple data sources, organized and arranged in computerized text and database file formats for easy processing and retrieval.

Modelling tools for data integration and evaluation of decision alternatives: By integrating stock map data and the knowledge base information on height growth stand growth projections can be made through computer simulation regarding the number of plants available under different height categories during different periods and possible number of trees that can be harvested can be obtained. A sample computer program in FoxPro for getting these information from stock map data and the knowledge base on height growth is also given in appendix 6. (Appendix 6, computer program 3). The sample output for stand growth projection based on height growth and harvesting schedule is also given in this appendix.

4. DISCUSSION

The problems and prospects of multi-tier forestry as a forestry practice were examined through a demonstration plot. Lack of understanding of nature of multi-tier forest required, opportunities and challenges involved in matching species and management practices with micro-site conditions over time and space, scope for integrating productive potential of the site with needs and capabilities of local population and neighbouring ecosystem were the major aspects which required attention. Complexity of the problem demanded use of Operations Research approach. The problem was explored from multi-disciplinary and trans-disciplinary angles with a holistic perspective.

A demonstration plot was established at KFRI campus at Peechi (10 32 N and 76 20 E) in an area of 2.17 hectares. Through various operations an effort was made to convert this degraded site of moist deciduous forest type into a multi-tier forest which is ecologically sound, economically viable and socially relevant, capable of meeting multifarious needs of local people on a sustainable basis. A small area, easily accessible and thus amenable for close monitoring was selected to facilitate in-depth study of the problem.

Exhaustive evaluation of study site to assess vegetation and micro-site conditions, a comprehensive socio-economic-vegetal survey after identifying an influence zone to decide needs and potential of people living there, a detailed survey of species and management practices possible and a series of operations to transform the given site to a multi-tier forest integrating above aspects were the major activities of this study. The prospects of multi-tier forestry, problems involved in planning and implementation and strategies for management were also studied. The potential of utilising various computer aided management tools was another aspect studied.

The improvement in vegetation status and socio-economic benefits realised within three years demonstrated the potential of multi-tier forestry as a sustainable and ecologically viable

forestry practice. Stocking increased from 396 plants ha^{-1} to 12,284 plants ha^{-1}, 45% through natural regeneration. Number of species increased from 15 to 163. During third year, there was a yield of 4.52 tonnes of fuel wood, 3.3 tonnes of green manure, 1.67 tonnes of fodder, 1.27 tonnes of small timber, 0.438 tonnes of teak leaves (packing material) and 0.249 tonnes of materials of medicinal importance per hectare. Various activities generated 696 man-days $ha^{-1}yr^{-1}$ of labour in the form of partial employment. Of this, women constituted 65%. Through various goods and services 255 families were benefited. The overall cost per hectare incurred (adjusted to the year 1999 at 6% interest) was only Rs.18, 900/-. The wages of 128 man-days $ha^{-1}yr^{-1}$ towards costs of various cultural operations were saved through participation and involvement of local people. An amount of Rs.769/- per hectare was realized through supply of various materials produced from the plot on subsidized rates during the third year.

Observations made during the subsequent 6 years emphasised the initial findings. Growing stock in terms of stand volume increased from 94.44m^3 ha-1 to 309.4m^3 ha-1 within ten years. During this period crown area increased from 3567.14m^2 ha-1 to 10678.98m^2 ha-1. In this period, substantial amount of material such as bamboo, teak poles, green manure, fodder and teak leaves were collected by local people. These included an average of 4.5 tonnes of green manure, 14.6 tonnes of fodder, 9.16 tonnes of fuel wood, 2.56 tonnes of small timber, 1.28 tonnes of medicinal produces, 3.85 tonnes of teak leaves, 150 numbers of bamboo culms, 25 numbers of rattans ha^{-1} yr^{-1}. The value of these produces for the last three years, in economic terms came to Rs. 13,033/- $ha^{-1}yr^{-1}$ at local rates. In addition to these, about 1095 man-days $ha^{-1}yr^{-1}$ of rural labour was generated.

Experience in the establishment of multi-tier forest revealed its superiority over plantation and natural forest on following aspects: (i) effective utilization of existing vegetation and available space, (ii) optimal utilization of resources and potential of neighboring ecosystem, (iii) shorter time span involved in getting the yield, (iv) multifarious types of yield obtained, (v) higher benefits accrued to the society particularly the sections of the people with low economic income living in the vicinity of the site, (vi) sustainability of the practice for

intensive multiple use, (vii) as a forestry practice which enhances productivity of the site, (viii) higher overall economical, ecological and social benefits, (ix) low cost of production and (x) early return.

The degraded forest areas in close proximity to human habitation were identified as the most suitable site for practicing multi-tier forestry. The high demand for various produces such as fodder, green manure, fuel wood, small timber, plant materials of medicinal value and raw material for cottage industries makes multi-tier forestry attractive to these localities. The highly labour intensive nature of the practice makes multi-tier forestry advantageous to the people in these areas where availability of labour is also very high. A recent study conducted in Kerala has found that fifty percent of the natural forests were degraded forest lying within a radius of five km from human habitations (Nair *et al*, 1997). Reports also exist on availability of large extent of similar sites in all third world countries (Arnold, 1988; Budowski, 1983; Byron, and Parz, 1996; Davidson, 1982; FSI, 1995; Jordan, 1971; Poore and Sayer, 1987). There is renewed worldwide interest in multi-species silviculture and uneven aged management, landscape approach, adoptive management, ecosystem approach, participatory management. (Anderson *et al*, 1998; Ashton and Peter, 1999; Bradshaw, 1992; Brunig, 1983; Colchester, 1996; Gorte, 1999; Johnson, 1999; Larsen *et al*, 1997; O'Hara, 1998; Poore and Sayer, 1987; Sayr *et al*, 1995; Schabel and Palmer, 1999; Smith *et al*, 1999; Steiguer, 1998; Stout, 1998; Whitmore, 1990; William and Eflefson, 1997). In this context multi-tier forestry provides an economically viable, ecologically sustainable and socially relevant forestry practice.

The study has identified the following planning and implementation problems in multi-tier forestry: (i) requirement of management decisions based on micro-site conditions at individual plant level, (ii) more attention to needs and potentials of neighboring ecosystem, (iii) decisions based on wider spectrum of plant species and management practices, (iv) need for planting stock of large number of species on a continuous basis, (v) yield regulation and harvest scheduling for diverse forest produces, (vi) more intensive management on a continuous basis, (vii) higher labour requirement, (viii) decision making through integrating

a number of related factors over time and space, (ix) lack of availability of technical information on many species and their management practices and (x) implementation problems in harvesting of various produces.

Major strategies identified for development and management of multi-tier forest are:
(i) transformation of existing degraded vegetation into multi-tier forests by regeneration and selective harvesting, (ii) choice of species and package of practices that can supplement and complement the ecosystem of the influence zone; (iii) enhancement of productivity of site through effective management of soil, water and micro-climate; (iv) development of a local permanent multi-species forest nursery to meet the requirement of the site and adjoining ecosystem on a continuous basis; (v) participation and involvement of the local people of the influence zone to minimize the biotic pressure, to reduce the operational cost and to ensure the full utilization of various produces; and (vi) decentralized planning and execution coupled with efficient coordination and control at different levels of management.

The potential management tools identified for multi-tier forestry are: (i) stock mapping system which can provide information on site condition, status of vegetation, (ii) a continuous inventory system for getting information on needs and potential of people in the influence zone of multi-tier forestry, (iii) a knowledge base which can provide information on different species and silvicultural management techniques and (iv) a set of modeling tools for integrating the above three and for informed decision making. With suitable illustrations and examples, the study highlights the scope of utilizing various computer-aided management tools such as Data base technology, Geographic Information System and Operations Research for developing them.

Though multi-tier forestry was found to be a successful forestry practice, multi- location trials in larger areas will be useful before it is taken up for field implementation. Efforts for standardisation of stock mapping procedure and continuous inventory system for assessment of needs and potential of neighbouring ecosystem suitable for larger sites are required. Studies are required for development of silvicultural knowledge base containing information

on species and plant management practices as well as site management procedures. Development of tools for scheduling of various activities and evaluating different decision alternatives connected with establishment and management of multi-tier forest is also needed. There is considerable scope for utilising Operations Research, Data base technology, Geographic Information System, Remote Sensing, and Expert System techniques in this task.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The conclusions of this study are as follows:

(i) Multi-tier forestry was found to be a sustainable forestry practice for intensive multiple use. Its suitability in rehabilitation of degraded forests, optimization of productive potential of the site and neighbouring ecosystem, and providing maximum benefits to the society in particular the local people in the immediate influence zone was established.

(ii) Experience in the establishment of multi-tier forest revealed its superiority over plantation and natural forest on following aspects: (i) effective utilization of existing vegetation and available space, (ii) optimal utilization of resources and potential of neighbouring ecosystem, (iii) shorter time span involved in getting the yield, (iv) multifarious types of yield obtained, (v) higher benefits accrued to the society particularly the sections of the people with low economic income living in the vicinity of the site, (vi) sustainability of the practice for intensive multiple use, (vii) as a forestry practice which enhances productivity of the site, (viii) higher overall economical, ecological and social benefits, (ix) low cost of production and (x) early return.

(iii) Forest areas lying close to human habitations were proved to be the ideal site for multi-tier forestry. The high demand for various produces such as fuel wood, fodder, green manure, small timber, materials of medicinal value, raw materials for cottage industries; availability of labour for maintenance, harvesting and marketing of various produces; low cost of production and early return were the major factors making multi-tier forestry attractive to these sites. In Kerala, 50% of the natural forests are degraded areas lying within 5 km. radius of human habitation. Large extent of degraded forests of similar nature exists in other parts of the country and in most of the third world countries.

(iv) The study identified the following planning and implementation problems in multi-tier forestry: (1) requirement of management decisions based on micro-site conditions at individual plant level, (2) closer attention to needs and potentials of neighbouring ecosystem, (3) decisions based on wider spectrum of plant species and management practices, (4) need for planting stock of large number of species on a continuous basis, (5) yield regulation and harvest scheduling for diverse forest produces, (6) more intensive management on a continuous basis, (7) higher labour requirement, (8) decision making through integrating a number of related factors over time and space, (9) lack of availability of technical information on many species and their management practices and (10) implementation problems in harvesting of various produces.

(v) Major strategies identified for development and management of multi-tier forest are: (1) transformation of existing degraded vegetation into multi-tier forests by regeneration and selective harvesting, (2) choice of species and package of practices that can supplement and complement the ecosystem of the influence zone; (3) enhancement of productivity of site through effective management of soil, water and micro-climate; (4) development of a local permanent multi-species forest nursery to meet the requirement of the site and adjoining ecosystem on a continuous basis; (5) participation and involvement of the local people of the influence zone to minimize the biotic pressure, to reduce the operational cost and to ensure the full utilization of various produces; and (6) decentralized planning and execution coupled with efficient coordination and control at different levels of management.

The study has identified the following management tools for multi-tier forestry: (i) stock mapping system which can provide information on site condition, status of vegetation, (ii) a continuous inventory system for getting information on needs and potential of people in the influence zone of multi-tier forestry, (iii) a knowledge base which can provide information on different species and silvicultural management techniques and (iv) a set of modeling tools for integrating the above three and for informed decision making. With suitable illustrations

and examples, the study demonstrated the scope of utilizing various computer aided tools such as Data base technology, Geographic Information System and Operations Research for developing them.

5.2 RECOMMENDATIONS

The recommendations of the study are the following:

(i) Multi-tier forestry is a sustainable forestry practice and can be used for rehabilitation of degraded forest areas lying close to human habitations.

(ii) Multi-locational trials in large areas will be useful before field implementation of multi-tier forestry.

(iii) Studies for developing various management tools for multi-tier forestry such as stock mapping system for site assessment, inventory system for assessing needs and potential of influence zone, silvicultural knowledge base, modeling tools for scheduling various operations and evaluating decision alternatives will be useful in handling various planning and implementation problems.

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APPENDICES

APPENDIX 1.

Sample proformae for continuous inventory of multi-tier forestry site and its influence zone.

Proforma 1: Sample field measurement sheet for monitoring vegetation (Stockmapping system for multi-tier forestry)

Date of measurement:

SL. No	X (Row 4m)	Y (Col. 4m)	Species	Height (m)	Girth (cm)	Bole Length (m)	Crown Length (m)	Crown Width (m)	No.of Branches	No*	Remarks **
				(0-1, 1-2, 2-5, 5-10, 10-15, 15-20, 20-30, 30-40)	0-10, 10-30, 30-60, 60-90, 90-150, 150-210, 210-300, 300-600)	(0-1, 1-2, 2-5, 5-10, 10-15, 15-20, 20-30)	(0-1, 1-2, 2-5, 5-10, 10-15, 15-25)	(0-1, 1-2, 2-5, 5-10, 10-15, 15-25)	(0-5, 5-10, 10-20)		
1	2	3	4	5	6	7	8	9	10	11	12

* Number of plants having same size (i.e., similar values for columns 5 to 10).

**In Remarks column information such as status of plants (Planted/year/ Natural/coppice/Dried/Crooked/Moderate/Good/flowering/fruiting) and features in the grids such as (road, canal, fence, rock or other features) can be noted.

Description of parameters used in proforma 1.

SL No.	Field Name	Description
1	X	X coordinate (in terms of 4m columns) – number of grids column wise
2	Y	Y coordinate (in terms of 4m rows) – number of grids row wise
3	Species	Species name-local name/botanical name
4	No	Number of plants
5	Height	Height code Height (m.) Code 0 0 0-1 1 1-2 2 2-5 3 5-10 4 10-15 5 15-20 6 20-30 7 30-40 8
6	Girth/Stump girth (for cut trees)	Girth code Girth (cm) Code 0 0 0-10 1 10-30 2 30-60 3 60-90 4 90-150 5 150-210 6 210-300 7 300-600 8
7	Bole length	Bole length Bl (m.) Code 0 0 0-1 1 1-2 2 2-5 3 5-10 4 10-15 5 15-20 6 20-30 7

8	Chcode	Crown height code Ch (m) Code 0 0 0-1 1 1-2 2 2-5 3 5-10 4 10-15 5 15-25 6
9	Cwcode	Crown width code Cw (m) Code 0 0 0-1 1 1-2 2 2-5 3 5-10 4 10-15 5 15-20 6
10	Nbcode	Number of branches code Nb Code 0 0 0-5 1 5-10 2 10-20 3
11	Remarks	Plant features: n - natural, n(t) - natural (teak), p90j - planted in June 1990, P91J - planted in June 1991, P92J - planted in June 1992, fl – flowered, f - fruited, tb - top broken, cr – crooked, dr – dried, c – cut, r – retained, p – poor m – moderate, g – good other site features: ca – canal, rd – road, b – blank (without plants), rk – rock, st-stony, f – fence, to – tower, tr – trench, pd – pond, pt – pit, wt - water tank, ep - electric post, wd – weed, pl - private land, cw – compound wall

Proforma 2. Stockmapping system for multi-tier forestry field measurement sheet for micro locality factors

SL. No	X (row 4m)	Y (Col 4m)	AL	SL	AS	SD	SM	SC	CD1	CD2	CD3	CD4	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1													
2													
3													
4													
5													
6													

Description of the parameters used in the field measurement sheet for micro locality factors of multi-tier forestry site.

SL. No	Field	Description
1	X	X coordinate (in terms of 4m columns) – number of grids column wise
2	Y	Y coordinate (in terms of 4m rows) – number of grids row wise
3	AL	Mean sea level altitude (in meter)
4	SD	Soil depth (shallow-1, moderate-2, deep-3)
5	SM	Soil moisture (dry-1, moderately wet-2, wet-3)
6	SC	Soil cover (barren-1, moderate cover-2, dense cover-3)
7	CD1	Canopy Density for 0-2m height [low(<40%)-1, moderately dense(40-70%)-2, thick(>70%)-3]
8	CD2	Canopy Density (2-10m height) [low(<40%)-1, moderately dense(40-70%)-2, thick(>70%)-3]
9	CD3	Canopy Density (10-20m height) [low(<40%)-1, moderately dense(40-70%)-2, thick(>70%)-3]
10	CD4	Canopy Density (>20m height) [low(<40%)-1, moderately dense(40-70%)-2, thick(>70%)-3]
11	SL	Slope (plane-1, moderate-2, steep-3)
12	AS	Aspect s - south, sw - south west, w - west, nw – north west, n- north, ne – north east, e – east
13	R	Remarks: Cl – canal, bp - bridal path, rk – rock, rd – road, f –fence, w – wall, t – trench,

Proforma 3

Sample proforma for documenting various operations carried out in the multi-tier forestry site

SL. No	X (row 4m)	Y (Col 4m)	Date	Operations	Remarks
1	2	3	4	5	6
1					
2					
3					
4					
5					
6					

Proforma 4. Sample proforma for rapid appraisal – complete enumeration survey covering all households (Continuous inventory system for needs and potentials of influence zone of multi-tier forestry site)

1 Name and address of house owner (including house no./survey no.) :

2 Distance from site (in multiples of 100m) :

3 Details of persons occupying the house :

SL. No.	Name	Male (M)/ Female (F)	Age (years)	Occupation
1				
2				
3				
4				
5				

4 Land extent (acre/hectare) :

5 Electrified (E)/non electrified (NE) :

6 Use of gas for cooking purposes (Yes/No) :

7 Number of animals :

SL. No	Particulars	Small	Medium	Big	Total
1	Cows				
2	Buffalo				
3	Goat				
4	Chicken				
5	Others (specify)				

8 Family monthly income :

9 Forest based needs :

- Fodder/day (in kg) :
- Fuel wood/day (in kg) :
- Green manure/year (in kg) :
- Litter/year (in kg) :
- Employment
  man-days/week :
  full/partial :
  skilled/semi skilled) :
- Small timber required for household consumption or agricultural purposes
  - Poles (in numbers and kg) :
  - Bamboo (in numbers and kg) :
- Raw material for forest based cottage industries involved by the household :
  - Bamboo/Reeds/Canes/Other (specify)
- Requirement for nontangible benefits
  - Protection from soil and water erosion and wind :
  - Pollution control, aesthetic :
  - Any other (specify) :

10 Interest in plant worship : yes/no
If yes, provide list of species

SL. no	species

11 Use of plants for medicinal purpose : yes/no
If yes, provide list of species

SL. no.	species

12 Earlier land use pattern and crop :
(natural forest/forest plantations/annual crops-monoculture/annual crop-polyculture/cash crop plantations-monoculture/cash crop-plantations mixture/home gardens)

13 Do they have forest trees in the homestead : yes/no
If yes, list of species

SL. no	species

If no, do they like to plant forestry species?
If yes,

Choice of plants for planting
a. Large trees :
b. Small trees :
c. Medicinal plants :
d. Grass :

List of species

SL. no	species

If no, tick mark the reasons against planting forestry species

(i) No land for planting :
(ii) More importance to other crops :
(iii) Not profitable :
(iv) Rules and regulations in harvesting forest tree species in the homesteads :
(v) Long gestation period involved in getting yield :
(vi) Any others

Proforma 5

Sample proforma for detailed sample survey of households (Continuous inventory system for needs and potentials of influence zone of multi-tier forestry site)

1 Name and address of house owner (including house no./survey no.) :

2 Status of vegetation :

SL. No	Species Name	Size of plant (height)			Total
		Small (0-10m)	Medium (10-20m)	Large (20-40m)	
1	2	3	4	5	6

3. Past land use history (agricultural land/paddy field/ cash crop plantation/home garden/ forest/other land use - specify) :

4. Availability of vacant spaces and gaps for planting (in effective hectare) :

5 Potential forestry species required for planting and quantity of planting stock required

SL. No	Name of species	Quantity of planting stock
1		
2		
3		

Proforma 6

Sample proforma for monitoring various produces provided from the multi-tier forestry site (Continuous inventory system for needs and potentials of influence zone of multi-tier forestry site)

SL. No	**Date of supply**	**Name & Address (including house no. or survey no.)**	**Materials provided** **FG - Fodder grass** **FL - Fodder leaves** **GM - Green manure** **FW - Fuel wood** **TL - Teak leaves** **ST - Small timber** **M - Medicinal** **PS - Planting stock**	**Quantity given**	**Rate (if any)**	**Amount Realised**
1	2	3	4	5	6	7

Proforma 7

Sample proforma for monitoring labour generated through multi-tier forestry (Continuous inventory system for needs and potentials of influence zone of multi-tier forestry site)

SL. No	Date	Labour (Male-M Female-F)	No. of hours	Name & address (including Survey. Number & house number)	Remarks (direct employment/ indirect employment)
1	2	3	4	5	6

APPENDIX 2

Database file formats for computerisation

File format 1: Selected Fields of computerised database file of the Stockmapping system of multi-tier Forestry

X	Y	Spn	Htcode	Gtcode	Blcode	Chcode	Cwcode	Nbcode	No	Rem	M_time
4	13	412	3	1	3	1	2	1	1	N	JUN92
4	13	29	0	0	0	0	0	0	4	c	MAR99
4	13	427	1	1	1	1	1	1	1		MAR99
4	13	209	1	1	1	1	1	1	1		MAR99
4	14	29	3	1	3	2	1	1	1	N	SEP89
4	14	18	1	1	1	1	1	1	1	P90J	JUN90
4	14	29	3	2	3	2	1	1	3	N	JUN90
4	14	224	1	1	1	1	1	1	1	P91J	OCT91
4	14	224	1	1	1	1	1	1	3	P91J	JUN91
4	14	29	3	1	3	1	2	1	1	N	JUN92

Description of the selected fields used in the computerized database file of the Stock mapping system

Fields	Description of field
X	X coordinate in terms of 4m columns
Y	Y coordinate in terms of 4m rows
Spn	Species code - the species in the field measurement sheets were assigned numerical numbers as codes
Htcode	Height code
Gtcode	Girth code - stumb girth code in the case of trees which are cut
Blcode	Bole length code
Chcode	Crown height code
Cwcode	Crown width code
Nbcode	Number of branches code
No	Number of plants
Rem	Remarks
M_time	Month &Year of data collection

File format 2: Data base file format - Socio-economic-vegetal survey (selected fields)

SN	NA_AD	SURN	DISTANCE	INCOME	LE	E_NE
1	2	3	4	5	6	7

SL. No	Database field name	Description of database fields and values of the codes used for different parameters
1	SN	Serial Number
2	NA_AD	Name and address
3	SURN	Survey number
4	DISTANCE	Distance 1 - 0-100 m. 7 - 600 - 700m 2 - 100 - 200m. 8 - 700 - 800m. 3 - 200 - 300m. 9 - 800 - 900m 4 - 300 - 400m. 10 - 900 - 1000m 5 - 400 - 500m. 11 - 1000 - 1100m. 6 - 500 - 600m. 12 - 1100 - 1200m
5	INCOME	Income 1 - Very poor 2 - Poor 3 - Medium 4 - High
6	LE	Land extent (in cent)
7	E_NE	Electrified or Non-electrified

File format 3: Socio-economic-vegetal survey - database on people

SN	NOP	M	F	TYPEL
1	2	3	4	5

SL. No	Field	Description
1	SN	Serial Number
2	NOP	Number of persons
3	M	Male
4	F	Female
5	TYPEL	Type of labour A - Service B - Agriculture C - Animal husbandry D - Business / Industry E - Labour (daily wage labour)

File format 4: Socio-economic-vegetal survey - database on vegetation

SN	SPN	NO	SIZ
1	2	3	4

SL. No	Field	Description
1	SN	Serial Number
2	SPN	Species code
3	NO	Number
4	SIZ	Size S - Small (<10m) M - Medium (10-20m) L - Large (> 20m)

File format 5: Socio-economic-vegetal survey - database on domestic animals

SN	AN	C	B	G	CH
1	2	3	4	5	6

SL. No	Field	Description
1	SN	Serial Number
2	AN	Total Animals
3	C	Cow
4	B	Buffalo
5	G	Goat
6	CH	Chicken

APPENDIX 3

Database file formats for species knowledge base.

Format 1: Format for assembling species information for silvicultural knowledge base from multiple data sources

1. Taxonomical and Vegetative Characteristics
1.1. Nomenclature
1.1.1. Botanical Name
1.1.2. Family
1.1.3. Genus
1.1.4. Trade Name
1.1.5. Common Name
1.1.6. Vernacular names (Local Name)
1.2. Habit
1.2.1. Tree
1.2.2. Root
1.2.3. Stem
1.2.4. Bark
1.2.5. Crown/Branches
1.2.6. Leaves
1.2.7. Flowers
1.2.8. Fruits
1.2.9. Seeds

2. Habitat, Distribution and Forest types
2.1. Habitat
2.2. Distribution
2.3. Forest types

3. Associate Species

4. Uses
4.0. Tree (Non-tangible)
4.1. Roots
4.2. Stem
4.3. Bark & latex
4.4. Leaves
4.5. Flowers
4.6. Fruits
4.7. Seeds

5. Growth, Yield & Demand
5.1. Growth
5.1.1. Root
5.1.2. Stem
5.1.3. Bark & latex
5.1.4. Leaves
5.1.5. Flowers
5.2.3. Bark & latex
5.2.4. Leaves
5.2.5. Flowers
5.2.6. Fruits
5.2.7. Seeds
5.3. Demand/Price
5.3.1. Root
5.3.2. Stem
5.3.3. Bark & latex
5.3.4. Leaves
5.3.5. Flowers
5.3.6. Fruits
5.3.7. Seeds

6. Site Requirements
6.1. Climate
6.2. Topographic
6.3. Edaphic
6.4. Biotic

7. Natural Regeneration

8. Artificial Regeneration
8.1. Preparation of planting stock
8.1.1. Collection of materials for preparation of planting stock
8.1.2. Storage
8.1.3. Nursery
8.2. Plantation site preparation
8.3. Planting

9. Stand Management
9.1. Stand establishment (Weeding, soil working, fertilisation)
9.2. Thinning/pruning
9.3. Felling/harvesting

10. Protection problems and control measures
10.1. Insects
10.1.1. Root
10.1.2. Stem
10.1.3. Bark
10.1.4. Leaves
10.1.5. Flowers
10.1.6. Fruits
10.1.7. Seed

5.1.6. Fruits
5.1.7. Seeds
5.2. Yield
5.2.1. Root
5.2.2. Stem

10.1.8. Stored material
10.2. Other pests
10.3. Diseases
10.4. Other Biotic factors

11. References

A sample output of information on species in text file format (MS Word) from species knowledge base.

Species: *Artocarpus hirsutus* Lam.

1. Taxonomical and vegetative characteristics

1.1. Nomenclature : 1.1.1. Botanical name: *Artocarpus hirsutus* [302]; 1.1.2. Family: Moraceae [302]; 1.1.3. Genus: Artocarpus [302]; 1.1.4. Trade name: Aini [302]; 1.1.5. Common name: Anjili, Aini, Agani; 1.1.6. Vernacular name (local name) - Nil. 1.1.7. Varieties - Nil [302].

1.2. Habit : 1.2.1. Tree - A very large evergreen tree [157], 25-45m height with a clear bole of 10-20m and up to 130cm in diameter [189]. 1.2.2. Root - taproot, orange reddish. 1.2.3. Stem - Colour - sapwood greyish or yellowish-white [189]. Heart wood - golden yellow to yellowish-brown [157, 189, 302 and 440]. Hardness - moderately hard [189]. Weight - moderately heavy, 595kg/m3 at 12%m.c [189]. Grain - straight to interlocked, texture medium [189]. Durability - durable [189]. Growth rings - indistinct [189]. Wood structure - diffuse-porous, seasons and polishes well, not eaten by white ants, [189]. Vessels - large, few, solitary or in radial multiples filled with tyloses or white chalky deposits [189]. Parenchyma - paratracheal [189]. Rays - broad to fine, fairly wide spread [189]. 1.2.4. Bark - grey, smooth, dark brown [157, 189, 302 and 440]. 1.2.5. Crown/branches - crown with spreading branches. 1.2.6. Leaves - alternate, petiolate, 6 x 9m, broadly ovate, obovate or elliptic, sub-acute or very shortly acuminate, base rounded or somewhat narrowed, tawny hairy on the midrib above and the nerves below, 5-12m long, 3-6m wide [157, 189, 302 and 440]. Stipules yellow hairy. 1.2.7. Flowers - Nil. 1.2.8. Fruits - spinous, oblong or cylindrical, 2-3m long, erect, covered with spines [157, 189, 302 and 440]. Fruiting - every year [157, 189, 302 and 440]. Fruiting ripening - May-June [157, 189, 302 and 440]. 1.2.9. Seeds - 2000/kg [157, 189, 302 and 440].

2. Habitat, distribution and forest types

2.1. Habitat - Elevation up to 4000ft [302]. 2.2. Distribution - Evergreen forests of the west coast from sea level to 3500ft. Coorg, Mysore, Wynad, Anamalais to Travancore [157]. 2.3. Forest types - West Coast tropical evergreen, west coast semi-evergreen and southern secondary moist mixed deciduous forests [189].

3. Associate species - Nil.

5. Uses

4.1. Roots - Nil. 4.2. Stem - House building, furniture, agricultural elements, boat building, ship building, vehicle bodies, rafters, window, door frames and ceiling boards, piles, flush door shutters, class I plywood and veneers, mayine plywood, black boards, fence posts, textile mill accessories, brushware, engineering and drawing instruments, carts and carriages, valuable for panelling and flooring [157, 189 and 302]. 4.3. Bark and latex - Nil. 4.4. Leaves - fodder. 4.5. Flowers - Nil. 4.6. Fruits - edible for wild animals. Nil. 4.7 Seeds - Edible

5. Growth, yield and demand

5.1. Growth : 5.1.1. Root - Nil. 5.1.2. Stem Seedling growth rate [302]

Nursery	Date of Sowing	Date of Measurement	Average length (cm)		Remarks
			Root	Shoot	
Agumbe	12/6/76	22/8/77 (14 months old)	15.7	12.2	Polybag seedlings
Gundia (i)	28/5/76	22/6/77 (13 months old)	67.2	93.5	Raised beds
(ii)	28/5/76	22/7/77 (14 months)	82.2	119.8	Raised beds

5.1.3. Bark - Nil. 5.1.4. Leaves - Nil. 5.1.5. Flowers - Nil.

5.1.6. Fruits - Nil. 5.1.7. Seeds - Nil. 5.2. Yield : 5.2.1. Root - Nil. 5.2.2. Stem [379]

B.G. (Breast height girth in cm)	C.V. (Commercial volume in cu.m)	F.W. (Fuel wood in cu.m)
75	0.117	0.258
85	0.124	0.431
95	0.144	0.546
105	0.180	0.669

(Continued….)

B.G. (Breast height girth in cm)	C.V. (Commercial volume in cu.m)	F.W. (Fuel wood in cu.m)
115	0.230	0.795
125	0.593	0.536
135	0.706	0.630
145	0.834	0.720
155	0.976	0.805
165	1.133	0.887
175	1.305	0.962
185	1.491	1.035
195	1.691	1.102
205	1.907	1.166
15	2.136	1.227
225	2.381	1.281
235	2.640	1.331
245	2.913	1.378
255	3.202	1.421
265	3.504	1.459
275	3.822	1.492
285	4.154	1.521
295	4.500	1.547
305	4.801	1.567
315	5.237	1.583
325	5.627	1.595
335	6.032	1.603
345	6.452	1.608
355	6.886	1.608
365	7.335	1.608
375	7.798	1.608
385	8.276	1.608
395	8.276	1.608
405	9.275	1.608

5.2.3. Bark - Nil. 5.2.4. Leaves - Nil. 5.2.5. Flowers - Nil.

5.2.6. Fruits - Nil. 5.2.7. Seeds - Nil. 5.3. Demand (price) - Nil. 5.3.1. Root - Nil. 5.3.2. Stem - Nil. 5.3.3. Bark - Nil.

5.3.4. Leaves - Nil. 5.3.5. Flowers - Nil. 5.3.6. Fruits - Nil.

5.3.7. Seeds - Nil.

6. Site requirements

6.1. Climate - Nil. 6.2. Topographic - Nil. 6.3. Edaphic - Nil.

7. Natural regeneration - Good coppicer (302)

8. Artificial regeneration

8.1. Preparation of planting stock : 8.1.1. Collection of materials for preparation of planting stock - Nil. 8.1.2. Storage - Nil. 8.1.3. Nursery - Seeds sown in raised germination beds/polybags within a week after collection [302]. Seeds dibbled in beds at 5cm distant. Seedling shade tolerant. [302]. Germination percentage 80 [302]. 8.2. Planting site preparation - Nil. 8.3. Planting-Nil.

9. Stand management

9.1. Stand establishment - Nil. 9.2. Thinning/pruning - Nil.

9.3. Felling/harvesting - Nil.

10. Protection problems and control measures

10.1. Insects : 10.1.1. Root - Nil. 10.1.2. Stem - Nil. 10.1.3. Bark - Nil. 10.1.4. Leaves - Nil. 10.1.5. Flowers - Nil. 10.1.6. Fruits - Nil. 10.1.7. Seeds - Nil. 10.1.8. Stored material - Nil. 10.2. Other pests : 10.2.1. Root - Nil. 10.2.2. Stem - Nil. 10.2.3. Bark - Nil. 10.2.4. Leaves - Nil. 10.2.5. Flowers - Nil. 10.2.6. Fruits - Nil. 10.2.7. Seeds - Nil. 10.2.8. Stored material - Nil. 10.3. Diseases : 10.3.1. Root - Nil. 10.3.2. Stem - Nil.10.3.3. Bark - Nil. 10.3.4. Leaves - Nil. 10.3.5. Flowers - Nil. 10.3.6. fruits - Nil. 10.3.7. Seeds - Nil. 10.3.8. Stored material - Nil. 10.4. Other biotic factors - Nil.

11. References

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John Cameron. (1894). Forest trees of Mysore and Coorg. Printed at Mysore Government Central Press, 3rd edition, 294-295 p. (Ref. code: 302)

Nair, N.R. Commercial volume table for the forest trees of Kerala, 34 p. (Ref. code: 379)

Rai, S.N. (1978). Nursery and planting of some tropical semi-evergreen and evergreen species. Silviculturist Southern Zone, Madikeri - 371 201, India, 8-9 p. (Ref. code: 440)

Format 2: Sample copy of database file formats with Dbase/FoxPro compatible data structure of height growth data of species knowledge base. (organised in 3 levels)

level 1 Height growth database of different plant species over age

SPN	CX1	CX2	CX3	CX4	CX5	CX6	CX7	CX8
1	1	2	3	4	5	6	7	8
2	3	4	4	5	5	5	6	8
3	1	2	3	4	4	5	5	5
4	2	3	3	3	4	4	5	5
5	1	2	3	4	5	6	7	8
6	2	2	3	4	5	6	7	8
7	1	2	3	4	4	5	6	7
8	3	4	4	4	5	5	6	8
9	4	5	5	6	7	8	8	9
10	1	2	3	5	6	7	8	9

Level 2. Database describing fields of database provided in level 1

Code	Description of the fields
CX1	Height in 0-5 years
CX2	Height in 5-10 years
CX3	Height in 10-15 years
CX4	Height in 15-20 years
CX5	Height in 20-25 years
CX6	Height in 25-30 years
CX7	Height in 30-40 years
CX8	Height in > 40 years

Level 3. The values corresponding to different height categories used in the database provided in level 1

Code	Description
1	0-1m
2	1-2m
3	2-5m
4	5-10m
5	10-15m
6	15-20m
7	20-25m
8	25-30m
9	>30m

Format 3: Sample copy of database file corresponding to the parameter 'Use' (in five point scale) of the species knowledge-base (organised in 3 levels)

Level 1: Database on different uses (organised in different fields) of plant species

SPN	EX1	EX2	EX3	EX4	EX5	EX6	EX7	EX8	EX9	EX10	EX11	EX12	EX13	EX14
1	5	0	5	2	5	5	5	4	5	0	0	5	0	3
2	4	3	3	2	5	4	3	1	4	0	1	4	0	3
3	0	5	3	0	1	0	2	0	2	0	0	0	0	2
4	2	2	3	1	5	3	3	1	4	0	0	0	0	2
5	5	0	0	5	2	5	0	0	4	5	5	2	0	3
6	4	1	2	1	5	0	2	0	0	0	4	2	0	3
7	0	2	5	3	2	0	4	0	5	2	5	5	3	3
8	0	0	5	0	2	0	2	0	5	0	5	0	0	4
9	0	3	5	2	5	4	3	1	5	3	0	0	0	3
10	0	0	0	0	5	0	0	0	2	0	5	5	5	3

Level 2: Description of fields in the database file given in level 1

Code	Description
EX1	Tangible use - food
EX2	Tangible use - medicinal
EX3	Tangible use - industrial
EX4	Tangible use - cottage
EX5	Tangible use - fuel wood
EX6	Tangible use - fodder
EX7	Tangible use - small timber
EX8	Tangible use - green manure
EX9	Tangible use - construction
EX10	Tangible use - pulp wood

EX11	Tangible use - ply wood
EX12	Tangible use - packing case
EX13	Tangible use - match wood
EX14	Tangible use - other uses

Level 3. The values corresponding to degree of suitability for different 'Uses' given in the database of level 1

Field	**Description**
1	Very poor
2	Poor
3	Moderate
4	Good
5	Very good

APPENDIX 4

Computer program 1 Stockmap

Description:
A program for getting details on various aspect of vegetation in the multi-tier forestry site from the stockmapped database file. This program is prepared in FoxPro.

The following files are used in this program.

(i) Mulcom.dbf : Stockmapped file containing the details of plants during different stages of the study.
(ii) Tmps.dbf : Indexed file of selected fields copied from Mulcom.dbf
(iii) Species.dbf : A database file from species knowledge-base containing species code, botanical name, local name, common name and family

Out put file: Result.dbf (resulting file with desired fields and records)

Program

```
set talk off
set safety off
CLOSE ALL
clear

store 0 to fc,n,x,fc1,count,i,sum,sm
store space(2) to ans,htv,gtv,chv,cwv,tmv,nbv,blv,qt,spv,g1v,g2v
store space(45) to cap1,cap2
```

```
@2,25 say " STOCKMAP"
@3,15 say "Program Directory :- c:\tmp\tmps.dbf"
@4,5 say "Program  to   provide   details  of plants on   desired parameters
"
@6,5 say "Grid number  (G1,G2),  Height,  Girth,  Bole length,  Crown height,
"
@7,5 say "Crown width, Number of branches, Species and measurement time "
@8,5 say "from the Stockmapped database on Multi-tier forestry site."
@10,5say "Files used:- The stockmapped data of multi-tier forestry site "
@11,5 say "containing information on vegetation at different periods of "
@12,5 say "measurement"
@14,5 say "The file should have following fields"
@15,5 say "G1= X co-ordinate, G2= Y co-ordinate, SPN= Species code, "
@16,5 say "HTCODE=height code,GTCODE=girth code,CHCODE=crown heightcode,"
@17,5 say "CWCODE=crown width code, NBCODE=number of branch code, NO=number"
@18,5 say "of plants, BLCODE=bole length, TIME= measurement time(first three "
@19,5 say "letters of month in capital and last two digits of years)"
@22,5 say "Do you want to continue (y/n)?"
@22,35 get ans
read

if upper(ans)='Y'
   clear
   @5,10 say "Select the Parameters you want (y/n)"
   @7,12 say "G1 - X co-ordinate (row number)"
   @8,12 say "G2 - Y co-ordinate (column number)"
   @9,12 say "Species"
   @10,12 say "Height"
   @11,12 say "Girth"
   @12,12 say "Crown height"
   @13,12 say "Crown width"
   @14,12 say "Bole Length"
   @15,12 say "Number of branches"
   @16,12 say "Measurement time"
   @7,45 get g1v
   read
   @8,45 get g2v
   read
   @9,21 get spv
   read
   @10,20 get htv
   read
   @11,20 get gtv
   read
   @12,26 get chv
   read
   @13,26 get cwv
   read
   @14,28 get blv
   read
   @15,32 get nbv
   read
   @16,32 get tmv
   read
```

```
   clear
else
 exit
endif
@20,3 say "Exit and Go to command window, copy the fields corresponding to the
"
@21,3 say "parameters of interest and  the   field 'no' along   with   records
"
@22,3 say "corresponding to the  code  values chosen   from  stockmapped  file
"
@23,3 say "copy to c:\tmp\tmp.dbf fields g1,g2,....(chosen) for htcode=1,...
<condition>"
@24,3 say "sort to c:\tmp\tmps on tmp.g1,tmp.g2,....(chosen)"

 if upper(g1v)='Y'
     @2,40 say " G1 ->  1 to 82"
  endif

 if upper(g2v)='Y'
     @3,40 say "G2 ->  -3 to 43 "
  endif

  if upper(spv)='Y'
    @4,42 say "Tall trees(>20m)     - 1 to 101"
    @5,42 say "Medium trees(10-20m) - 201 to 281"
    @6,42 say "Small trees(2-10m)   - 401 to 483"
    @7,42 say "Shrubs               - 601 to 642"
    @8,42 say "Herbs                - 701 to 750"
    @9,42 say "Climbers & Creepers  - 801 to 855"
    @10,42 say "Grass               - 901 to 918"
    @11,40 say "For details on species code refer file species.dbf"
   endif
   if upper(htv)= 'Y'
      @2,2 say "htcode"
      @3,2 say "1. 0-1m"
      @4,2 say "2. 1-2m"
      @5,2 say "3. 2-5m"
      @6,2 say "4. 5-10m"
      @7,2 say "5. 10-15m"
      @8,2 say "6. 15-20m"
      @9,2 say "7. 20-30m"
      @10,2 say "8. >30m"
   endif

   if upper(gtv)= 'Y'
      @2,15 say "gtcode"
      @3,15 say "1. 0-10cm"
      @4,15 say "2. 10-30cm"
      @5,15 say "3. 30-60cm"
      @6,15 say "4. 60-90cm"
      @7,15 say "5. 90-150cm"
      @8,15 say "6. 150-210cm"
      @9,15 say "7. 210-300cm"
      @10,15 say "8. >300cm"
   endif
```

```
   if upper(blv)= 'Y'
      @2,30 say "blcode"
      @3,30 say "1. 0-1m"
      @4,30 say "2. 1-2m"
      @5,30 say "3. 2-5m"
      @6,30 say "4. 5-10m"
      @7,30 say "5. 10-15m"
      @8,30 say "6. 15-20m"
      @9,30 say "7. 20-30m"
      @10,30 say "8. >30m"
   endif

    if upper(chv)= 'Y'
      @12,2 say "chcode"
      @13,2 say "1. 0-1m"
      @14,2 say "2. 1-2m"
      @15,2 say "3. 2-5m"
      @16,2 say "4. 5-10cm"
      @17,2 say "5. 10-15m"
      @18,2 say "6. >15m"
     endif

  if upper(cwv)= 'Y'
      @12,15 say "cwcode"
      @13,15 say "1. 0-1m"
      @14,15 say "2. 1-2m"
      @15,15 say "3. 2-5m"
      @16,15 say "4. 5-10cm"
      @17,15 say "5. 10-15m"
      @18,15 say "6. 15-20m"
     endif

  if upper(nbv)= 'Y'
      @19,2 say "nbcode"
      @19,10 say "1. 0-5"
      @19,15 say "2. 5-10"
      @19,22 say "3. >10"
   endif

   if upper(tmv)= 'Y'
      @12,30 say "time"
      @13,30 say "SEP89-SEPTEMBER1989"
      @14,30 say "JUN90-JUNE1990"
      @15,30 say "JUN91-JUNE1991"
      @16,30 say "OCT91-OCTOBER1991"
      @17,30 say "JUN92-JUNE1992"
      @17,30 say "JUL93-JULY1993"
      @18,30 say "MAR99-MARCH1999"
     endif
@14,51 say "Do you want to quit?(y/n)"
@14,77 get qt
read

if upper(qt)='Y'
   exit
```

```
else
clear
@10,10 say "Enter the Title of the Output"
@11,3 get cap1
read
@12,3 get cap2
read
endif

sele a
use c:\tmp\tmps.dbf
*indexed file copied from mulcom.dbf

copy stru to c:\tmp\result.dbf
sele b
use c:\tmp\result.dbf
zap
sele a
go
 top
fc=fcount()
fc1=fc-1
dimension x[fc1]
dimension y[fc1]
for n=1 to fc1
 if field[n]!='NO'
    x[n]=field(n)
 endif
next
for n=1 to fc1
Y[N]=&X[N]
next
sum=no
skip
do while .not. eof()
  count=0
  for n=1 to fc1
    if(&x[n]=y[n])
      count=count+1
    endif
  next

  if fc1=count
     sm=no
     sum=sum+sm
   else
      sele b
      append blank
      for n=1 to fc1
      repl &x[n] with y(n)
     next
     repl no with sum
    sum=0
    endif
      sele a
```

```
     for n=1 to fc1
     y[n]=&x[n]
     next
     if sum=0
     sum=no
     endif

    skip
    enddo
    clear
sele b
go top

 ACCEPT "SEND OUTPUT TO PRINTER   " TO AN
 CLEAR
 FLAG=.F.
 M=2
 IF UPPER(AN)="Y"
    FLAG = .T.
      SET PRINTER ON
      SET DEVICE TO PRINT
 ENDIF
 IF FLAG
    M=PROW()
 ENDIF
 clear
 M=M+2
 @M,5 SAY cap1
 M=M+1
 @M,5 say cap2
 M=M+2
 fc1=fcount()
 dimension x[fc1]
 for n=1 to fc1
 x[n]=field(n)
 next
 I=10
 for n=1 to fc1
 I=I+1
 @M,I say x[n]
 I=I+6
 @M,I say "|"
 next
 i=10
 M=M+2
 DO WHILE .NOT. EOF()
  for n=1 to fc1
    @M,i SAY "|"
    i=i+1
    @M,i SAY &x[n]
    i=i+6
  next
    @M,I SAY "|"
    I=10
      IF FLAG
```

```
    P=55
  ELSE
    P=20
  ENDIF

 IF ( M > P )
    IF FLAG
       EJECT
     ENDIF

     SET PRINTER OFF
     WAIT " NEXT PAGE  PRESS ENTER TO CONTINUE"
 IF FLAG
     SET PRINTER ON
     ELSE
        CLEAR
     ENDIF
      M=4
 ENDIF
 M=M+1
SKIP
ENDDO
WAIT " OVER ..PRESS ENTER TO CONTINUE  "
IF FLAG .AND. EOF()
     SET PRINTER OFF
     SET DEVICE TO SCREEN
     CLEAR GETS
ENDIF
CLEAR
SET DEVICE TO SCREEN
SET PRINTER OFF

    set talk on
    set safety on
    return
```

APPENDIX 5

Computer program and sample output file for selecting species based on a given use.

Computer program 2: Use

Description:

A program in FoxPro for classifying vegetation based on use from stock mapped data or species knowledge-base.

The tasks for which the program is used are,
(i) To list the species in the species knowledge base for a given use.
(ii) To quantify the number of plants in the multi-tier forest based on use

The following files are used:
(i) Mulcom.dbf DBF containing the details of plants during different stages of the study
(ii) At.dbf : File containing the botanical name of each species indexed on spn (field corresponding to species) chosen from species knowledge-base.
(iii) Et.dbf: Knowledge-base file on use

Output file:

Use1.dbf: Output file in which plants in multi-tier forest are obtained based on use.
Use2.dbf : Output file when species based on use are obtained from knowledge-base.

Program

```
SET TALK OFF
clear
CLOSE ALL DATABASE
CLOSE ALL WINDOWS
STORE 0 TO ANS,S,CH,CHOICE,SP,SP1
x=0
y=0
z=0
sm1=0
sm2=0
sm3=0
tm=space(10)
select B
use c:\tmp\tmp1\at.dbf
*.....File containing the botanical name of each species
index on spn to at
```

```
use at index at
sele D
use c:\tmp\tmp1\new.dbf
*...Resulting DBF containing the records in which the spn *...for
the files ET and MULCOM
zap
select C
use c:\tmp\tmp1\mulcom.dbf
              *......DBF containing the details of plants
              *......during different stages of the study
SET COLO TO W+
@1,1 TO 5,79 DOUBLE

@3,20 SAY "SPECIES SELECTION BASED ON USES"
WAIT WINDOW
CLEAR
@10,10 SAY "SELECTION FROM"
@12,12 SAY "1.MULTI-TIER PLANTATION DATA BASE"
@14,12 SAY "2.KNOWLEDGE BASE"
@17,38 SAY "Enter your choice (1 or 2) -->  "
@17,70 GET CH PICT "9"
READ

CLEAR
 @8,2 SAY  "1.FOOD"
 @9,2 SAY  "2.MEDICINAL"
 @10,2 SAY "3.INDUSTRIAL"
 @11,2 SAY "4.COTTAGE"
 @12,2 SAY "5.FUEL WOOD"
 @13,2 SAY "6.FODDER"
 @14,2 SAY "7.SMALL TIMBER"
 @15,2 SAY "8.GREEN MANURE"
 @16,2 SAY "9.TIMBER"
 @17,2 SAY "10.PULP "
 @18,2 SAY "11.PLYWOOD"
 @19,2 SAY "12.PACKING CASE"
 @20,2 SAY "13.MATCH WOOD"
 @21,2 SAY "14.LIVE HEDGE"
 @22,2 SAY "15.ASETHETIC"
 @8,18 SAY "16.AVENUE "
 @9,18 SAY "17.SOIL"
 @10,18 SAY "18.WATER CONSERVE"
 @11,18 SAY "19.NITROGEN"
 @12,18 SAY "20.WIND BREAK"
 @13,18 SAY "21.FIRE BREAK"
 @14,18 SAY "22.POLLUTION CONTROL"
```

```
@15,18 SAY "23.RELIGIOUS"
@16,18 SAY "24.BENEFICIAL TO ANIMALS"
@17,18 SAY "25.BENEFICIAL TO INSECTS"
@18,18 SAY "26.COVER CROP"
@20,18 SAY "50.QUIT FROM HERE"
@22,38 SAY "Enter your choice -->  "
@22,62 GET ANS PICT "99"
READ



DO CASE
    CASE ANS=1
         HD="FOOD"
         S="EX1"
    CASE ANS=2
         HD="MEDICINAL"
         S="EX2"
    CASE ANS=3
         HD="INDUSTRIAL"
          S="EX3"
    CASE ANS=4
         HD="COTTAGE"
          S="EX4"
    CASE ANS=5
         HD="FUEL WOOD"
          S="EX5"
    CASE ANS=6
         HD="FODDER"
           S="EX6"
    CASE ANS=7
         HD="SMALL TIMBER"
          S="EX7"
    CASE ANS=8
         HD="GREEN MANURE"
           S="EX8"
    CASE ANS=9
          HD="TIMBER CONSTRUCTION"
          S="EX9"
    CASE ANS=10
         HD=" PULP "
          S="EX10"
    CASE ANS=11
         HD="PLYWOOD"
          S="EX11"
    CASE ANS=12
```

```
      HD=" PACKING CASE"
       S="EX12"
 CASE ANS=13
      HD="MATCH WOOD"
      S="EX13"
 CASE ANS=14
      HD="LIVE HEDGE"
      S="EX23"
 CASE ANS=15
      HD="ASETHETIC"
      S="EX24"
 CASE ANS=16
      HD="AVENUE"
      S="EX25"


CASE ANS=17
      HD="SOIL"
      S="EX26"
 CASE ANS=18
      HD="WATER CONSERVATION"
      S="EX27"
 CASE ANS=19
      HD="NITROGEN"
      S="EX28"
 CASE ANS=20
      HD="WIND BREAK"
      S="EX29"
 CASE ANS=21
      HD="FIRE BREAK"
      S="EX30"
 CASE ANS=22
      HD="POLLUTION CONTROL"
      S="EX31"
 CASE ANS=23
      HD="RELIGIOUS"
      S="EX32"
 CASE ANS=24
      HD="BENEFICIAL TO ANIMALS"
      S="EX33"
 CASE ANS=25
      HD="BENEFICIAL TO INSECTS"
      S="EX34"
 CASE ANS=26
      HD="COVER CROP"
      S="EX35"
```

```
      CASE ANS=50
           CLEAR
           EXIT()
   ENDCASE
clear
@10,20 SAY " Please wait...."
@15,25 SAY " Process is in progress......"
DO CASE
   CASE CH=1
   clear
   @5,10 say "SELECT THE TIME PERIOD"
   @7,12 say "1. SEPTEMBER 1989"
   @9,12 say "2. JUNE 1990"
   @11,12 say "3. JUNE 1991"
   @13,12 say "4. OCTOBER 1991"
   @15,12 say "5. JUNE 1992"
   @17,12 say "6. JULY 1993"
   @19,12 say "7. MARCH 1999"
   @21,13 say "ENTER YOUR CHOICE (1/2/3/4/5/6/7):-->"
   @21,70 GET CHOICE PICT "9"
   READ
  DO CASE
   CASE CHOICE=1
        tm="SEP89"
       cap="SEPTEMBER 1989"
   CASE CHOICE=2
        tm="JUN90"
       cap="JUNE 1990"
   CASE CHOICE=3
        tm="JUN91"
       cap="JUNE 1991"
   CASE CHOICE=4
        tm="OCT91"
       cap="OCTOBER 1991"
   CASE CHOICE=5
        tm="JUN92"
       cap="JUNE 1992"
   CASE CHOICE=6
        tm="JUL93"
       cap="JULY 1993"
    CASE CHOICE=7
        tm="MAR99"
       cap="MARCH 1999"
    OTHERWISE
       ? "Error : Entry not between 1 and 7"
   ENDCASE
```

```
  clear
  @10,20 SAY " Please wait...."
  @15,25 SAY " Process is in progress......"

  sele C
  copy to multmp for time=tm
  use multmp
  go top
  sp1=spn
  skip
do while .not. eof()
  if spn!=sp1
   select D
   append from et for spn=sp1
  endif
  sele C
  sp1=spn
  skip
enddo
 sele D
 copy to use1 for &S=3 or &S=4 or &S=5
 sele E
 use use1
 go top

do while .not. eof()
    s=spn
    sele C
    sum no  for spn=s to sm1
    sele E
    repl sno with sm1
    s=spn
     skip
enddo
index on spn to use1
use use1 index use1
set relation to spn into B
clear
ACCEPT "SEND OUTPUT TO PRINTER (Y/N)"  TO AN
CLEAR
FLAG=.F.
X=2
IF UPPER(AN)="Y"
   FLAG = .T.
    SET PRINTER ON
```

```
    SET DEVICE TO PRINT
 ENDIF
 IF FLAG
    X=PROW()
 ENDIF
 X=X+1
 @X,5 SAY HD
 X=X+1
 @X,5 SAY "THE FOLLOWING SPECIES HAVE THE ABOVE USE"
 X=X+2
@X,3 SAY "-----------------------------------------------"
 X=X+1
 @X,3 SAY "|SNO  |SPN   |SPECIES NAME          |           |"
 @X,45 SAY CAP
 X=X+1
 @X,3 SAY "-----------------------------------------------"
 X=X+1
 Z=1
 go top
 DO WHILE .NOT. EOF ()
    @X,3 SAY "|"
    @X,5 SAY STR(Z,3)
     @X,9 SAY "|"
     @X,11 SAY SPN
     @X,16 SAY "|"
     @X,18 SAY  B->B_NAME
     @X,43 SAY "|"
     @X,45 SAY SNO
     @X,60 SAY "|"
     X=X+1
     @X,3 SAY "-----------------------------------------------"
  IF FLAG
    Y=55
  ELSE
    Y=20
  ENDIF
 IF ( X > Y )
    IF FLAG
       EJECT
     ENDIF
     SET PRINTER OFF
     WAIT " NEXT PAGE PRESS ENTER TO CONTINUE"
 IF FLAG
     SET PRINTER ON
     ELSE
        CLEAR
```

```
     ENDIF
      X=4
 ENDIF
 X=X+1
 Z=Z+1
 SKIP
ENDDO
WAIT " OVER ..PRESS ENTER TO CONTINUE  "
IF FLAG .AND. EOF()
     SET PRINTER OFF
     SET DEVICE TO SCREEN
     CLEAR GETS
ENDIF
CLEAR
CASE CH=2
 use c:\tmp\tmp1\et.dbf
 copy to use2 for &S=3 or &S=4 or &S=5
 ACCEPT "SEND OUTPUT TO PRINTER   " TO AN
 CLEAR
 FLAG=.F.
 X=2

 IF UPPER(AN)="Y"
  FLAG = .T.
     SET PRINTER ON
     SET DEVICE TO PRINT
 ENDIF

 IF FLAG
   X=PROW()
 ENDIF
 X=X+1
 @X,5 SAY HD
 X=X+1
 @X,5 SAY "THE FOLLOWING SPECIES HAVE THE ABOVE USE"
 X=X+2
 @X,3 SAY "----------------------------------------"
 X=X+1
 @X,3 SAY "|SNO  |SPN   |SPECIES NAME              |"
 X=X+1
 @X,3 SAY "----------------------------------------"
 X=X+1
 Z=1
 USE USE2
 index on spn to use2
 use use2 index use2
```

```
 set relation to spn into B
 go top

 DO WHILE .NOT. EOF()
 @X,3 SAY "|"
 @X,5 SAY STR(Z,3)
 @X,9 SAY "|"
 @X,11 SAY SPN
 @X,16 SAY "|"
 @X,18 SAY  B->B_NAME
 @X,43 SAY "|"
 X=X+1
 @X,3 SAY "-----------------------------------------------"

 IF FLAG
     Y=55
  ELSE
      Y=20
  ENDIF

 IF ( X > Y )
    IF FLAG
       EJECT
     ENDIF
     SET PRINTER OFF
     WAIT " NEXT PAGE… PRESS ENTER TO CONTINUE"
 IF FLAG
     SET PRINTER ON
     ELSE
       CLEAR
     ENDIF
      X=4
 ENDIF
 X=X+1
 Z=Z+1
 SKIP
ENDDO
WAIT "OVER ..PRESS ENTER TO CONTINUE  "

IF FLAG .AND. EOF()
     SET PRINTER OFF
     SET DEVICE TO SCREEN
     CLEAR GETS
ENDIF
CLEAR
ENDCASE
```

```
SET DEVICE TO SCREEN
SET PRINTER OFF
SET TALK ON
RETURN
```

A sample output file of species suitable for livehedge obtained from the knowledge base (species having values three or above in five point scale in the database is selected)

Species code	**Species name**
5	*Bambusa bambos*
22	*Casuarina equisetifolia*
75	*Garuga pinnata*
83	*Cananga odorata*
205	*Bambusa vulgaris*
208	*Dendrocalamus strictus*
215	*Azadirachta indica*
230	*Bambusa balcooa*
275	*Bambusa polymorpha*
405	*Ziziphus mauritiana*
416	*Erythrina indica*
417	*Gliricidia maculata*
422	*Caesalpinia sappan*
429	*Caesalpinia coriaria*
432	*Moringa oleifera*
444	*Ziziphus xylopyrus*
452	*Thevetia peruviana*
460	*Acacia planifrons*
601	*Adhatoda vasica*
610	*Euphorbia tirucalli*
611	*Hibiscus rosa-sinensis*
612	*Lawsonia alba*
613	*Bougainvillaea spectabilis*
623	*Opuntia dillenii*
711	*Agave sisalana*
747	*Ananas comosus*
802	*Tinospora cordifolia*
808	*Cissus quadrangularis*
828	*Calamus thwaitesii*

APPENDIX 6

Computer program 3: Stand_simulation

Description

A sample program for stand projection and harvesting in the multi-tier forestry site based on height growth of plant species. This program comprises two subprograms - Simula.prg & Cut.prg. Subprogram Simula calculate the height of each plant using their age and subprogram Cut prepare the cutting plan.

It performs following tasks.

(i) Calculating the number of trees in different height class in multi-tier forestry site for the next 30 years
(ii) It provides the number of trees that can be harvested under the proposed scheme of height growth

Assumptions regarding regeneration, stand growth and spacing requirement
(i) The same regeneration trend will continue in the plot.
(ii) Different species follow growth as given in the knowledge-base on height growth.
(iii) Plants under different height categories 0-1m, 1-2m, 2-10m, 10-20m and 20-40m will have mortality or unauthorised removal 20%, 10%, 5% and 1% respectively during the five year interval.
(iv) Optimal expected stocking under different height categories 0-1m. 1-2m, 2-10m, 10-20m and 20-40m 7000, 3000, 2500, 1875 and 625 respectively.
(v) While cutting species will be selected in proportion to their size (number) in each height class.

The following files used:

(i) Mul.dbf : Database file containing the number of plants and their age in multi-tier forestry on March 1999.
(ii) Height.dbf : Knowledge-base on height growth.

Output files:

(i) Final1.dbf : Output file containing number of plants in the multi-tier forestry site for different height classes.
(ii) Final2.dbf : Output file containing number of plants per hectare for different height classes.
(iii) Cut.dbf : Number of plants per hectare for different height classes that can be harvested.

Program

```
SET TALK OFF
SET SAFETY OFF
CLOSE ALL DATABASE
CLOSE ALL WINDOWS
CLEAR

store 0 to smh0,smh1,smh2,smh3,smh4
store 0 to i,j,cut1,cut2,cut3,cut4,cut5
store 0 to sm01,sm05,sm010, sm015, sm020, sm025, sm030, sm040
store 0 to sm11,sm15,sm110, sm115, sm120, sm125, sm130, sm140
store 0 to sm21,sm25, sm210, sm215, sm220, sm225, sm230, sm240
store 0 to sm31,sm35,sm310, sm315, sm320, sm325, sm330, sm340
store 0 to sm41,sm45, sm410, sm415, sm420, sm425, sm430, sm440
store 0 to ct11,ct15,ct110,ct115,ct120,ct125,ct130,ct140
store 0 to ct21,ct25,ct210,ct215,ct220,ct225,ct230,ct240
store 0 to ct31,ct35,ct310,ct315,ct320,ct325,ct330,ct340
store 0 to ct41,ct45,ct410,ct415,ct420,ct425,ct430,ct440
store 0 to ct51,ct55,ct510,ct515,ct520,ct525,ct530,ct540

store space(7) to ht
cap=space(10)
file1=space(22)
an=' '
hd=space(15)
s=space(3)

use c:\tmp\tmp1\mul.dbf
file1='c:\tmp\tmp1\mul.dbf'
do simula.prg
copy to c:\tmp\tmp1\appmul.dbf

sele d
use c:\tmp\tmp1\final1.dbf
zap

sele e
use c:\tmp\tmp1\appmul.dbf
delete all for htcode=0
pack

ht='htcode'
do cut.prg
sm01=smh0
sm11=smh1
sm21=smh2
sm31=smh3
sm41=smh4

copy to c:\tmp\tmp1\year.dbf for HTCODE=1 and h5!=1
sele c
FILE1="c:\TMP\TMP1\YEAR.DBF"
use c:\tmp\tmp1\year.dbf
repl all htcode with 0
```

```
repl all age with 0
repl all a5 with  1
repl all a10 with 6
repl all a15 with 11
repl all a20 with 16
repl all a25 with 21
repl all a30 with 26
use
do SIMUL1.prg

sele e
append from c:\tmp\tmp1\year.dbf
ht='h5'
do cut.prg
 sm05=smh0
 sm15=smh1
 sm25=smh2
 sm35=smh3
 sm45=smh4

copy to c:\tmp\tmp1\year.dbf for h5=1 and h10!=1
sele c
use c:\tmp\tmp1\year.dbf
repl all htcode with 0
repl all age with 0
repl all a5 with  0
repl all h5 with 0
repl all a10 with 1
repl all a15 with 6
repl all a20 with 11
repl all a25 with 16
repl all a30 with 21
use

do SIMUL1.prg
sele e
append from c:\tmp\tmp1\year.dbf
ht='h10'
do cut.prg
sm010=smh0
sm110=smh1
sm210=smh2
sm310=smh3
sm410=smh4
copy to c:\tmp\tmp1\year.dbf for h10=1 and h15!=1

sele c
use c:\tmp\tmp1\year.dbf
repl all htcode with 0
repl all age with 0
repl all a5 with  0
repl all h5 with 0
repl all a10 with 0
repl all h10 with 0
repl all a15 with 1
```

```
repl all a20 with 6
repl all a25 with 11
repl all a30 with 16
use
do SIMUL1.prg

sele e
append from c:\tmp\tmp1\year.dbf
ht='h15'
do cut.prg
 sm015=smh0
 sm115=smh1
 sm215=smh2
 sm315=smh3
 sm415=smh4
copy to c:\tmp\tmp1\year.dbf for h15=1 and h20!=1

sele c
use c:\tmp\tmp1\year.dbf
repl all htcode with 0
repl all age with 0
repl all a5 with  0
repl all h5 with 0
repl all a10 with 0
repl all h10 with 0
repl all a15 with 0
repl all h15 with 0
repl all a20 with 1
repl all a25 with 6
repl all a30 with 11
use
do SIMUL1.prg
sele e
append from c:\tmp\tmp1\year.dbf
ht='h20'
do cut.prg
 sm020=smh0
 sm120=smh1
 sm220=smh2
 sm320=smh3
 sm420=smh4

copy to c:\tmp\tmp1\year.dbf for h20=1 and h25!=1
sele c
use c:\tmp\tmp1\year.dbf
repl all htcode with 0
repl all age with 0
repl all a5 with  0
repl all h5 with 0
repl all a10 with 0
repl all h10 with 0
repl all a15 with 0
repl all h15 with 0
repl all a20 with 0
repl all h20 with 0
```

```
repl all a25 with 1
repl all a30 with 6

use
do SIMUL1.prg
sele e
append from c:\tmp\tmp1\year.dbf
ht='h25'
do cut.prg
 sm025=smh0
 sm125=smh1
 sm225=smh2
 sm325=smh3
 sm425=smh4
copy to c:\tmp\tmp1\year.dbf for h25=1 and h30!=1

sele c
use c:\tmp\tmp1\year.dbf
repl all htcode with 0
repl all age with 0
repl all a5 with  0
repl all h5 with 0
repl all a10 with 0
repl all h10 with 0
repl all a15 with 0
repl all h15 with 0
repl all a20 with 0
repl all h20 with 0
repl all a25 with 0
repl all h25 with 0
repl all a30 with 1

use
do SIMUL1.prg
sele e
append from c:\tmp\tmp1\year.dbf
ht='h30'
do cut.prg
 sm030=smh0
 sm130=smh1
 sm230=smh2
 sm330=smh3
 sm430=smh4

 sele d
  for i=1 to 5
   append blank
  next i

 go top
 repl n0 with sm01
 repl n5 with sm05
 repl n10 with sm010
 repl n15 with sm015
 repl n20 with sm020
```

```
repl n25 with sm025
repl n30 with sm030

skip
repl n0 with sm11
repl n5 with sm15
repl n10 with sm110
repl n15 with sm115
repl n20 with sm120
repl n25 with sm125
repl n30 with sm130

skip
repl n0 with sm21
repl n5 with sm25
repl n10 with sm210
repl n15 with sm215
repl n20 with sm220
repl n25 with sm225
repl n30 with sm230

skip
repl n0 with sm31
repl n5 with sm35
repl n10 with sm310
repl n15 with sm315
repl n20 with sm320
repl n25 with sm325
repl n30 with sm330

skip
repl n0 with sm41
repl n5 with sm45
repl n10 with sm410
repl n15 with sm415
repl n20 with sm420
repl n25 with sm425
repl n30 with sm430

copy to c:\tmp\tmp1\final2.dbf
use c:\tmp\tmp1\final2.dbf
repl all n0 with n0/2.17 for n0>0
repl all n5 with n5/2.17 for n5>0
repl all n10 with n10/2.17 for n10>0
repl all n15 with n15/2.17 for n15>0
repl all n20 with n20/2.17 for n20>0
repl all n25 with n25/2.17 for n25>0
repl all n30 with n30/2.17 for n30>0

copy to c:\tmp\tmp1\cut.dbf
sele f
use c:\tmp\tmp1\cut.dbf

c=0
sub=7000
```

```
go top
do while .not. eof()
     repl n0 with n0-sub
   repl n5 with n5-sub
   repl n10 with n10-sub
   repl n15 with n15-sub
   repl n20 with n20-sub
   repl n25 with n25-sub
   repl n30 with n30-sub
   c=c+1
   do case
      case  c=1
            sub=3000
      case  c=2
            sub=2500
      case  c=3
            sub=1875
      case  c=4
            sub=625
   endcase
skip
enddo

repl all n0 with 0 for n0<1
repl all n5 with 0 for n5<1
repl all n10 with 0 for n10<1
repl all n15 with 0 for n15<1
repl all n20 with 0 for n20<1
repl all n25 with 0 for n25<1
repl all n30 with 0 for n30<1
go top

clear
go top
ACCEPT "SEND OUTPUT TO PRINTER   " TO AN
CLEAR
FLAG=.F.
X=2
IF UPPER(AN)="Y"
   FLAG = .T.
     SET PRINTER ON
     SET DEVICE TO PRINT
ENDIF

IF FLAG
   X=PROW()
ENDIF

clear
X=X+1
@X,5 SAY "HEIGHT WISE SIMULATION OF THE NUMBER OF PLANTS"
X=X+1
@X,8 SAY "AFTER THE FOLLOWING PERIODS"

X=X+2
```

```
 @X,3 SAY "-----------------------------------------------"
 X=X+1
 @X,7 SAY "| 5 YRS |10  YRS |15 YRS |20YRS |25YRS |30YRS |"
 X=X+1
 @X,3 SAY "-----------------------------------------------"

 X=X+1
 @X,2 say "0-1m"
 @x+2,2 say"1-2m"
 @x+4,2 say "2-10m"
 @x+6,2 say "10-20m"
 @x+8,2 say ">20m"

 go top
 DO WHILE .NOT. EOF()
    @X,9 SAY "|"
      @X,25 SAY N5
      @X,32 SAY "|"
      @X,33 SAY N10
      @X,40 SAY "|"
      @X,41 SAY N15
      @X,48 SAY "|"
      @X,49 SAY N20
      @X,55 SAY "|"
      @X,56 SAY N25
      @X,63 SAY "|"
      @X,64 SAY N30
      @X,71 SAY "|"
      X=X+1
      @X,3 SAY "-----------------------------------------------"
      IF FLAG
    Y=55
  ELSE
    Y=20
  ENDIF

  IF ( X > Y )
    IF FLAG
       EJECT
    ENDIF

   SET PRINTER OFF
   WAIT " NEXT PAGE PRESS ENTER TO CONTINUE"

   IF FLAG
      SET PRINTER ON
   ELSE
      CLEAR
   ENDIF
   X=4
 ENDIF
 X=X+1
SKIP
ENDDO
```

```
WAIT " OVER ..PRESS ENTER TO CONTINUE  "
IF FLAG .AND. EOF()
     SET PRINTER OFF
     SET DEVICE TO SCREEN
     CLEAR GETS
ENDIF

CLEAR
SET DEVICE TO SCREEN
SET PRINTER OFF
SET TALK ON
SET SAFETY ON
RETURN
```

Program name : simula.prg

```
SET TALK OFF
clear
store 0 to sp,ht,rno,ans,ch
store 0 to ht1,ht2,ht5,ht10,ht15,ht20,ht25,ht30,ht40
store 0 to ag1,ag2,ag5,ag10,ag15,ag20,ag25,ag30,ag40
store '   ' to s_1,s0,s,s1,s2,s3,s4,s5,s6
store 0 to s51,s52,s53
cap=space(10)
an=' '
hd=space(15)
s=space(3)

select B
use c:\tmp\tmp1\height.dbf

select A
use &file1        *......DBF containing the details of plants
                  *......during different stages of the study



go top
do while .not. eof()
 sp=spn
 ag5=a5
 ag10=a10
 ag15=a15
 ag20=a20
 ag25=a25
 ag30=a30
 @10,15 say "Please wait..."

 do case
    case ag5=1
         s='CX1'
    case ag5=2
         s='CX2'
    case ag5>2 and ag5<6
```

```
         s='CX3'
   case ag5>5 and ag5<10
         s='CX4'
   case ag5>9 and ag5<15
         s='CX5'
   case ag5>14 and ag5<20
         s='CX6'
   case ag5>19 and ag5<25
         s='CX7'
   case ag5>24 and ag5<30
         s='CX8'
   case ag5>29 and ag5<40
         s='CX9'
   case ag5>39
         s='CX10'
endcase

do case
   case ag10=1
         s1='CX1'
   case ag10=2
         s1='CX2'
   case ag10>2 and ag10<6
         s1='CX3'
   case ag10>5 and ag10<10
         s1='CX4'
   case ag10>9 and ag10<15
         s1='CX5'
   case ag10>14 and ag10<20
         s1='CX6'
   case ag10>19 and ag10<25
      s1='CX7'
   case ag10>24 and ag10<30
         s1='CX8'
   case ag10>29 and ag10<40
           s1='CX9'
   case ag10>39
         s1='CX10'
endcase

do case
   case ag15=1
         s2='CX1'
   case ag15=2
         s2='CX2'
   case ag15>2 and ag15<6
         s2='CX3'
   case ag15>5 and ag15<10
         s2='CX4'
   case ag15>9 and ag15<15
         s2='CX5'
   case ag15>14 and ag15<20
         s2='CX6'
   case ag15>19 and ag15<25
           s2='CX7'
```

```
   case ag15>24 and ag15<30
        s2='CX8'
   case ag15>29 and ag15<40
        s2='CX9'
   case ag15>39
        s2='CX10'
endcase

do case
   case ag20=1
        s3='CX1'
   case ag20=2
        s3='CX2'
   case ag20>2 and ag20<6
        s3='CX3'
   case ag20>5 and ag20<10
        s3='CX4'
   case ag20>9 and ag20<15
        s3='CX5'
   case ag20>14 and ag20<20
        s3='CX6'
   case ag20>19 and ag20<25
        s3='CX7'
   case ag20>24 and ag20<30
        s3='CX8'
   case ag20>29 and ag20<40
        s3='CX9'
   case ag20>39
        s3='CX10'
endcase

do case

   case ag25=1
        s4='CX1'
   case ag25=2
        s4='CX2'
   case ag25>2 and ag25<6
        s4='CX3'
   case ag25>5 and ag25<10
        s4='CX4'
   case ag25>9 and ag25<15
        s4='CX5'
     case ag25>14 and ag25<20
      s4='CX6'
     case ag25>19 and ag25<25
            s4='CX7'
     case ag25>24 and ag25<30
      s4='CX8'
   case ag25>29 and ag25<40
      s4='CX9'
   case ag25>39
      s4='CX10'
endcase
```

```
do case
     case ag30=1
            s5='CX1'
   case ag30=2
      s5='CX2'
   case ag30>2 and ag30<6
      s5='CX3'
   case ag30>5 and ag30<10
            s5='CX4'
     case ag30>9 and ag30<15
      s5='CX5'
   case ag30>14 and ag30<20
      s5='CX6'
   case ag30>19 and ag30<25
            s5='CX7'
     case ag30>24 and ag30<30
      s5='CX8'
     case ag30>29 and ag30<40
            s5='CX9'
     case ag30>39
      s6='CX10'
endcase
  sele B
  locate for  spn=sp

  if s!=' '
     ht5=&s
  endif
  if s1!=' '
     ht10=&s1
  endif
  if s2!=' '
     ht15=&s2
  endif
  if s3!=' '
     ht20=&s3
  endif
  if s4!=' '
     ht25=&s4
  endif
  if s5!=' '
     ht30=&s5
  endif
  sele A
  repl h5 with  ht5
  repl h10 with ht10
  repl h15 with ht15
  repl h20 with ht20
  repl h25 with ht25
  repl h30 with ht30
  store 0 to ht1,ht2,ht5,ht10,ht15,ht20,ht25,ht30
skip
enddo
use
RETURN
```

Subprogram name : CUT

```
store 0 to i,j
store 0 to cut1,cut2,cut3,cut4,cut5
store 0 to smh0,smh1,smh2,smh3,smh4
store 0 to sv0,sv1,sv2,sv3,sv4
store 0 to mor0,mor1,mor2,mor3
store 0 to s1,s2,s3,s4,s5
 sum no for &ht=1 to smh0
 sum no for &ht=2 to smh1
 sum no for &ht=3 or &ht=4 to smh2
 sum no for &ht=5 or &ht=6 to smh3
 sum no for &ht>6 to smh4

 if ht='htcode'
    s1=smh0
    s2=smh1
    s3=smh2
    s4=smh3
    s5=smh4
 endif
 mor0=smh0*(20/100)
 mor1=smh1*(10/100)
 mor2=smh2*(5/100)
 mor3=smh3*(1/100)

 sv0=smh0/2.17
 sv1=smh1/2.17
 sv2=smh2/2.17
 sv3=smh3/2.17
 sv4=smh4/2.17

 if sv0>7000
    cut1=sv0-7000
    cut10=cut1+1400
 else
    cut10=mor0
 endif

 set filter to &ht=1
 go top
 j=no
 do while .not. eof()
    j=j+no
    if j<=cut10+1
       if  &ht=1 and htcode=0
           delete
       endif
    endif
 skip
 enddo
 set filter to
 if sv1>3000
    cut2=sv1-3000
```

```
   cut22=cut2+300
else
   cut22=mor1
endif

set filter to &ht=2
go top
j=no
do while .not. eof()
   j=j+no
   if j<=cut22+1
      if &ht=2 and htcode=0
         delete
      endif
   endif
skip
enddo
set filter to
if sv2>2500
   cut3=sv2-2500
   cut33=cut3+125
else
   cut33=mor2
endif

set filter to &ht=3 or &ht=4
go top
j=no
do while .not. eof()
   j=j+no
   if j<=cut33+1
      if (&ht=3 or &ht=4) and htcode=0
         delete
      endif
   endif
skip
enddo
set filter to
if sv3>1875
   cut4=sv3-1875
   cut44=cut4+19
else
   cut44=mor3
endif

set filter to &ht=5 or &ht=6
go top
j=no
do while .not. eof()
   j=j+no
   if j<=cut44+1
      if (&ht=5 or &ht=6) and htcode=0
          delete
      endif
   endif
```

```
skip
enddo
set filter to
if sv4>625
   cut5=sv4-625
   set filter to &ht>6
   go top
   j=no
   do while .not. eof()
      j=j+no
      if j<=cut5+1
         if &ht>6 and htcode=0
              delete
         endif
      endif
   skip
   enddo
endif
set filter to

if ht!='htcode'
      smh0=smh0-cut10
      smh1=smh1-cut22
      smh2=smh2-cut33
      smh3=smh3-cut44
      smh4=smh4-cut5
else
    smh0=s1
      smh1=s2
      smh2=s3
      smh3=s4
      smh4=s5
endif

return
```

A sample output of stand projection on height growth and harvesting possible

Number of trees in each height class in the Demonstration Plot for the next 25 years assuming the same regeneration trend.

Age/Height	0-1m	1-2m	2-10m	10-20m	20-40m
Initial	4510	1409	3093	177	18
After 5 years	3625	1855	3099	1929	459
After 10 years	3625	2399	3101	2048	737
After 15 years	3625	2626	3113	2132	767
After 20 years	3625	2626	3113	2170	841
After 25 years	3625	2626	3113	2170	841
After 30 years	3625	2626	3113	2170	841

Number of plants that can be harvested under the proposed scheme of simulation of height growth.

Age/Height	0-1m	1-2m	2-10m	10-20m	20-40m	Total
Initial	0	0	593	0	0	593
After 5 years	0	0	599	54	0	653
After 10 years	0	0	601	173	112	886
After 15 years	0	0	613	257	142	1012
After 20 years	0	0	613	295	216	1124
After 25 years	0	0	613	295	216	1124
After 30 years	0	0	613	295	216	1124