

**INFESTATION DYNAMICS AND CLONAL
RESISTANCE OF TEAK TO TRUNK BORER**
Alceterogystia cadambae Moore.
(LEPIDOPTERA : COSSIDAE)

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FEBRUARY, 2002

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Thesis submitted to the
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By

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This is to certify that the thesis entitled “**INFESTATION DYNAMICS AND CLONAL RESISTANCE OF TEAK TO TRUNK BORER *Alcterogystia cadambae* Moore. (LEPIDOPTERA : COSSIDAE)**” submitted by **Mr. SANTOSH K.**, for the degree of **Master of Science (Forestry)** in **FOREST BIOLOGY AND TREE IMPROVEMENT**, to the University of Agricultural Sciences, Dharwad is a record of research work carried out by him during the period of his study in this University, under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship, or other similar titles.

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Introduction

I. INTRODUCTION

Forests constitute one of the most productive renewable natural resources providing food, fodder, fuel and timber to the human kind. Increased population of human as well as of herbivores has resulted in sharp decline in the availability of fodder, fuel and timbers. An undisturbed forest ecosystem is capable of creating an ecological balance, which will be inimical to many deleterious factors. However, such ideal conditions seldom exist in any forest. They are invariably exposed to depredatory agencies. Insect pests are one of the important biological determinants limiting the productivity of our natural and plantation forests. Insect damage commences from the seed stage itself and culminates in the damage of the processed and finished products. Further, in the current plantation practices, a definite shift has taken place from mixed forests to mono-cultural forests. This has increased insect related losses in productivity to many folds. Because of this enormous loss by forest insects, their management becomes imperative. There are several examples where plantation efforts had failed because of insect menace. Besides the direct loss in the form of death or reduced increment, the price of timber is generally reduced if attacked by borers.

Prime among the Indian timber yielding tree species is Teak (*Tectona grandis* Linn.). Among housing and furniture-grade timbers in India, teakwood constitutes the premium class. India has over 9.77 million hectares under natural teak forest (Bapat and Phulari, 1995), but severe restrictions on the harvesting of teak from natural forests, introduced in 1997, have limited the domestic supply. Even though India is one of the biggest producers of teak in the world, a large amount of timber is imported to meet the internal demand of the plywood and veneer industry (Bebarta,

1999). Teak plantations have become important to help fill the gap between demand and supply of teakwood.

Teak is distributed in Southern Tropical Deciduous forests of Peninsular India situated below 24°N latitude (Seth and Kaul, 1978). It is extensively grown in coastal and heavy rainfall tracts of many states including Karnataka. The major teak growing states are Kerala, Karnataka, Tamil Nadu, Andhra Pradesh and Madhya Pradesh. In Karnataka teak forest cover an area of 77,900 hectares with an annual production of 7080 m³ (Kadambi, 1993).

Teak is probably one of the few tree species that have been successfully planted on a large scale in India. Unlike many other species that have been extensively tried in plantations, teak is able to withstand continued pest attacks. It is an extensively studied timber species for its entomology. The species is attacked by a large number of insect fauna and suffers assiduously from insect damage. Nearly 288 insect pests identified on teak include the representatives of the order Coleoptera (147), Lepidoptera (95), Hemiptera (20), Orthoptera (18), Isoptera (7), and Hymenoptera (1) (Mathur, 1960; Mathur and Singh, 1960; Tewari, 1992; Sudheendrakumar, 1994). These insects attack teak from seed to mature including dead tree. According to Roychoudhury (1998) about 186 species of insects are associated with living teak, comprising mainly defoliators (138), sap-suckers (16), borers (15), root-feeders (9) and seed-feeders (8).

Pest species that cause major damage in plantations and natural stands include two species of defoliators under Lepidoptera, *Hyblaea puera* (Cramer) (Hyblaeidae) and *Eutectona machaeralis* (Walker) (Pyraustidae) causing increment losses. Of the 8 species of trunk borers on teak two borers, one in sapling stage,

Sahyadrassus malabaricus (Moore) (Hepialidae), and the other in mature tree stage, *Alcterogystia cadambae* (Moore) (Cossidae), are considered to be economically important (Sudheendrakumar, 1994).

A. cadambae (= *Cossus cadambae* Moore.) is a relatively new insect pest of teak in India recently which has assumed major pest status in several plantations in Kerala, Tamil Nadu and Karnataka states. *A. cadambae* belongs to the Lepidopteran family Cossidae. Cossids are popularly known as 'Goat moths' because of the production of characteristic odour and 'Carpenter worms' due to larval habit of boring into the wood. The attack of the borer causes extreme bark damage injury and riddles the bole with numerous holes. Formation of callus growth around the pest entry sites have led to the naming of this damage syndrome as 'Gandumale' (tow of galls and knots) in local language. The value of the timber reaching the depots is reduced due to irregular holes and hollowness in the heartwood.

Any effort to protect the valuable heartwood of teak is worthwhile in the present context as state forest departments, private land holders and big companies have come up with mega projects for growing teak trees in large scale especially in south India.

Recently, the trunk borer *A. cadambae* has attained major pest status in heavy rainfall tracts of Karnataka. The pest problem has been cited as threat to forest gold. Except the work carried out by Lingappa *et al.* (1991) and Prasad Kumar *et al.* (2001), no other reports are available in Karnataka.

Extensive investigations on the extent of spread, quantum of damage and population build up are to be undertaken to formulate strategies for the management of this pest in nature. Presently no control operations are practiced, therefore a more

detailed basic study of the pest and its ecosystem are necessary to plan out integrated method of management.

In this background, the present study was taken with the following objectives: -

1. To study the distribution pattern of teak trunk borer in space and time among the plantations of Uttara Kannada.
2. To assess economic losses due to teak trunk borer and to record alternate hosts and natural enemy complex of teak trunk borer.
3. To identify resistant clones of teak in different clonal seed orchards and study their bio-chemical characters.

Review of Literature

II. REVIEW OF LITERATURE

Teak is one of the important timber tree crops occupying a prominent place in the country's wood scenario. Being one of the prime species yielding high-class timber useful for numerous purposes its production in terms of quantity and quality is most important.

Research on management of insects has received considerable attention in recent years (Tewari, 1992; Sudheendrakumar, 1994), because insect pests are one of the major limiting factors affecting the seed production, quality seedlings and tree volume. Obviously, control of insect pests may lead to substantial economic gain in tree improvement programme due to high value of timber and the large area under teak (Seth and Kaul, 1978; Pandey, 1983).

Borers are unique in that they directly destroy vascular tissues and weaken structural integrity while operating in a secluded and protected environment. Their relative habits and relatively long generation time (from one to several years) complicate efforts to study or control them. Consequently few effective control programmes have been developed that reduce the serious economic losses caused by borers (Neilsen, 1981).

Cossids as pests of trees

All members of the family Cossidae without exception are internal feeders inside the woody tissues of plants. Although the number of recorded species are rather few; species belonging to many genera like *Cossus*, *Zeuzera*, *Azygophleps* and *Xyleutes* are widely distributed.

Literature records on the cossid pests of the world indicate that atleast 15 species have been noted as pests of various forest or horticultural trees. Among the

important carpenter worms are *Cossus cossus* (attacking a variety of trees such as alder, ash, beech, birch, elm, oak, poplar, walnut, willow, etc. in USA); the southern heart wood borer, *Prionoxystus robiniae* (attacking several species of wild, ornamental as well as broad leaved trees in USA and Europe); the leopard moth *Zeuzera pyrina* (attacking ash, apple, beech, maple, oak, olive, elm, hazel, hickory, plum, walnut etc. in Europe and USA) and the teak bee-hole borer *Xyleutes ceramica* (attacking teak in several Asian countries).

In India, about 25 species of carpenter worms belonging to 6 genera viz. *Cossus*, *Xyleutes*, *Azygophleps*, *Zeuzera*, *Phragmataecia* and *Eremocossus* have been reported (Hampson, 1892). Of these, the economic importance as well as host range of only a few species have been fully investigated. The important carpenter worms affecting various tree crops in India are, the coffee borer *Zeuzera coffeae* (attacking about 30 plants including coffee, teak, mahogany and lagerstroemia; Beeson, 1941); *Z. multistrigata* (attacking cherry, sandal and oak; Bharadwaj, 1982) and *Z. sp.* (attacking poplars; Joshi *et al.*, 1984).

Carpenterworms as pests of teak

Three species of carpenter worms viz. *X. ceramica*, *Z. coffeae* and *A. cadambae* are known to attack teak in the Asian region. Of these, the first two species attack both saplings as well as trees, while the last species attacks only grown up trees. *X. ceramica* occur in Burma, Philippines, Thailand, Indonesia and Java and is not considered to occur in India (Beeson, 1941), although Hampson (1892) has recorded it from Sikkim. *Z. coffeae* which is widely distributed in the Indian and Indo-Malayan sub regions, is mostly a pest of tea and coffee although occasional outbreaks have been reported in forest nurseries and natural regeneration areas of

teak (Beeson, 1941; Toxopeus, 1948). *C. cadambae* occurs only in India. Characteristically it attacks grown up teak trees and is never reported to damage seedlings or saplings.

Alceterogystia cadambae was first described by Moore in 1885 in the Proceedings of the Zoological Society of London. Hampson (1892) who recorded it from Calcutta gave a general description, which is based essentially on the wing pattern and colouration. Lefroy (1909) first reported it as a pest on young teak plants. Beeson (1941) reported it as a minor pest of living teak in southern India.

2.1. Survey of Cossid borer infestation

2.1.1.1. Survey of Teak trunk borer infestation

The work done on teak trunk borer *A. cadambae* is very limited in India. Therefore there is no comprehensive and broad-based compilation available on this pest. Earlier workers mentioned its nature of damage. However Mathew (1990) in Kerala made a detailed study on all the aspect of the pest. He conducted a survey in 48 selected plantations of Kerala, 11 were found infested in which the percentage of incidence varied from 3 to 58 per cent. The highest infestation was recorded in Kothamangalam division (20 per cent) followed by Trichur (19 per cent) and Nemmara (19 per cent).

In Karnataka, Lingappa *et al.* (1991) published a preliminary work, which includes survey and extent of damage in parts of Uttara Kannada district. They undertook preliminary survey in Karnataka during 1988 to 1989 and reported the incidence of the pest to the extent of 15 to 20 per cent in Barchi sub-division and also reported the occurrence of the pest in heavy rainfall tracts covering Honnavar, Yellapur, Dandeli and Haliyal causing damage 5 to 10 per cent.

Prasad Kumar *et al.* (2001) conducted survey in 1998-2000 on the infestation status of the trunk borer in all the taluks of Uttara Kannada. They reported that 30 plantations in 11 taluks of Uttara Kannada were found to be affected by trunk borer with infestation ranging from 1.81 per cent to 72.38 per cent and heavy infestations were noticed in Yellapur taluk (64.8%) followed by Mundgod taluk (58.8%).

Apart from these informations, there are no extensive studies made on this pest. However, an attempt has been made to present relevant literature on different aspects of teak trunk borer and borers of related genera in particular and also on borers of other tree species in general under the following headings.

2.1.1.2. Cossid borer infestation on other tree species

Islam *et al.* (1989) reported that Keora (*Sonneratia apetala*) plantations established in 1967-85 were infested by stem borer *Zeuzera conferta* with 52 per cent of overall stocking been infested and 22 per cent of trees in severe infestation, 17 per cent in moderate infestation and 13 per cent in slight infestation.

A survey conducted on attack of stem borer *Zeuzera conferta* in mixed species and monocultural plantations of *Sonneratia apetala* in Bangladesh revealed that in monoculture stands 51 per cent of trees were attacked by the borer whereas it was 32 per cent in mixed species (Wazihullah *et al.*, 1996).

2.1.2. Nature of borer damage by teak trunk borer

Beeson (1941) reported that larva of *A. cadambae* bores into the sound wood and producing irregular shape tunnels in the wood which is usually wider than the diameter of its body. Mathew (1987) reported larvae of Cossids feed on woody tissues of various plants and are restricted to deciduous forests of the temperate and tropical regions of the world.

Mathew (1990) reported that the newly hatched larvae of *A. cadambae* are extremely active and move about on the bark. After some time they get lodged in the axils of side shoots, in crevices or injuries on the bark or in sites of earlier infestation. They start feeding on the bark. Larval feeding results in the girdling of the side shoots leading to die back which is one of the initial symptoms of the borer attack. Caterpillars initially feed on bark and sapwood and subsequently tunnel into the heartwood.

Lingappa *et al.* (1991) reported that larva tunnels from periphery initially and bores vertically up and down from entry point at various heights of the plant. Continuous infestation leads to the bee-holed appearance on the trunk.

2.1.3. Spatial distribution pattern

2.1.3.1. Spatial distribution pattern of teak trunk borer

Mathew *et al.* (1989) studied the spatial distribution of *A. cadambae* in selected plantations of Kerala. Plantations having different phases of trunk borer attack (*i.e.* low, medium and heavy infestation) selected at Parambikulam, Thattakkad and Palappilly belonging to the age group of 24-30 years were studied for spatial distribution of infested trees. The situation at Parambikulam was typical of initial phase, at Thattakkad it was second phase while at Palappilly it was the third phase. During the initial and second stage of attack by the borer the affected trees are usually confined to distinct patches. During the last stage, the infestation spreads at a faster pace leading to a more or less uniform distribution of attack in the plantation.

2.1.3.2. Spatial distribution pattern in other borers

Wang *et al.* (1988) reported that eggs, larvae and pupae of *Anoplophora nobilis* (Coleoptera: Buprestidae) all showed aggregated distribution pattern (negative binomial) with the degree of aggregation increasing during development. The distribution of beetles in tree stems was related to diameter.

Shibata *et al.* (1995) reported that the adults of Sugi borer *Semanotus japonicus* (Coleoptera: Cerambycidae) infesting *Cryptomeria japonica* were distributed contagiously among trees in the stand. The damaged trees distributed contagiously in the stand and were observed to be the larger ones. The distribution pattern of the adults reflected the contagious distribution of the damaged trees suggesting that larger trees influenced the distribution patterns of damaged trees in the stand.

He Fangliang and Alfavor (1997) reported spatial attack pattern of White pine weevil *Pissodes strobi* (Coleoptera: Curculionidae) on white pine *Picea glauca* to be aggregated in the initial stages of the infestation, changing to random when the infestation reached intermediate levels but regular over the entire plantation when the infestation was at its peak. The probability of attack was dependent on the distance from the trees attacked in the previous year and on the resistance level of the tree.

2.1.3.3. Vertical distribution pattern

2.1.3.3.1. Vertical distribution pattern of trunk borer infestation

Prasad Kumar *et al.* (2001) recorded that more number of holes per tree was at 2m height compared to 1m height.

2.1.3.3.2. Vertical distribution pattern of other borers

Donley and Rast (1984) studied vertical distribution of the red oak borer *Enaphalodes rufulus* (Coleoptera: Cerambycidae) and found that median attack height was always 5m or less for trees upto 30 cm in dbh. Nearly 75% of the attack were found in the economically important basal 4m trunk portion in all size classes of trees. Mishra *et al.* (1985) reported that stem borer *Aristobia horridula* (Coleoptera: Lamiidae) attack on *Dalbergia sissoo* damaged stem upto 4m from ground level.

Harman and Harman (1990) studied vertical distribution of larval tunnels made by locust borer *Megacyllene robiniae* (Coleoptera: Cerambycidae) on black locust trees *Robinia pseudoacacia* ranging in age from 7 to 57 years was studied in Maryland, USA and found tunnel concentrations were negatively correlated with height above ground level and with boll diameter. With greater tree size, attacks were concentrated higher on the main stems. However, the upper extremities of trees of all sizes and ages were lightly attacked.

2.1.4. Temporal incidence

2.1.4.1. Temporal incidence of Teak trunk borer

Nair (1987) reported that most of the cossids adult female emerged in late April to May in the pre monsoon in Kerala. Light trap studies in Kerala have indicated that the moth emergence occurs through out the year with two distinct peaks one in May to June and another in September to October. The population was very low in January to February (Mathew, 1990).

Lingappa *et al.* (1991) reported that adult female emerged more in numbers during the monsoon and emergence of first brood in the second week of July. Then

onwards the light trap collection and adult emergence in the laboratory were coinciding, thus establishing occurrence of over lapping generations.

2.1.4.2. Temporal incidence of other cossids

Fang *et al.* (1984) reported adults of *Holcocerus orientalis* (= *Cossus cossus*) appearing from mid May to early September and eggs were laid from early June to September.

2.1.4.3. Progression of teak trunk borer infestation in affected plantations

Mathew (1990) studied the rate of progression of infestation in 24-year-old plantation at Cheenikunnu in Palappilly range in Kerala during 1984-86. An annual infestation progression rate of 14.5 per cent was observed. A progression of 3.5 per cent in score-1 (low level infestation), 7.5 per cent in score 2 (medium level attack), 1 per cent in score 3 (heavy infestation) and 2.5 per cent for score 4 (death due to heavy infestation) was recorded.

2.1.5. Pre-disposing factors

2.1.5.1. Pre-disposing factors to teak trunk borer infestation

Beeson (1941) reported that attack of teak trunk borer was limited to trees of poor quality that are unhealthy or badly treated by lopping, coppicing or burning. Dead wood in the form of scars or snags appears to be an essential pre-disposing factor as healthy trees in the vicinity of seriously infested individuals remain immune.

In Kerala, trunk borer infestation was noticed in teak plantations adjacent to human habitations and trees growing in such areas are frequently subjected to mechanical damages such as lopping of branches plucking of leaves etc., such trees are more susceptible to the attack by the borer (Mathew, 1990).

Lingappa *et al.* (1991) reported that the incidence of teak trunk borer was more in fire-affected areas and where cattle keepers are dwelling. These two agents cause damage to the bark making easy way for the entry of the pest.

Prasad Kumar *et al.* (2001) reported roadside trees that are vulnerable to mechanical injuries by man and animals had highest trunk borer infestation.

2.1.5.2. Pre-disposing factors for infestation in other cossids

Rossem *et al.* (1978) reported the trend for increasing damage to roadside trees by *Cossus cossus* were attributed to damage to trunk by mowing machines. Balarin *et al.* (1979) reported *Zeuzera pyrina* as one of the pests posing increasing problems on several broad-leaved species especially ash in parks and avenues.

Gavioli (1984) reported that the carpenter moth (*Cossus cossus*) usually attacked trees weakened by age or other causes. Fearn (1985) reported that the adult females of wood moth *Xyleutes liturata* oviposit in cracks or depressions in the bark of any suitable sized tree in the genus *Acacia*, and damaged trees being particularly prone to attack.

2.1.5.3. Pre-disposing factors for incidence of other borers

Dunn *et al.* (1986) reported that the buprestid *Agrilus bilineatus* (Coleoptera: Buprestidae) attacks stressed oaks (*Quercus* spp.) and is associated with extensive mortality of trees in the eastern deciduous forests of N. America. Braza (1988) reported that pest attack of the buprestid varicose borer *Agrilus sexsignatus* (Coleoptera: Buprestidae) attacked only weakened or stressed trees of *Eucalyptus deglupta*.

Liu *et al.* (1989) reported that the fire in Daxinganling Mountain forests of China resulted in a region wide outbreak of stem borers of more than 20 species on

Pinus sylvestris and *Larix olgensis* dominated by *Monochamus sutor* and *Ips subelongatus*. All burned stands, timber depots and dumps being severely infested by these borers.

Rogers and Grant (1990) reported the highest average infestation by the dogwood borer *Synanthedon scitula* (Lepidoptera: Sesiidae) was 60 per cent in the urban habitat where mechanical injury like damage caused by lawn mowers or string trimmers which provide oviposition or larval entry sites. Dunn *et al.* (1990) reported that buprestid *Agrilus bilineatus* attacks oak trees (*Quercus* spp.) that have been weakened by prior environmental or biotic stress.

Ranjeet Singh *et al.* (2001) have reported that the mortality of Chir Pine (*Pinus roxburghii*) in Haryana caused due to heavy infestation by Coleopteran borers was mainly attributed to trees growing in forest tracts badly abused by high biotic pressure, recurrent fires and heavy resin tapping which exposed the bark.

2.1.6. Age of host and trunk borer infestation

Mathew (1990) reported based on the survey carried out in plantations of differing age groups which ranged from 10-56 years that as the age of the plantations increases the proportion of trees affected by *A. cadambae* in the plantations also increased. The youngest plantation affected was 22 years old with 3.4 per cent infestation. The oldest plantation affected was 56 years old which had 38 per cent infestation. The increase in infestation with age of the plantation was attributed to re-infestation of the affected trees over the years.

2.2. Impact of borer damage on host trees

2.2.1.1. Economic losses due to teak trunk borer

Sharma *et al.* (1985) isolated the fungus *Phialophora richardsii* from wood attacked by *A. cadambae*. Hence teak trunk borer infestation led to wood rot and subsequent loss in economic value.

Mathew (1990) reported extensive feeding leads to callus growth and often distorted bark formation. The bark that is lost due to larval feeding never recovers and as a result the wood is exposed, which may subsequently get infected by pathogenic/saprophytic fungi leading to decay of wood and perhaps the fungal association might be essential for the larval establishment. He also reported that occurrence of borer holes in timber affected by *A. cadambae* was a serious defect which adversely affects its commercial value. The larval tunnels are radial and follow a zig-zag course, reaching as far as the heartwood. Planks sawn from such billets will have numerous holes and are not cherished for use in building construction, furniture making etc.

Mathew and Rugmini (1996) reported that trees which fall under the 3rd (representing very seriously damaged trees) and the 4th (representing trees which were dead due to infestation) categories constituted 10 per cent and 20 per cent in Trichur, 19.4 per cent and 20.2 per cent in Kothamangalam and 15.75 per cent and 16.5 per cent in Nemmara Forest Divisions and that these trees were not useful for any commercial use.

2.2.1.2. Economic losses caused by other borers

Morris (1962) reported the occurrence of heart-rot in oaks attacked by *P. robiniae*. Chatterjee and Thapa (1970) reported that about 2213 Sal trees were

killed causing a loss of Rs 18000 due to an epidemic of Sal heartwood borer *Hoplocerambyx spinicornis* (Coleoptera: Cerambycidae) in Uttara Pradesh.

Harris (1986) reported that butt lengths of logs of 45 year old *Eucalyptus regnans* trees infested by 2 species of *Xyleutes* were found to be unsuitable for mill logs, and therefore were harvested as pulpwood, with a corresponding reduction in royalty from \$A 20.41/m³ to \$A 10.60/m³. About 20% of the anticipated saw log volume was degraded to pulpwood.

Sivaramakrishanan (1986) reported that Sandal heartwood borer *Aristobia octopasciculata* caused an estimated loss of Rs 3.5 million/year in Karnataka.

Rogers and Grant (1990) reported that Dogwood *Cornus florida* trees infested by the borer *Synanthedon scitula* (Lepidoptera: Sesiidae) were not marketable thus economic losses averaged ca. \$1800/block (mean of 1770 trees/block).

2.2.2. Alternate host of trunk borer

Other than teak, *A. cadambae* is known as a pest of tendu (*Diospyros melanoxylon*) in Madhya Pradesh (Bhandari and Upadhyay, 1986). Mathew (1990) has reported the incidence of this borer on *Grewia tiliæfolia* and *Terminalia bellarica* growing naturally in affected teak plantations in Kerala. Prasad Kumar *et al.*, (1999) have reported *Terminalia tomentosa* as alternate host for *A. cadambae* from Kirvatti and Barchi plantations of Yellapur and Haliyal taluks respectively.

2.2.3. Natural enemy complex

2.2.3.1.1. Bird predators of teak trunk borer

Woodpeckers are insectivorous birds have specialized in drilling holes into the insect-infected portions of trees and feed on the insects and their grub. They periodically check all the trees in their areas to find out the infected parts of the trees,

and carry out the beneficial surgery to feed on the insects. They, therefore, may be called as the Nature's tree-doctors to keep the trees in good health.

Mathew (1990) based on field observations has reported the occurrence of two species of predatory birds viz. Lesser golden-backed woodpecker (*Dinopium benghalense*) and an unidentified barbet both feeding on the caterpillars after extracting them from the larval tunnels.

2.2.3.1.2. Bird predators of borers in other species

Mc Innes and Carne (1978) reported serious damage in plantations of *Eucalyptus grandis* by the Cockatoo (*Calyptorhynchus funereus*) while excavating larvae of Wood moth *Xyleutes boisduvali* (Lepidoptera: Cossidae) but was a major predator of the cossid moth larvae.

Mendel *et al.* (1984) have reported that the average mortality due to predation by Syrian woodpecker of *Phorocantha semipunctata* (Coleoptera: Cerambycidae) boring on *Eucalyptus camakdulensis* logs was 29.21 per cent of total larval mortality and 78.7 per cent among larvae that survived intraspecific competition. The larval mortality caused by the woodpecker decreased with increasing density of larvae.

Nair (1987) observed predation of Sapling borer *Sahyadrassus malabaricus* (Lepidoptera: Hepialidae) infesting Teak and *Trema orientalis* by woodpeckers.

Petit *et al.* (1988) have reported that woodpeckers *Piccoides pubescens* and *P. villosus* preyed upon Red oak borers *Enaphalodes rufulus* excavating 7.4-12.8 per cent of the borers in two sides in Wayne National Forest, Ohio. Small diameter stems were excavated more frequently than larger stems. The low rate of borer mortality suggested that wood peckers may not be significant predators in regenerating broad-leaved clear fellings.

Huang (1989) reported that when large number of natural enemies of the leopard moth *Zeuzera multistrigata* (Lepidoptera: Cossidae) are present the incidence of the cossid on *Casuarina equisetifolia* can readily be controlled.

Spradberry (1990) studied predation of Siricid larvae in coniferous trees by woodpeckers by observing siricid infested logs with evidence of woodpeckers viz. *Dryocopus maritus* and *Piccoides major*. Overall predation was 28.8 per cent of a total population of 3617 larvae in logs worked by woodpeckers. Based on the total siricids available in all timber-collected predation was 6.1 per cent only.

2.2.3.2. Insect predators or parasites of teak trunk borer

Mathew (1990) attempted to trap parasitic/predatory insects by setting up sticky traps near the borer holes or by pasting the eggs on the bark so as to attract the egg parasites. In addition to this periodical larval sampling and rearing was also carried out for information on the extent of parasitism. However, no parasitic or predatory insects could be collected.

2.2.3.3. Microbial pathogens of teak trunk borer

Six species of pathogenic organisms were isolated and identified from field and laboratory specimens of larvae. The microbial pathogens reported, includes the fungi *Aspergillus flavus* and *Paecilomyces fumosoroseus* and the bacterium *Serratia marcescens* (Mathew and Mohamed Ali, 1987). In the pathogenicity trials maximum larval mortality was observed in the case of treatment with bacterium *Serratia marcescens* (83.3%) followed by the fungi *Aspergillus flavus* and *Paecilomyces fumosoroseus* (57%).

Mathew (1990) opined that the microbial pathogens reported to be useful in controlling some cossid pests also are unlikely to be of any practical use due to

difficulties involved in their application and also due to the fact that their success is dependent on a number of edaphic as well as biotic factors. The six species of microbial pathogens and 2 species of predatory birds recorded in the study were of academic importance and are not directly useful in developing management strategies.

2.2.3.3.1. Microbial pathogens of other cossid borers

Larval mortality due to a fungal pathogen *Beauveria bassiana* has been reported on the bee-hole borer *Xyleutes ceramica*, which is a major pest of teak in Myanmar. Direct application of this pathogen is known to cause 95 per cent larval mortality under laboratory conditions (Ghaiglom, 1966). Similarly, mycelial growth of the wood decaying fungus *Irpex mollis* has been reported to circumvent the pupae of the southern hardwood borer, *Prionoxystus robiniae* in the tunnels, thus preventing the eclosion of moths (Solomon and Toole, 1971).

2.3. Host resistance/clonal resistance

2.3.1. Host resistance/clonal resistance in teak to principal insect pests

Clonal resistance in teak has provided a highly practical approach to solve insect problems (Tewari, 1992; Kedhamath, 1984; Roychoudhury *et al.*, 1997b). After realization of potential practical importance of host resistance and their profitable application in evolving resistance trees, programmes have been undertaken to select phenotypically superior trees (plus trees) in different parts of the country. Though the criteria for selection of plus trees also include resistance to insect pests, only few studies have been carried out to screen them for resistance (Thakur, 1983).

The timber of teak has been reported to be resistant to borer attack due to the presence of certain phenolic compounds, such as tectoquinone and lapachol

(Sandermann and Simatupang, 1966). But until now no works has been carried out with respect to resistance to Trunk borer attack.

Concerted efforts for utilizing insect resistance in teak improvement programme started with the preliminary observations of Kedharnath and Singh (1975) on the relative resistance in eight clones of *T. grandis* and one clone of *T. hamiltoniana* to larvae of leaf skeletonizer. Of these, Teli clone of *T. grandis* and the clone of *T. hamiltoniana* are highly resistant to larvae of *E. machaeralis*. Subsequently, further fragmentary information on the same insect host-plant interactions through laboratory studies has also been reported.

Ahmad (1991) has evaluated the relative resistance of 20 teak clones of southern India planted in the clonal orchard at Walayar, Kerala. Clones TNT-6, TNT-11, and KLK-2 were found to be most resistant ones as the larvae have least preference to the leaves and consumed only minimum leaf area.

Mishra (1992) has investigated the natural variation in susceptibility of 16 teak clones maintained in teak germplasm bank at New Forest, Dehradun, U.P. on the basis of quantity of leaf consumed by larvae, Bori and FG-1 clones appeared to be most resistant followed by clone from Gorakhpur. FG-19, Allapalli, Togo and Orissa are most susceptible. Meshram (1993) and Meshram *et al.* (1994) have examined clones of teak for their natural variation in susceptibility. Based on the leaf area consumed by the larvae, clone APT-8, APT-20, and MHSC-J2 are observed to be the most resistant and UP-D1 and TNT-11, as the most susceptible.

Roychoudhury and Joshi (1996) based on their study carried out with 167 clones planted at National Teak Germplasm Bank, Lohara, Chandrapur, Maharashtra

reported the existence of resistance phenomenon in teak clones against *E. machaeralis*.

Antixenosis (non-preference) resistance in teak clones through field observations (damage intensity) and feeding bioassay (no choice and choice tests) in laboratory showed the ratio of nitrogen to potassium to be directly proportional to feeding potentiality and inversely proportional to antixenosis resistance in teak clones (Roychoudhury *et al.*, 1997a).

Titer of leaf protein/polyphenol is correlated with the degree of resistance/susceptibility. The teak resistance towards *Eutectona machaeralis* inversely correlated with the protein and directly with polyphenol contents of clonal leaves. The ratio of protein to polyphenol determines the degree of resistance offered by the teak clones whereas higher ratio makes them susceptible (Jain *et al.*, 1999).

Manjunath and Prasad Kumar (2000) reported that amongst 24 clones in Clonal Seed Orchard, Manchikeri, 13 clones exhibited resistance to gall midge *Asphondylia tectonae* with infestation level ranging between 0 to 91 per cent and remaining 5 clones showed greater susceptibility with 100 per cent infestation.

But until now no studies have been carried out regarding clonal resistance of teak with respect to trunk borer *A. cadambae*.

2.3.2. Host resistance/clonal resistance of other species to defoliator/borer damage

Lagunov (1981) reported Green ash (*Fraxinus pennsylvanica*) was damaged by the wood borer *Zeuzera pyrina* (Lepidoptera: Cossidae) more frequently (25% Vs 7%) and severely than hybrid ash (*F. excelsior* X *F. pennsylvanica*). Survival of young larvae was 90-97% on green ash and 57-77% on hybrid ash. The shoots of

green ash contained more starch and less Ca and Mg than those of Hybrid ash suggesting that starch is responsible for the greater susceptibility of green ash.

Wang *et al.* (1987) related poplar resistance to the stem borer *Anoplophora nobilis* (Coleoptera: Buprestidae) to the amounts of soluble sugars and phenolic compounds in the tree with lower proportions of soluble sugars and tannic acid giving higher resistance and gallic acid content influencing palatability.

Lindeman (1988) reported that loss of resistance of *Fraxinus pennsylvanica* was indicated by normal larval development of *Zeuzera pyrina*. Dunn *et al.* (1990) reported that *Quercus* trees with relatively low winter starch reserves are more likely to be attacked by the Buprestid *Agricolus bilineatus*. Also there was a trend of larvae of the cossid *Prionoxystus robiniae* a generalist bark and wood borer to be more successful in establishing galleries on low starch trees.

Noh *et al.* (1992) reported that in 1 year old 25 Aspen clones (*Populus davidiana*) planted at 4 locations in Korea tolerance to poplar borers *Endoclyta excrescens* and *Cryptorhynchus lapathi* (Lepidoptera: Hepialidae) was more affected by environment than by genotype, although there were significant differences among genotypes. There was also significant difference in the interaction between location and genotype. Broad sense heritabilities were low, estimated at 0.36 for clones and 0.04 for individual ramets.

Sun Li Yan and Han Yifen (1995) reported resistance of *Populus deltoides* varieties to *Batocera horsfieldi* (Coleoptera: Cerambycidae) to be related to phenol and tannin contents of young shoots and bark rather than nutrient components.

Wang *et al.* (1995) investigated amino acid, sugar, phenolic compound (acids and glucosides) content of *Populus tomentosa* (resistant to *Anoplophora*

glabripennis) bark and reported that phenolic acid and glucoside content were related to insect resistance in *Populus*.

Sharma and Bhatia (1996) identified Poplar clones resistant to stem borer *Apriona cinerea* (Coleoptera: Cerambycidae) based on observations like minimum attack and maximum tolerance. Tomlin and Borden (1997) reported that most resistant clones of Sitka spruce (*Picea sitchensis*) to white pine weevil *Pissodes strobi* (Coleoptera: Curculionidae) had combination of thin bark and high density of outer resin canals and susceptible clones had thin bark and low densities of outer resin canals.

Wang *et al.* (1998) reported that degree of damage caused by *Apriona gemari* (Coleoptera: Curculionidae) in 34 *Populus* clones (complex hybrid of *P. tomentosa*) varied considerably between the clones. The clones which exhibited an infested tree percentage of 7.25%, and insect density of <1.0 head/tree were classified as resistant to the borer.

Hanks *et al.* (1999) suggested that variation in resistance of Eucalypts to attack by the longhorned borer *Phorocantha semipunctata* (Coleoptera: Cerambycidae) is associated with moisture deficit in the bark.

Meshram *et al.* (1999) reported resistance of *Dalbergia sissoo* seedling against defoliator *Plectoptera reflexa* to be related to high polyphenol content (6.24%) and low protein content (9.54%).

Material and Methods

III. MATERIAL AND METHODS

The present study on 'Infestation dynamics and clonal resistance of teak to trunk borer *Alcterogystia cadambae* Moore. (Lepidoptera: Cossidae)' was carried out during 1999-2001 at College of Forestry, Sirsi. The details of material used and methodology adopted for the investigation are included here under.

3.1. Distribution pattern of teak trunk borer in space and time.

3.1.1. Study area

An intensive survey work was taken up during 1999-2000 in selected teak plantations in and around two localities viz. Gunjavathi and Tatwala in Uttara Kannada district of Karnataka state. Gunjavathi included under Mundgod forest range jurisdiction whereas Tatwala under Yellapura forest range.

3.1.1.2. Criteria for selection of study area

Lingappa *et al.* (1991) found that the occurrence of trunk borer in high numbers in places like heavy rainfall tracts covering Honnavar, Yellapur, Dandeli and Hallyal. Prasad Kumar *et al.* (2001) have reported that trunk borer infestation was severe and causing more damage to trees in plantation of Gunjavathi and Tatwala. Hence the study area was more confined to these two localities.

Further, presence of large number of teak plantations, their extent of spread, ease of accessibility by road and availability of plantations of different ages was found most suitable in these localities to study infestation dynamics.

3.1.2. Survey

Survey was conducted in 12 teak plantations with 6 each in Gunjavathi and Tatwala. In Gunjavathi most of the plantations were of the age between 20 to 30 years whereas most of the plantations in Tatwala were 30 years and above. The

details of the plantations selected for studying infestation dynamics is presented in Table 1. Localities from where the survey was made to assess the trunk borer infestation are presented in Fig-1.

3.1.2.1. Sampling method

A minimum of 6 quadrats of 20 X 20 m dimension per plantation were randomly laid covering an area of 1%. In each sample plot, the total number of healthy and infested trees, *i.e.* trees with bored holes were enumerated to assess the extent of infestation, their GBH and height was measured.

3.1.2.2. Assessment of trunk borer infested trees and healthy ones

The infested trees were identified with the help of holes present on the trunk, presence of frass or excreta at the mouth of the tunnels or at the base of the tree or trees with large holes due to wood rot following severe trunk borer infestation.

The following visual scoring was used to assess the borer infestation

H – Healthy tree, free of borer attack,

A – Low level infestation, less than 5 holes per tree,

B – Medium level attack with 5 to 25 borer holes distributed on the stem at wider intervals,

C – Heavy infestation 25-50 holes per tree characterized by the occurrence of several feeding scars, distributed more or less uniformly throughout the trunk,

D – Severe infestation >50 holes per tree or tree characterized by feeding scars coalescing and holes distributed uniformly or those trees dead due to heavy infestation.

The trees were observed for occurrence of borer holes within 4m height of main trunk and lower primary branches if any.

Table 1: Details of the plantations selected for survey of teak trunk borer

Locality	Forest Range	Forest Division	Plantation No.	Year of Establishment	Area of Plantation (Ha)
Gunjavathi	Mundgod	Yellapura	1	1980	14.4
			2	1979	50.0
			3	1978	42.0
			4	1977	30.7
			5	1973	73.8
			6	1969	25.0
Tatwala	Yellapura	Yellapura	7	1983	19.7
			8	1970	19.7
			9	1969	36.0
			10	1967	42.1
			11	1965	25.0
			12	1963	13.8

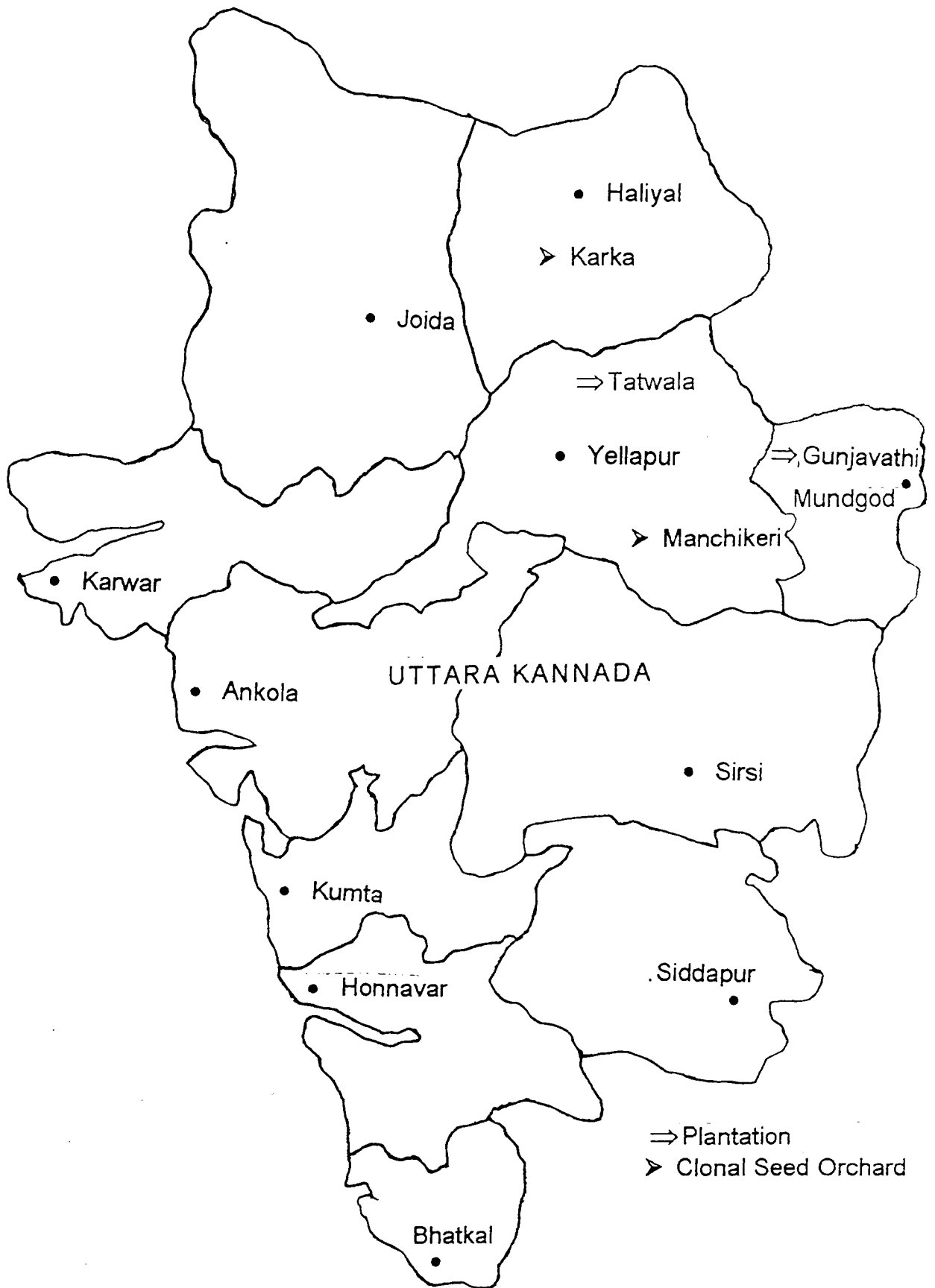


Fig 1: Map showing localities which were surveyed for trunk borer incidence

3.1.3. Estimation of mean infestation and variance

The estimated mean infestation and the estimated variance of infestation for both the localities were obtained for total infestation, low, moderate and heavy level of infestation.

$$\text{Estimated mean infestation } \frac{\hat{y}}{Y_t} = \frac{1}{n_t} \sum_{j=1}^{n_t} P_{tj}$$

Where

\hat{y}

y

$-$ = Estimator of the proportion of affected trees in the 't'th locality

Y_t

P_{tj} = Estimated proportion of infested trees in the 'j'th plantation of the 't'th Locality

n_t = number of plantations selected in the 't'th locality

The variance estimate is given by

$$V \frac{\hat{y}}{Y_t} = \frac{1}{n_t(n_t-1)} \sum_{j=1}^{n_t} P_{tj}^2 - \frac{1}{n_t} \left(\sum_{j=1}^{n_t} P_{tj} \right)^2 \quad 2$$

3.1.4. Binomial distribution

In order to assess the frequency of occurrence of trees under various infestation scores in a hypothetical sample of 10 trees, the total infestation in both the localities were tabulated separately and the binomial distribution for occurrence of 1 to 5 individuals in economic damage categories was worked out. The binomial was obtained by the formula as follows

$$\text{Probability (r)} = \frac{n!}{r!(n-r)!} p^r q^{n-r}$$

Where, r = Probability of getting ' r ' successes (*i.e.* infestations)

p = Proportion of trees in economic damage category

q = 1 - p.

3.1.5. Distribution pattern of infested trees in plantations

In every plantation, individuals of different levels of infestation were mapped. This revealed the level of infestation at plantation level as well as the geographical inventory of trees. The procedure was carried out in all the plantations. Later, based on the status of the plantations for trunk borer infestation the plantations featuring low, moderate to heavy and heavily infested plantations were identified.

From the field inventory of low, moderate to heavy and heavily infested plantations of both the localities randomly 50 trees belonging to A, B, C & D score classes were selected. The health score of the trees immediately adjacent to them on to their right at 2 m, 4 m and 6 m distance were noted. The frequency of occurrence of various combinations of infested scores existing at various distances was tabulated.

3.1.6. Vertical distribution of trunk borer infestation

To assess the establishment pattern of borer on tree trunks, the number of tunnels (both fresh and old) were counted at different heights of the main trunk from the ground level *i.e.*, <1 m, 1-2 m and 2-3 m. Ten trees were selected in each infested scores *i.e.*, A, B, C & D for this purpose in each locality.

In order to know the susceptible portions on the stem where the borer infestation occurred frequently, 20 trees in the different infestation categories were observed. The occurrence of holes on three susceptible portions such as base of branches, bark damage or callus formations on the stem was recorded and the percentage under each category was calculated.

3.1.7. Temporal distribution of teak trunk borer

Plantations having different stages of infestation were selected at Gunjavathi and Tatwala based on the estimates of infestation during the survey taking into account the number of affected trees present as well as their damage intensity. Thus 3 plantations were selected infestation for temporal studies from both the localities which featured three important phases of borer infestation such as:

- an initial phase (when the affected trees show only low level infestation, mostly A and B scores with a few number of C & D scores);
- an advanced phase (when the affected trees show moderate to high level of infestation, featuring all the infestation scores in good number almost in equal proportions); and
- a later phase (when the affected trees show heavy infestation, featuring all the infestation scores in large numbers mostly of C & D scores apart from A and B scores in substantial proportion).

Two quadrats of 20 X 20 m dimension in each of the plantations selected were marked for temporal studies. The initial infestation status of each tree was recorded. Bi-monthly observations from July 2000 to July 2001 during first week of alternate months were done in the quadrats to record 'new recruits' under various infestation scores.

3.1.7.1. Annual rate of progression of infestation

In order to assess the rate of progress of infestation in the plantations under temporal study, the initial proportion of infested trees of all the infestation categories were noted down at the start of temporal studies. At the end of the temporal studies the proportion of trees falling under different infestation categories were again noted down. The difference in percentage of infestation categories before and after temporal studies gave the annual rate of progression of infestation.

3.1.8. Pre-disposing factors

In order to identify the pre-disposing factors leading to infestation, disturbance factors were noted in all the plantations surveyed, such as:

- Closeness to human settlements
- Closeness to agricultural fields
- Cattle grazing and
- Fire incidence

Principal component analysis was carried out to determine the most important factor/factors related to infestation levels in the plantations.

3.1.8.1. Infestation pattern around disturbed locations

Within the plantations separate survey of the trees bordering special locations such as agricultural fields, human habitation and along the roads were studied for borer incidence. Two transects of 10 X 80 m were laid around these locations and the results were tabulated.

The infestation level on the trees at different distances viz. 20m, 40m, 60m, and 80m perpendicular to the road was surveyed in both the localities.

3.1.9. Age of the tree and trunk borer incidence

In order to know the association between age of plantation and percentage of infestation, correlation co-efficient was computed after subjecting the per cent infestation values to angular transformation (Snedecor and Cochran, 1967).

3.2. Assessment of economic loss due to teak trunk borer, record of alternate host and natural enemy complex of teak trunk borer

3.2.1. Impact of borer infestation on growth parameters

Along with the assessment of infestation status, the GBH and height of trees were measured in all the plantations to assess the effect of trunk borer infestation on volume of the infested trees. The height of the tree was estimated by using Ravi multimeter and GBH was measured using a measuring tape. The mean of the GBH and height of trees under all the health scores were worked out for all the plantations and the corresponding volume was estimated from the volume table for teak (Tewari, 1992). The reduction in volume of the infested trees were expressed as per cent reduction in comparison with that of the healthy trees.

3.2.1. Impact of borer infestation on economic value of teak

The impact of the borer holes and tunnels on the economic wood loss of teak was estimated by comparative value method. The Government timber depot, Mundgod was visited during public auction period. The borer damage status of the logs and the value fetched by the auctioned lots and poles was recorded and compared with that of the undamaged ones. The value fetched by the logs was converted to per cubic meter value for uniformity of comparison.

3.2.2. Alternate host

During the study, survey was also carried out to record alternate tree species other than teak, which are infested with trunk borer *A. cadambae*. They were identified with the presence of borer holes and larva. Pre-disposing factors, leading to the infestation on the alternate host by the trunk borer was also recorded.

3.2.3. Natural enemy complex

3.2.3.1. Selection of plantations for survey

The possibility and prevalence of a wide range of natural enemies is more in places which feature heavy pest pressure and a long history of trunk borer damage. Hence the two localities Gunjavathi and Tatwala drew the attention for discovery and identification of natural enemies, if any, attacking different life stages of the pest.

For detection of natural enemies such as predators, parasitoids, pathogens and birds, periodic observation were carried out throughout the year on all the life stages of pest in both the localities.

3.2.3.2. Survey for predatory birds

The survey for predatory birds feeding of larval stages of the pest were observed for their feeding habit and verified from the book titled 'The book of Indian birds' by Salim Ali (1997) for their identity.

The efficiency of bird predation on pest control was also studied by observing trunk borer infested trees under various health scores. The number of tunnels within 3m from ground level was counted and the number of tunnels worked out by woodpeckers for reaching the larvae was counted.

3.2.3.3. Survey for predatory/parasitic insects

The survey for parasitic and predatory insects was done using sticky traps at the mouth of the active tunnels and also by close visual observation around highly infested trees. The plantations were visited during the pre- monsoon rains and early monsoon season and egg masses of trunk borer on tree trunks were searched and closely observed for occurrence of egg parasites.

3.2.3.4. Survey for microbial pathogens

The possibility of encountering diseased larvae deep inside the wood, which would otherwise be inaccessible at the mouths of tunnels, would be more if the wood in which they thrive is split and opened. Therefore the trunk borer infested plantations in which thinning operations were in progress in both the localities were visited. The extracted trees that were highly infested by the trunk borer were split with axes and searched for infected larvae.

3.3. Identification of resistant clones to teak trunk borer and bio-chemical studies

3.3.1. Selection of clonal plantations

For studying clonal resistance of teak to trunk borer infestation two teak clonal seed orchards (CSO) maintained by Karnataka Forest Department were selected. CSO, Manchikeri established during 1980 in the Yellapur division (Plate 1) and another CSO, established at Karka during 1980 in the Haliyal division (Plate 2) were selected. The exact location of the clones in both the seed orchards is presented in Appendix I & II.

The CSOs have good number of plus tree clones from all over Karnataka and hence are the treasure of unique clonal collections in Karnataka. The CSOs being



Plate 1: General view of the Clonal Seed Orchard, Manchikeri.



Plate 2: General view of the Clonal Seed Orchard, Karka.

present in Yellapur and Haliyal divisions were found ideal and appropriate for full fledged and reliable study on trunk borer.

3.3.2. Characterization of clones

The CSO, Manchikeri & CSO, Karka consists of 24 clones of teak previously selected for phenotypic superiority from various provenance of Karnataka. In CSO, Manchikeri there are 13 clones derived from Haliyal division, 3 from Shimoga division, 1 from Lakkavalli, 6 from Hunsur division and 1 from Mysore division. Thus 13 clones have derived from northern zone, 4 from central zone and 7 from southern zone. In CSO, Karka there are 12 clones from northern zone, 4 from central zone and 8 from southern zone. In both the CSOs the planting has been done by Completely Randomised Design (CRD) with unequal replications over an area of four hectares. The infestation was assessed by visual observation for all the clones and ramets at both the locations. The health scores such as H, A, B, C, D as used for assessing borer infestation in teak plantations were followed.

3.3.3. Bark thickness and trunk borer infestation

Bark gauge was used to measure the bark thickness of all the clones present in the CSOs. The bark thickness and the per cent infestation of the clones were correlated to find out the type of association of bark thickness and clonal resistance to teak trunk borer.

3.3.4. Bio-chemical analysis of bark contents of resistant/susceptible

clones

3.3.4.1 Selection of clones for the study

For bio-chemical analysis, 8 clones from CSO, Karka which showed apparent resistance or susceptibility to trunk borer incidence were selected based on the

evaluation of the entire plantation. Four clones which featured none or very low infestation (clone I.D. MyHaD4, MyHaV1, MyHuT2 and MyHuT3) and 4 clones which featured heavy infestation (clone I.D. MyHaD2, MyHaV2, MyHaV5 and MySA2) were selected for analyzing the bark contents to ascertain the chemical basis, for their resistance/susceptibility. In each selected clone, three healthy ramets were randomly selected for extracting bark samples of 1 sq. in. at breast height.

3.3.4.2. Estimation of bark moisture content

The fresh weight of the bark samples derived from the clones was taken, they were later dried at 70°C to constant weight and oven dry weight was recorded. The moisture content was calculated using the following formula:

$$\text{Moisture content (\%)} = \frac{\text{Fresh weight}}{\text{Oven dry weight}} \times 100$$

3.3.4.3. Estimation of total phenols

Phenols, the aromatic compounds with hydroxyl groups are widespread in plant kingdom. They occur in all parts of the plants. Phenols are said to offer resistance to diseases and pests in plants. Grains containing high amount of poly-phenols are resistant to pest attack. Phenols include an array of compounds like tannins, flavonoids etc. Total phenol estimation was carried out by Folin-Ciocalteu method (Folin and Ciocalteu, 1927).

Procedure

The oven dried bark samples were finely powdered using a grinding machine. Exactly 0.5 g of powdered samples of all the 8 clones were taken and ground with a

pestle and mortar in 10 times volume of 80% ethanol. The extract was centrifuged at 10,000 rpm for 20 min. The residue was re-extracted with five times the volume of 80% ethanol, centrifuged and the supernatant pooled. The supernatant was evaporated to dryness. The residue was dissolved in a known volume of distilled water (5ml).

Different aliquots were pipetted out into labelled test tubes 10-100 mg from working standard solution and made up the volume to 1ml in all the test tubes. A blank with 1ml distilled water was maintained. 1.0 ml of Folin-Ciocalteu reagent was added to all the test tubes and mixed well. After 3 min, 2 ml of 20% Na_2CO_3 solution were added to each tube. Then the test tubes were placed in a boiling water bath for exactly one minute, cooled and made upto a suitable volume (*i.e.*, 15, 20 or 25 ml); finally the absorbance at 650 nm against a reagent blank was measured and a standard curve was developed.

Clonal samples (0.5 ml) were taken in different test tubes and the procedure as said above was followed. Finally the absorbance at 650 nm against a reagent blank was measured and the concentration of phenols present in the sample was estimated from the standard curve and expressed as percentage.

3.3.4.4. Estimation of proteins

Protein was estimated by Lowry's method (Lowry *et al.*, 1951). The working standard solutions (20-100mg) were pipetted out into labelled test tubes and distilled water was added to make the volume upto 1 ml each. One test tube with 1ml distilled water was maintained as a blank. Then 5 ml of alkaline copper reagent was mixed thoroughly and kept for 10 minutes. 0.5 ml 1N FCR was added to all the test tubes, mixed well and kept in dark for 30 minutes.

Aliquots of the clonal bark extracts were also treated as explained above. Finally, the %T values of the standard and the samples against the reagent blank was read out at 750nm. The protein content was calculated from the standard graph and expressed as percentage.

3.3.4.5. Estimation of total sugars

Sugars occur in two forms as reducing and non-reducing sugars. Thus to estimate the total amount of sugars present in the bark samples the reducing and non-reducing sugars were estimated separately and added to obtain amount of total sugars in the samples.

3.2.4.5.1. Estimation of reducing sugars by Dinitro-Salicylic acid method

Procedure: Suitable aliquots from stock standard solution (100-1000 μg) were pipetted out into a series of labelled test tubes and made up to 1 ml in all the tubes. A blank tube with 1 ml - distilled water was kept. Then 0.5ml of DNSA reagent was added to all the tubes mixed well and kept in boiling water bath for 5 minutes. The tubes were cooled and made up to a suitable volume (*i.e.*, 10,15 or 20 ml).

Aliquots of the clonal bark extract were also treated as explained above. Finally, the % T of the standard and the sample against reagent blank, which was adjusted to 100% T at 540 nm was read out. The amount of reducing sugar was estimated from the standard graph.

3.3.4.5.2. Acid hydrolysis of non reducing sugar and its estimation as reducing sugar

Procedure: For this experiment, 0.5-ml sucrose solution was taken in a test tube and 0.5 ml of water was added followed by 1.0 ml of 1N HCl then test tube was placed in a water bath at 50° C for 20 min. The solution was cooled down and indicator

solution was added and mixed well. 1N NaOH was added till the solution turned pink due to excess alkali. The excess alkali was re-neutralized with 0.1 N HCl till the solution became colorless and made upto known volume (5 or 10 ml). Suitable aliquots (*i.e.*, 0.5 ml or more) were taken and reducing sugar present in the hydrolysate was estimated by DNSA method.

The amount of reducing sugar in clonal bark extract before and after hydrolysis was estimated by DNSA method. The reducing sugar in the hydrolysate was a measure of total sugar. The quantity of reducing sugar was subtracted from the total sugar value. This value was multiplied by a conversion factor 0.95 to get non-reducing sugar.

The amount of both reducing and non-reducing sugars in the samples were added up to give total sugars and then expressed as percentage.

3.3.5. Statistical analysis

Results on the clonal variation was analysed in computer using MSTATC program.

Experimental Results

IV. EXPERIMENTAL RESULTS

The results of the investigations on 'Infestation dynamics and clonal resistance of teak to trunk borer *A. cadambae* Moore. (Lepidoptera: Cossidae)' carried out during 1999-2001 at College of Forestry, Sirsi are presented here under.

Biology and nature of damage

Different stages of the life history were photographically documented. The eggs are brownish in colour and spherical in shape (Fig-2) are laid in small crevices on the bark of trees. The larva is polypodous, the newly hatched larva is light reddish in colour and measures about 1.9 - 2.2 cm in length. The last instar larva is bright red in colour (Plate 3) and attains a length of 4-5 cm. The larvae bore tunnels inside the wood (Plate 5) which run vertically up and down from entry point at various heights of the tree, and if disturbed, it starts excreting brownish fluid from the mouth. The pupa is brownish in colour measuring 2.2 to 3.3 cm and is obtect type. The developed larvae descend down to the ground and pupate in the soil after forming a puparium within the soil (Plate 4). The fore-wing of moth is dull brown in colour, whereas hind wing is transparent and antennae pectinate type (Fig-3).

4.1. Distribution pattern of teak trunk borer in space and time.

4.1.1. Distribution of Infestation

Results on the infestation status in Gunjavathi and Tatwala are given in Table 2 and 3 and the distribution of infestation among the plantations are depicted in Fig 4 and 5. The mean percentage of infestation distribution for both the localities is depicted in Fig-6. At Tatwala the mean percentage of healthy trees was higher (67.45%) than Gunjavathi (64.24%). The intensity of infestation in different health scores varied slightly.



Fig 2: Egg mass of teak trunk borer

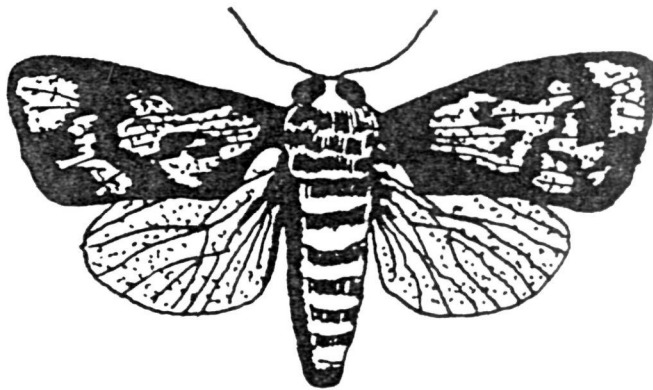


Fig 3: Adult of teak trunk borer



Plate 3: Grown-up larva of teak trunk borer *Alcterogystia cadambae*

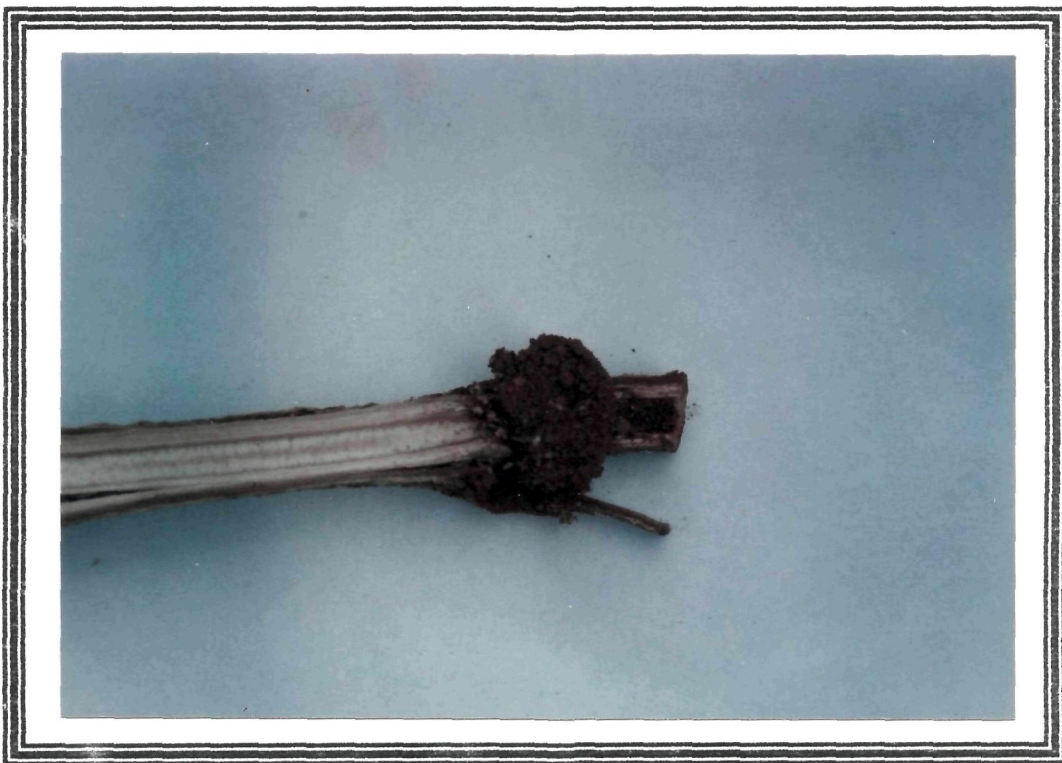


Plate 4: Puparium of teak trunk borer *Alcterogystia cadambae*.



Plate 5: Larval tunnels running zig-zag into the heartwood of infested trees.

Table 2: Distribution of individuals into different health score in various plantations at Gunjavathi.

Sl. No.	Age of plantation (Yr.)	No. of Plots	No. of trees sampled	Infestation (%)	Trees under different health scores (%)				
					H	A (1-5 holes)	B (5-25 holes)	C (25-50 holes)	D (> 50 holes)
1	20	6	348	19.91	80.09	13.50	6.41	0.0	0.0
2	21	13	592	48.94	51.06	12.30	14.70	4.40	17.50
3	22	11	383	39.60	60.40	7.90	11.60	6.70	13.40
4	23	10	305	47.43	52.57	6.48	9.95	12.42	18.58
5	27	13	562	37.42	62.58	3.42	5.20	12.20	16.60
6	31	6	203	21.28	78.72	2.36	2.12	9.33	7.47
Mean				35.76	64.24	7.66	8.33	7.51	12.26

Table 3: Distribution of individuals into different health score in various plantations at Tatwala.

Sl. No.	Age of plantation (Yr.)	No. of Plots	No. of trees sampled	Infestation (%)	Trees under different health scores (%)				
					H	A (1-5 holes)	B (5-25 holes)	C (25-50 holes)	D (> 50 holes)
1	17	6	267	28.70	71.30	14.90	6.90	2.86	4.04
2	30	6	264	38.30	61.70	5.90	15.00	5.10	12.30
3	31	9	321	35.85	64.15	12.81	8.94	6.41	7.69
4	33	11	290	28.37	71.63	2.67	9.80	6.91	8.99
5	35	6	211	20.72	79.28	0.50	1.32	3.46	15.44
6	37	6	127	43.31	56.69	3.52	14.46	7.10	18.23
Mean				32.54	67.45	6.72	9.40	5.31	11.12

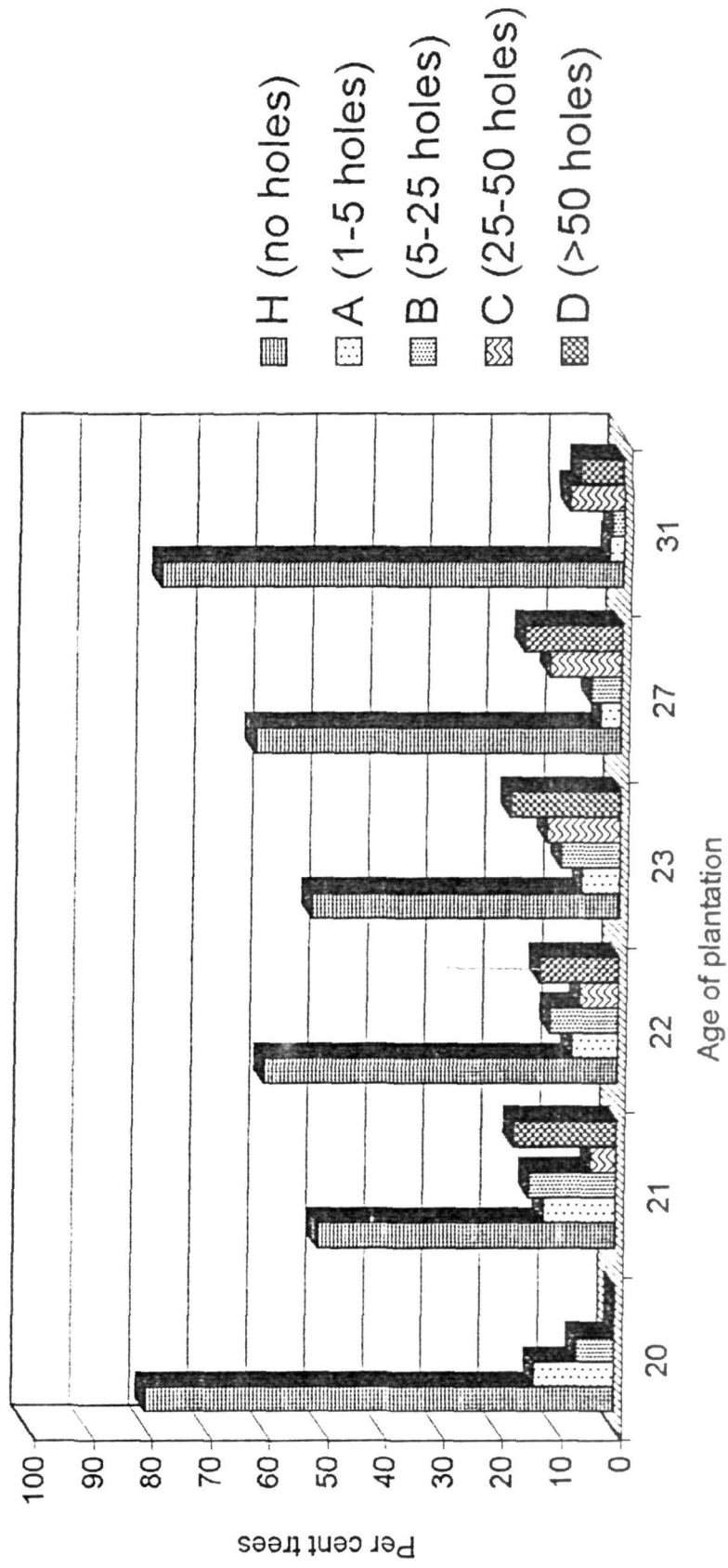


Fig 4: Distribution of individuals into different (Data pooled over all plantations) health scores at Gunjavathi plantations

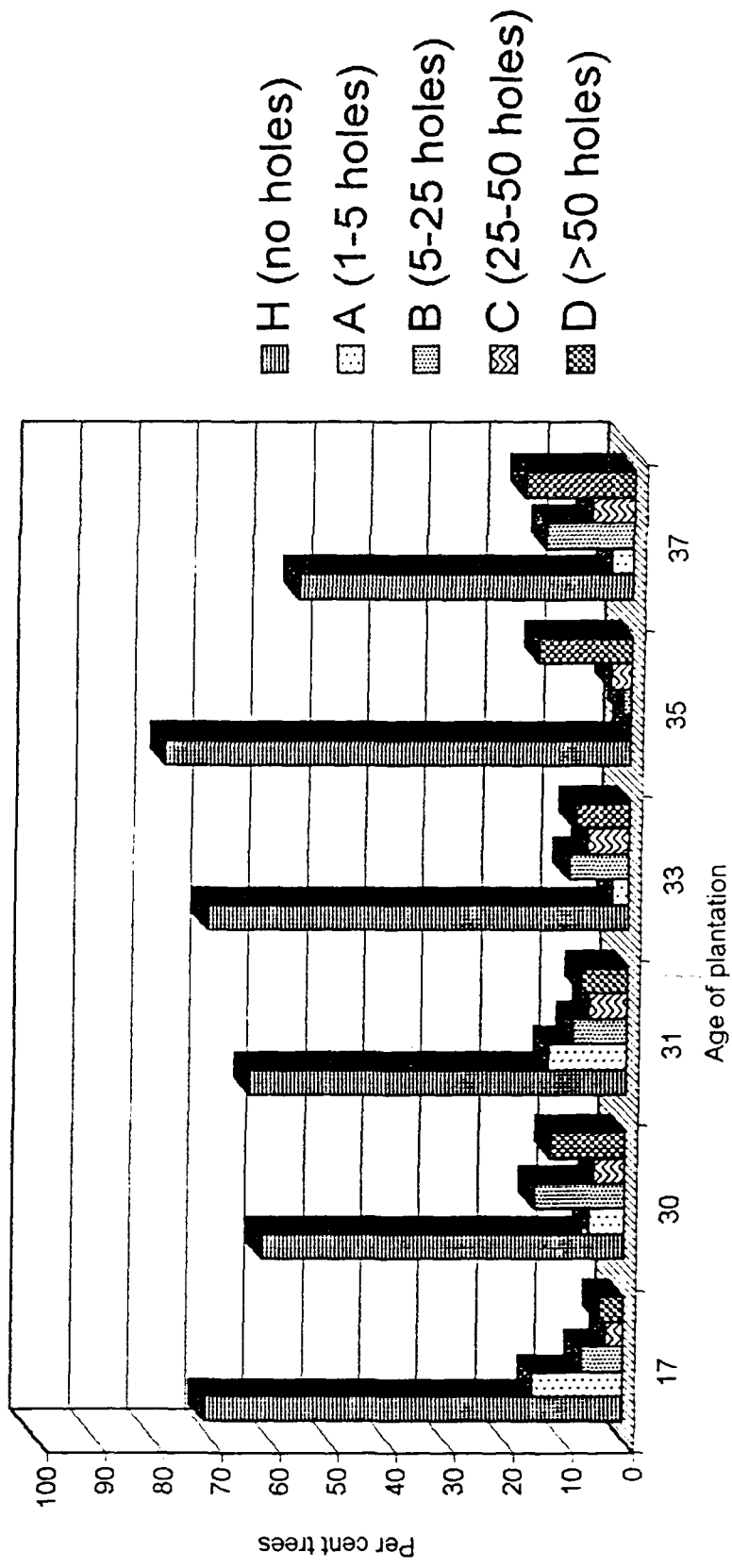


Fig 5: Distribution of individuals into different (Data pooled over all plantations) health scores at Tatwala plantations

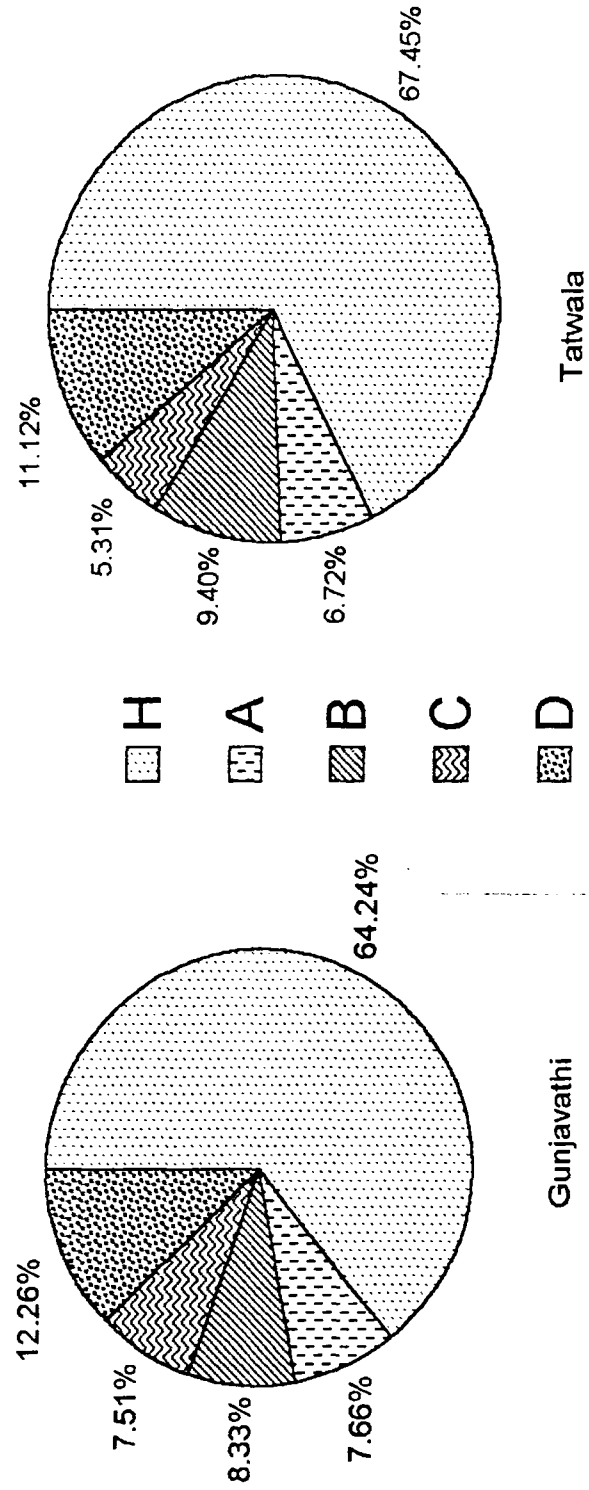


Fig 6: Comparison of Gunjavathi and Tatwala plantations for distribution of individuals into health scores

In case of economic damage categories Gunjavathi recorded 19.77% of trees with heavy infestation (C & D scores), which was higher than that in Tatwala (16.43%). Tatwala had higher percentage of trees that had moderate infestation (B-score) of 9.41% as compared to 8.33% in Gunjavathi. With respect to light infestation categories, Gunjavathi recorded slightly higher than that in Tatwala (7.66% vs 6.72%).

At Gunjavathi, the youngest plantation of 20 years had only 19.91% of early infestation (A & B). Other older plantations were characterized by higher infestation of later stages (*i.e.* D-score) (Plate 6).

The distribution of infestation in 20 years old plantation indicated initial phase of attack when infestation is mainly in A and B score classes. The 23, 27 and 31 years old plantations featured the second phase of attack where the infestation is mainly in heavy infestation classes. While the 21 and 22 years old plantations featured later phase of attack when the infestation is more in all the infestation classes.

In Tatwala also the youngest plantation of 17 years had much of its infestation percentage in the low infestation category with A-score (14.9%) and B-score (6.9%). Other older plantations were characterized by higher infestation of later stages (*i.e.* D-score) (Plate 7).

The distribution in 17 year old plantation indicated the initial phase of attack while that in 30, 31 and 37 year old plantations it showed the second phase of attack. The 33 and 35 year old plantations featured the later phase of attack by the borer.



Plate 6: A 'D-score' tree in a heavily infested plantation in Gunjavathi.



Plate 7: A 'D-score' tree in a heavily infested plantation in Tatwala.

4.1.1.1. Estimated mean infestation and variance

As shown in Table 4, the estimated mean for total infestation was higher in Gunjavathi (0.3575) than Tatwala (0.3254). The estimated mean for low level of infestation (A-score) was equal in both the localities. For moderate level of infestation (B-score) it was higher in Tatwala (0.0940) as compared to Gunjavathi (0.0788). For heavy infestation (C and D scores) Gunjavathi recorded higher estimated mean (0.1977) when compared to Tatwala (0.1642).

The estimated variance for total infestation was higher in Gunjavathi (0.00263) followed by Tatwala (0.00111). The estimated variance for low level of infestation (A-score) was higher in Tatwala (0.00057) compared to Gunjavathi (0.00021). For moderate level of infestation (B-score) it was higher in Tatwala (0.00043) as compared to that in Gunjavathi (0.00040). For heavy infestation (C and D scores) Gunjavathi recorded higher estimated variance (0.00074) when compared to Tatwala (0.00061).

Plantations at Gunjavathi showed higher infestation than that at Tatwala, as well as heavy infestation category than Tatwala. Plantations in Gunjavathi differ more for infestation status than Tatwala.

4.1.1.2. Binomial distribution

As shown in Table 5, the probability of getting one tree with low infestation was higher (0.3108) for Gunjavathi plantations. Interestingly for Tatwala plantations there is a higher probability of getting moderate infestation (0.3042) than lower infestation (0.2627). Further, in Gunjavathi plantations, the expected probability of getting 2 and 3 heavily infested tree is higher than that for only 1 tree. Except this,

Table 4: Estimated mean and variance of infestation by *A. cadambae* in two localities surveyed.

Locality	Infestation category	Estimated mean infestation	Estimated variance of infestation
Gunjavathi	Total	0.3575	0.00263
	Low-A	0.0672	0.00021
	Moderate-B	0.0788	0.00040
	Heavy-C&D	0.1977	0.00074
Tatwala	Total	0.3254	0.00111
	Low-A	0.0672	0.00057
	Moderate-B	0.0940	0.00043
	Heavy-C&D	0.1642	0.00061

Table 5: Expected probability of infested trees occurring under economic damage categories for a sample of 10 trees.

Locality	Infestation category	No. of infested trees occurring				
		1	2	3	4	5
Gunjavathi	Low (A)	0.3108	0.1165	0.0392	0.0057	0.0008
	Moderate (B)	0.3137	0.1389	0.0464	0.0114	0.002
	Heavy (C&D)	0.1783	0.2269	0.2095	0.1085	0.0469
Tatwala	Low (A)	0.2627	0.1145	0.0412	0.0112	0.0021
	Moderate (B)	0.3253	0.1721	0.063	0.0162	0.0031
	Heavy (C&D)	0.3042	0.2548	0.1458	0.0606	0.0188

there was a monotonic decrease in the probability of getting more number of infested trees in all infestation categories as expected.

4.1.2. Distribution pattern of infested trees in plantations

The pattern of distribution of health scores in heavily infested, moderately infested, and sparsely infested plantations are depicted in Fig 7, 8 and 9 respectively.

As shown in Table 6, around almost every subject tree and at every distance, there was a higher probability of occurrence of healthy tree (H). However, there was greater tendency of getting trees with B, C and D scores around subject tree of the same category. For instance, at 2m distance, the probability of getting B score besides B; C score besides C and D score besides D was 34, 30 and 35 respectively.

As shown in Table 7, around almost every subject tree and at every distance, there was a higher probability of occurrence of healthy tree (H). But, this was higher than in heavily infested plantations. However, the tendency of getting trees with B, C and D scores around subject tree of the same category reduced as compared to heavily infested plantation. For instance, at 2m distance, the probability of getting B score besides B; C score besides C and D score besides D was 22, 23 and 25 respectively.

As shown in Table 8, the infested trees did not show any pattern of establishment. The occurrence of healthy trees was almost equal at all distances from the subject trees.

The plantations with heavily and moderately infested levels thus feature a distinct patchy form of infested trees. While the patches in heavily infested plantations are as large as 6 m radius, those in moderately infested plantations the patches are rather small (up to 4 m radius). The occurrence of heavily infested trees

Fig 7: Spatial distribution pattern of health scores in heavily infested plantation.

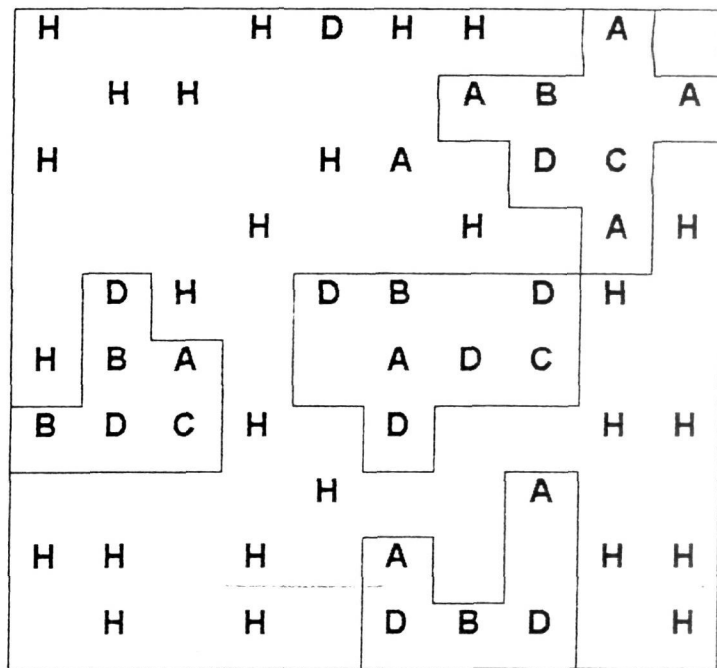


Fig 8: Spatial distribution pattern of health scores in moderately infested plantation.

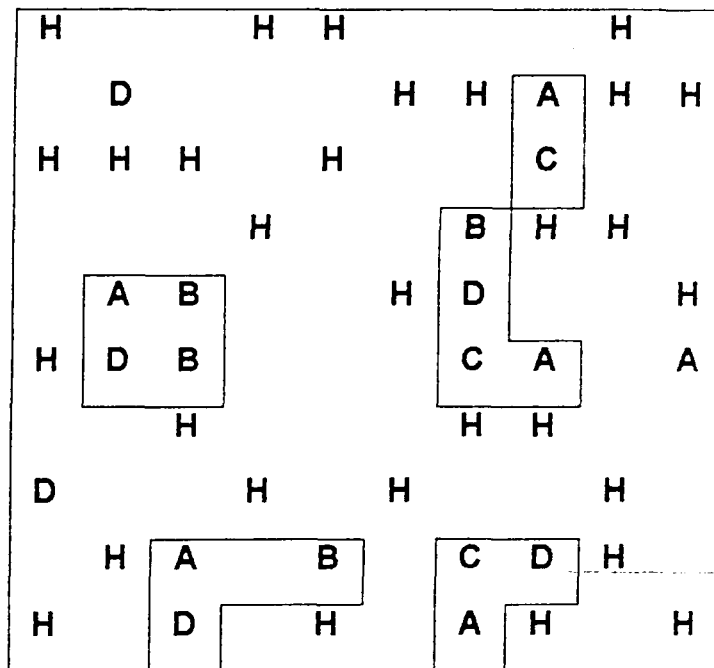


Fig 9: Spatial distribution pattern of health scores in sparsely infested plantation.

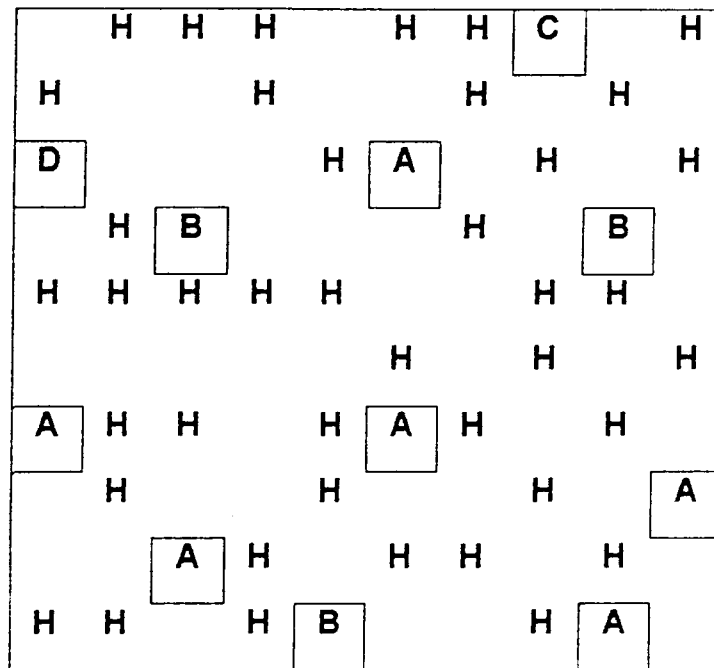


Table 6: Percentage occurrence of trees with different health scores around a subject tree at various distances in heavily infested plantations.

Distance	Subject tree	Per cent occurrence of health scores near the subject tree				
		H	A	B	C	D
2 m	A	49	31	10	5	5
	B	31	11	34	11	13
	C	28	7	14	30	21
	D	27	6	10	22	35
4 m	A	56	5	8	19	12
	B	43	8	11	15	23
	C	42	10	14	20	14
	D	38	11	22	17	12
6 m	A	60	5	7	11	17
	B	57	10	8	14	11
	C	58	13	18	7	4
	D	54	21	13	7	5

Table 7: Percentage occurrence of trees with different health scores around a subject tree at various distances in moderately infested plantations.

Distance	Subject tree	Per cent occurrence of health scores near the subject tree				
		H	A	B	C	D
2 m	A	58	17	10	8	7
	B	52	13	22	8	5
	C	44	6	10	23	17
	D	41	7	9	18	25
4 m	A	63	6	14	8	9
	B	58	8	10	13	11
	C	52	11	18	13	6
	D	48	20	11	8	13
6 m	A	70	8	7	11	4
	B	68	9	12	6	5
	C	63	16	10	7	4
	D	65	13	7	9	6

Table 8: Percentage occurrence of trees with different health scores around a subject tree at various distances in sparsely infested plantations.

Distance	Subject tree	Per cent occurrence of health scores near the subject tree				
		H	A	B	C	D
2 m	A	73	15	9	2	1
	B	68	16	10	4	2
	C	63	10	14	7	6
	D	70	7	10	5	8
4 m	A	80	10	7	2	1
	B	74	14	8	2	2
	C	68	16	8	5	3
	D	64	10	14	7	5
6 m	A	86	8	4	1	1
	B	83	9	2	3	3
	C	80	12	6	1	1
	D	72	15	6	7	0

near heavily infested trees is more and trees with initial attack borer the infestation patches. This is an indication that heavily infested trees are centers of spread of infestation to surrounding healthy trees.

4.1.3. Vertical distribution of trunk borer infestation

Observations on the number of trunk borer holes per tree at different heights of the main trunk are presented in Table 9 for various infestation scores. Results revealed that the maximum number of holes in all the infestation category congregated at 1-2 m height of the main trunk in the trees with maximum of 58.4 holes in D-score and minimum of 2.2 in A-score trees. In case of C and D score trees, the main trunk showed holes even up to 3 m. This was evident from the observations where the distribution of holes was almost similar in all the heights of the main trunk. In case of A and B-score trees there was sparse distribution of holes over the main trunk with more occurrence at 1-2 m height.

4.1.3.1. Occurrence of infestation on susceptible portions of the trunk

The results on the occurrence of borer holes on different susceptible portions of the stem are presented in the Table 10. The results indicated that the occurrence of borer holes was highest at base of coppice shoots/branches in A-score trees (65%) followed by B-score trees (54%). Maximum holes were located at bark damage or callus formation sites in case of C-score (83%) and D-score (90%).

4.1.4. Temporal distribution pattern in affected plantations

In order to understand the spread of infestation over time a study was conducted in affected plantations in both the localities namely Gunjavathi and Tatwala. The number of trees belonging to various infestation scores in all the

Table 9: Vertical distribution of borer holes in trees with various infestation scores.

Height of the main trunk	Average number of borer holes			
	A	B	C	D
0-1m	1.2	3.2	11.2	34.8
1-2m	2.2	8.4	18.4	58.4
2-3m	0.8	4.4	12.8	32.2

Table 10: Frequency of occurrence of infestation at different susceptible portions of the tree.

Infestation category	Occurrence of borer tunnels (%)	
	Base of coppice shoots/branches	Damaged bark/callus formation
A	65	35
B	54	46
C	17	83
D	10	90

selected plantations for temporal studies before the study started (July 2000) and after the study (July 2001) are given in Table 11 and 12.

The number of trees in each infestation scores and the subsequent numbers in bi-monthly observations are presented to know the crucial months of infestation spread. In both the localities the new recruits were added to the existing ones was found to be mainly in the months of July to November. This was due to the emergence of new adults in the months of April and May. This gave rise to new brood in the subsequent months whose successful establishment on tree trunks was visible in the months of July to November.

4.1.4.1. Annual Progression rate of infestation

The annual rates of progression in different infestation scores in both the localities and given in Table 13 and 14 and depicted in Fig-10. Results indicated that the infestation was in progress in both the localities. All the plantations under study showed an increase in infestation but differed with respect to the category of infestation.

In Gunjavathi the plantation with low infestation (Estd. 1980) featured only 10.64% of A-score class, 6.38% of B-score class and did not contain C & D scores. By the end of the study there was an increase of 2.13%, 2.13% and 1.06% in A, B & C respectively ending at 12.77%, 8.51% and 1.06% of A, B & C-score classes respectively in the plantation. D scores did not add up to the infestation level.

The plantation with moderate to heavy infestation (Estd. 1978) had 4.2%, 7.0%, 5.6% and 8.4% of A, B, C and D scores respectively, which ended at 5.6%, 11.2%, 6.99% and 9.1% of A, B, C and D respectively. Thus an increase of 1.4%, 4.2%, 1.39% and 0.7% in A, B, C and D-scores.

Table 11: Temporal distribution pattern of *A. cadambae* in plantations at Gunjavathi in the year 2000-2001.

Month of observation	Year of establishment											
	1980				1978				1979			
	No. of trees infested				No. of trees infested				No. of trees infested			
	A	B	C	D	A	B	C	D	A	B	C	D
July 2000	10	6	0	0	6	10	8	12	14	14	8	16
September	11	7	1	0	7	14	9	13	15	15	9	17
November	12	8	1	0	7	14	9	13	15	15	9	17
January 2001	12	8	1	0	7	14	9	13	15	15	9	17
March	12	8	1	0	7	14	9	13	15	15	9	17
May	12	8	1	0	7	14	9	13	15	15	9	17
July	12	8	1	0	8	16	10	13	16	17	10	17

Table 12: Temporal distribution pattern of *A. cadambae* in plantations at Tatwala in the year 2000-2001.

Month of observation	Year of establishment											
	1980				1978				1979			
	No. of trees infested				No. of trees infested				No. of trees infested			
	A	B	C	D	A	B	C	D	A	B	C	D
July 2000	14	8	4	4	6	14	6	12	10	8	6	8
September	15	9	4	5	7	15	7	13	11	10	7	8
November	15	10	4	5	7	16	7	13	11	10	7	8
January 2001	15	10	4	5	7	16	7	13	11	10	7	8
March	15	10	4	5	7	16	7	13	11	10	7	8
May	15	10	4	5	7	16	7	13	11	10	7	8
July	16	11	5	5	8	19	8	13	12	11	8	9

Table 13: Annual progression rate of trunk borer infestation in Gunjavathi plantations.

Locality	Age of plantations																							
	1980						1978						1979											
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D								
Gunjavathi	2	2	1	0	2	6	2	1	2	3	2	1	2.13	2.13	1.06	0.0	1.4	4.2	1.39	0.7	1.84	2.76	1.83	0.92
No. of new recruits													Low	Mode-rate	Heavy	Low	Mode-rate	Heavy	Low	Mode-rate	Heavy	Low	Mode-rate	Heavy
Progression rate (%)	2.13	2.13	1.06	0.0	1.4	4.2	1.39	0.7	1.84	2.76	1.83	0.92	2.13	2.13	1.06	1.4	4.2	2.09	1.84	2.76	2.75			
Progression of economic damage categories													2.13	2.13	1.06	1.4	4.2	2.09	1.84	2.76	2.75			
Total (%)	5.32						7.69						7.35											

Table 14: Annual progression rate of trunk borer infestation in Tatwala plantations.

Locality	Age of plantations																							
	1980						1978						1979											
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D								
Gunjavathi	2	3	1	1	2	5	2	1	2	3	2	1	1.79	2.68	0.89	0.89	1.7	4.24	1.7	0.85	1.91	2.86	1.91	0.95
No. of new recruits													Low	Mode-rate	Heavy	Low	Mode-rate	Heavy	Low	Mode-rate	Heavy	Low	Mode-rate	Heavy
Progression rate (%)	1.79	2.68	0.89	0.89	1.7	4.24	1.7	0.85	1.91	2.86	1.91	0.95	1.79	2.68	0.89	1.7	4.24	2.55	1.91	2.86	2.86	2.86		
Progression of economic damage categories													1.79	2.68	0.89	1.7	4.24	2.55	1.91	2.86	2.86			
Total (%)	6.25						8.49						7.63											

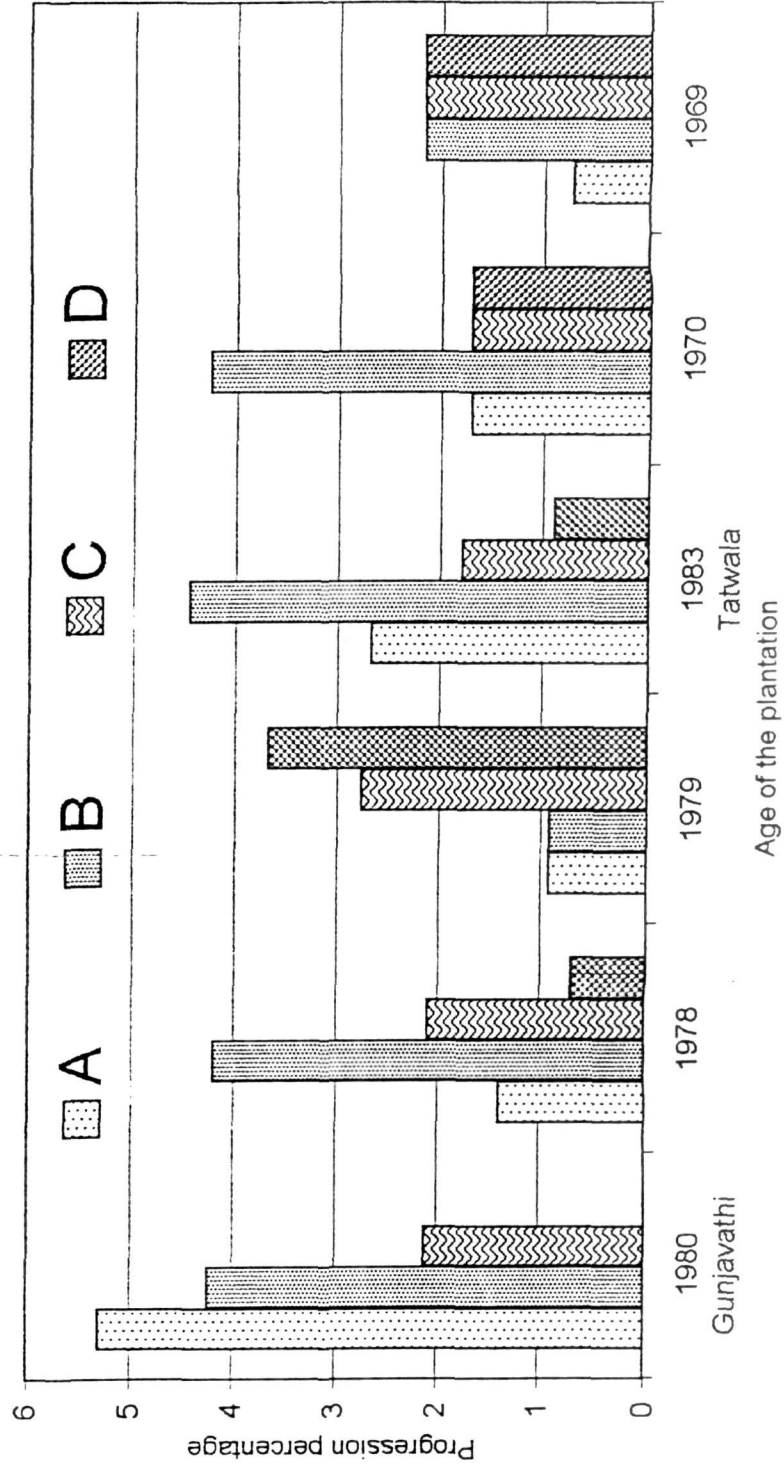


Fig 10: Annual progression rate of infestation of *A. cadambae* on different plantations of teak at Gunjavathi and Tatwala

The plantation with heavy infestation (Estd. 1979) featured 12.84%, 12.84%, 7.34% and 14.67% of A, B, C and D scores respectively. At the end of the study there was an increase of 1.84%, 2.76%, 1.83% and 0.92% in A, B, C and D-scores respectively ending at 14.68%, 15.6%, 9.17% and 15.59% in A, B, C and D-scores respectively.

In Tatwala, the plantation with low infestation (Estd. 1983) had 12.5% of A-score, 7.14% of B-score, 3.57% of C-score and 3.57% of D-score trees. By the end of the study there was an increase of 1.79%, 2.68%, 0.89% and 0.89% in A, B, C & D-scores respectively ending at 14.29%, 9.82%, 4.46% and 4.46% of A, B, C & D-scores respectively.

The plantation with moderate to heavy infestation (Estd. 1970) had 5.08%, 11.86%, 5.08% and 10.17% of A, B, C and D-scores respectively, which ended at 6.78%, 16.1%, 6.78% and 11.02% of A, B, C and D-scores respectively. Thus an increase of 1.7%, 4.24%, 1.7% and 0.85% in A, B, C and D-scores respectively.

The plantation with heavy infestation (Estd. 1969) featured 9.52%, 7.62%, 5.71% and 7.62% of A, B, C and D-scores respectively. At the end of the study there was an increase of 1.91%, 2.86%, 1.91% and 0.95% in A, B, C and D-scores respectively ending at 11.43%, 10.48%, 7.62% and 8.57% for A, B, C and D-scores respectively.

The number of trees acquiring fresh infestation was highest moderate to heavily infested plantations both in Gunjavathi (7.69%) and Tatwala (8.49%). Heavily infested plantations in Gunjavathi recorded an increase of 7.35% and that in Tatwala it was 7.63%. The lowest rise in infestation percentage was in plantations with low level of infestation i.e. 5.32% in Gunjavathi and 6.25% in Tatwala.

In case of economic damage categories highest rise in heavy infestation (C & D scores) was found to be in heavily infested plantations in both Gunjavathi (2.75%) and Tatwala (2.86%).

In moderate to heavily infested plantations in both the localities, there was similar pattern of increase in economic damage categories. Moderate infestation (B-score) registered the highest increase of 4.2% in Gunjavathi and 4.24% in Tatwala.

In low infestation plantation of Gunjavathi there was highest rise (2.13%) in both low and moderate level of infestation (A and B-scores), where as there was highest rise (2.68%) in moderate infestation (B-score).

4.1.5. Pre-disposing factors

Observations on the occurrence of various disturbance factors in the plantations has been presented in the Table 15. In both the localities more number of teak plantations were located near human habitation or agricultural fields. With human habitation there was the effect of cattle menace in the plantations. Fire was most evident in both the localities as the teak plantations are not kept in good hygiene with lot of weed growth and influence of firewood collectors or any type of human activities in the plantations accidentally giving rise to fire incidence especially in summer months.

According to Principal Component Analysis for disturbance factors the plantations segregated into 5 distinct groups as shown in Fig-11.

The results indicated that the group consisting of G2 and G4 plantations had the highest infestation percentage (48.28%). It also carried highest percentage of trees suffering economic damage (26.45%). The group was equally influenced by all the disturbance factors.

Table 15: Characterization of disturbance parameters and infestation status of teak plantations at Gunjavathi and Tatwala.

Sl No.	Year of Planting	Planta-tion code	Propor-tion of affected trees	Disturbance factors			
				Human habitation	Cattle grazing	Fire incidence	Agricultural fields
Gunjavathi							
1	1980	G1	0.199	Present	Present	Absent	Present
2	1979	G2	0.489	Present	Present	Present	Present
3	1978	G3	0.396	Absent	Present	Present	Absent
4	1977	G4	0.570	Present	Present	Present	Absent
5	1973	G5	0.474	Absent	Present	Absent	Absent
6	1969	G6	0.212	Absent	Absent	Absent	Absent
Tatwala							
1	1983	T1	0.387	Absent	Present	Present	Present
2	1970	T2	0.383	Absent	Absent	Present	Absent
3	1969	T3	0.385	Absent	Present	Present	Absent
4	1967	T4	0.183	Present	Present	Absent	Absent
5	1963	T5	0.207	Present	Present	Absent	Absent
6	1965	T6	0.483	Present	Absent	Present	Present

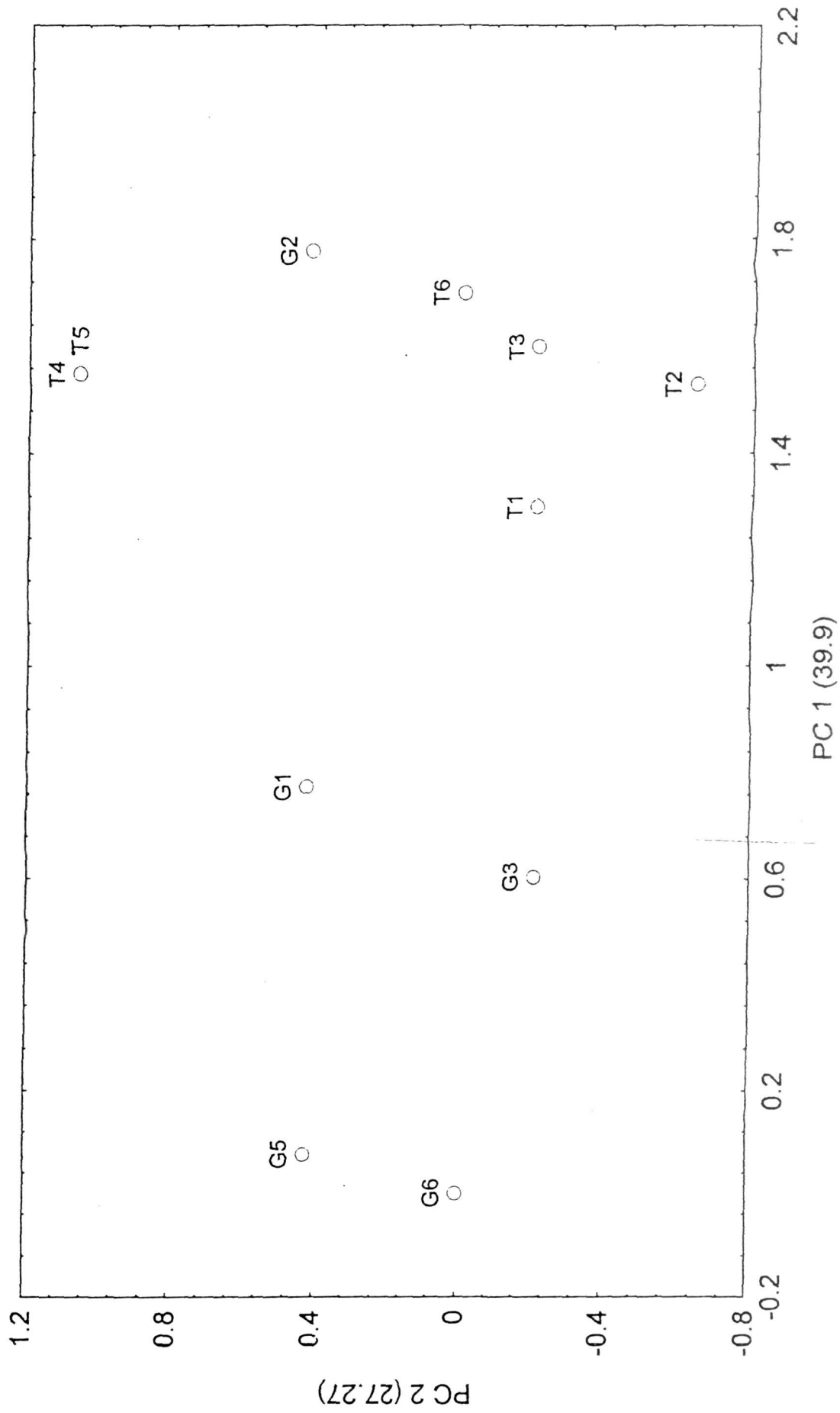


Fig 11: Configuration of plantations based on PCA for disturbance factors.
 The values in the parentheses indicate the per cent variation explained by PC1 and PC2. (G=Gunjavathi; T= Tatwala)

The second group consisted of T1, T2, T3 and T6 plantations. This group also featured a high rate of infestation (36.54%). There was comparatively low percentage of trees suffering economic damage levels (15.93%). The group had more fire incidence among disturbance factors.

The third group consisted of G1 and G3 plantations with a mean infestation percentage of 29.75% and the least percentage of trees suffering economic damage (9.87%). Both the plantations had influence of grazing while G3 had been subjected to fire G1 was close to agricultural fields.

The fourth group consisting of G5 and G6 had a mean infestation of 29.35%, but had a high percentage of trees suffering economic damage 22.8%. The last group consisting of T4 and T5 plantations had only 24.54% infestation but had a high percentage of trees suffering economic damage 17.39%. This group had plantations equally influenced by both human settlements and grazing.

Overall the occurrence of agricultural fields and fire in plantations had higher influence than grazing and human settlements.

4.1.5.1. Infestation pattern near disturbed locations

Observations made on extent of infestation near disturbed areas or portion of plantations bordering agricultural fields, human habitation and along road is given in Table 16. The trees nearer to all these locations were highly infested. The highest occurrence of C and D-score around human habitation i.e., 21.4% and 32.75% respectively. Similar pattern of infestation was also noticed for locations such as agricultural fields. Thus, a uniform pattern of distribution of highly infested trees near these locations could be seen in the transition portions of the plantations between the plantation interior and the disturbing location.

The infestation level on the trees at different distances viz. 20m, 40m, 60m, 80m and 100m perpendicular to the road are given in Table 17 and pattern of infestation at different distances are presented in Fig-12. Results showed that the occurrence of C and D-score trees was maximum 15.5% and 44.6% respectively within 20m from road (Plate 8), which decreased as the distance increase from the road before becoming similar to the overall infestation prevailing in the plantation. At the same time the occurrence of healthy trees increased with increasing distance from the road.

4.1.6. Age of the tree and trunk borer incidence

The correlation worked out between age of the plantation and borer infestation are presented in Table 18. It was found to be non-significant for all the health scores except for A score.

4.2. Assessment of economic loss due to teak trunk borer, record of alternate host and natural enemy complex of teak trunk borer

4.2.1.1. Impact of borer infestation on growth parameters

The results on the comparison of growth parameters of borer infested trees as compared to healthy trees are presented in Table 19 and the reduction in volume of infested trees compared to healthy trees are depicted in Fig-13. As per the results the reduction in volume of infested trees was highest in younger plantations when compared to older plantations. The per cent reduction in volume ranged from 4.88 to 15.60 for A scores, 9.65 to 36.36 in B scores, 15.9 to 46.79 in C scores and 21.20 to 56.88 in D scores. Overall the per cent reduction was more evident in younger plantations gradually decreasing in case of older ones.

Table 16: Distribution of infestation scores near various disturbance factors.

Disturbance factors	Trees in various health scores (%)				
	H	A	B	C	D
Agricultural fields	32.5	5.75	10.95	26	24.8
Human habitation	28.25	8.4	9.2	21.4	32.75
Along the road	29.45	9.9	16.45	21.35	31.45

Table 17: Distribution of infestation scores at varying distances perpendicular to road.

Distance from the road (m)	No. of trees sampled	Occurrence under various health scores (%)				
		H	A	B	C	D
0-20	88	18.2	9.6	12.4	15.5	44.6
21-40	82	27.5	15.75	13.75	15.2	27.5
41-60	85	38.25	26.75	10.4	9.45	15.15
61-80	90	49.95	23.6	11.75	5.4	9.2

Table 18: Correlation between age of the plantations and trunk borer incidence.

Correlation	Correlation coefficient (r)	<0.01
Age Vs % infestation	-0.129	NS
Age Vs %H	-0.129	NS
Age Vs %A	-0.763	**
Age Vs %B	-0.420	NS
Age Vs %C	-0.342	NS
Age Vs %D	-0.384	NS

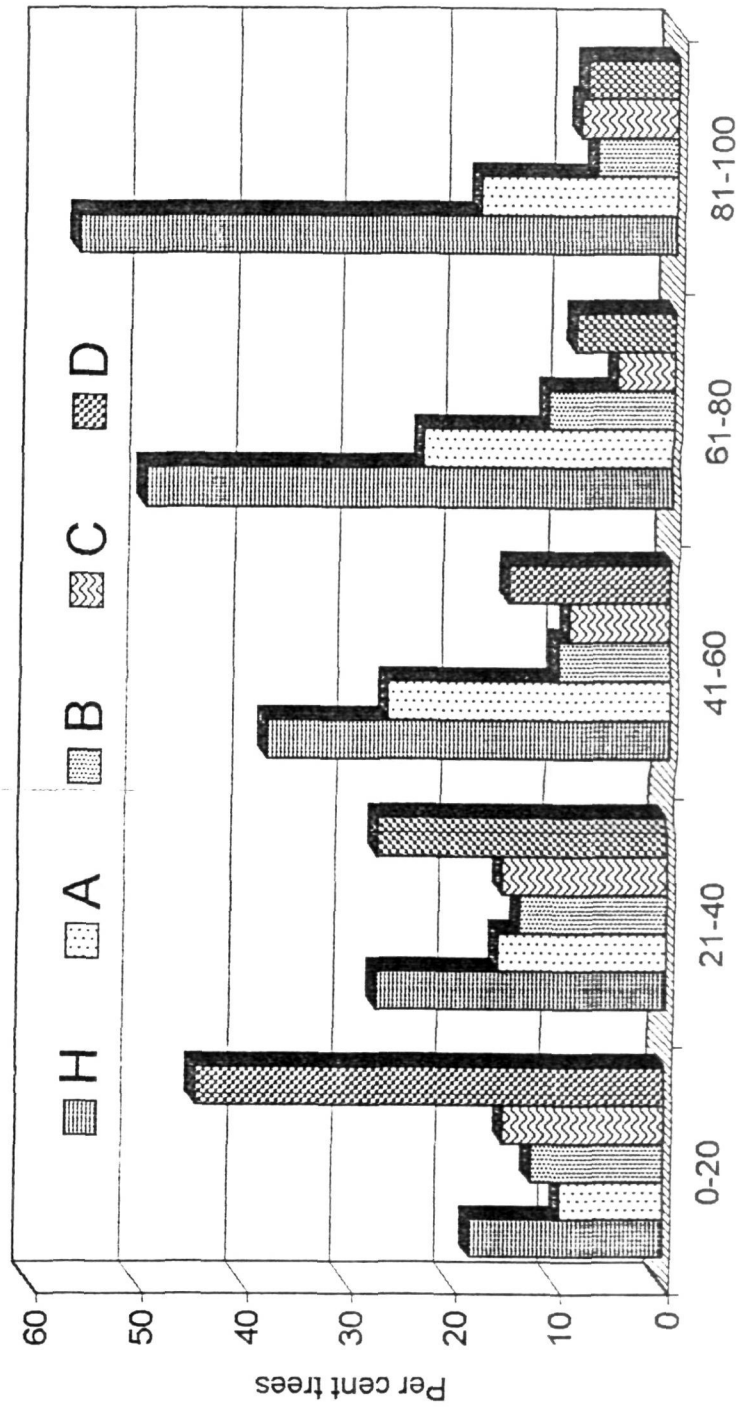


Fig 12: Per cent distribution of trees belonging to different infestation scores into classes of distance perpendicular to the road.

Table 19: Percent reduction in volume of infested trees as compared to healthy trees.

Age of plantation (Yr)	Average volume of trees (m ³) under different infestation categories				Percent reduction in volume of infested trees as compared to healthy trees				
	H	A	B	C	D	A	B	C	D
17	0.109	0.092	0.07	0.058	0.047	15.60	35.78	46.79	56.88
20	0.099	0.084	0.063	N.A	N.A	15.15	36.36	N.A	N.A
21	0.137	0.118	0.109	0.092	0.077	13.87	20.44	32.85	43.80
22	0.118	0.101	0.092	0.077	0.07	14.41	22.03	34.75	40.68
23	0.157	0.137	0.126	0.109	0.092	12.74	19.75	30.57	41.40
27	0.188	0.169	0.154	0.136	0.12	10.11	18.09	27.66	36.17
30	0.224	0.204	0.188	0.169	0.156	8.93	16.07	24.55	30.36
31	0.35	0.328	0.307	0.287	0.267	6.29	12.29	18.00	23.71
33	0.415	0.392	0.371	0.349	0.327	5.54	10.60	15.90	21.20
35	0.717	0.682	0.594	0.539	0.487	4.88	17.15	24.83	32.08
37	0.539	0.511	0.487	0.439	0.415	5.19	9.65	18.55	23.01

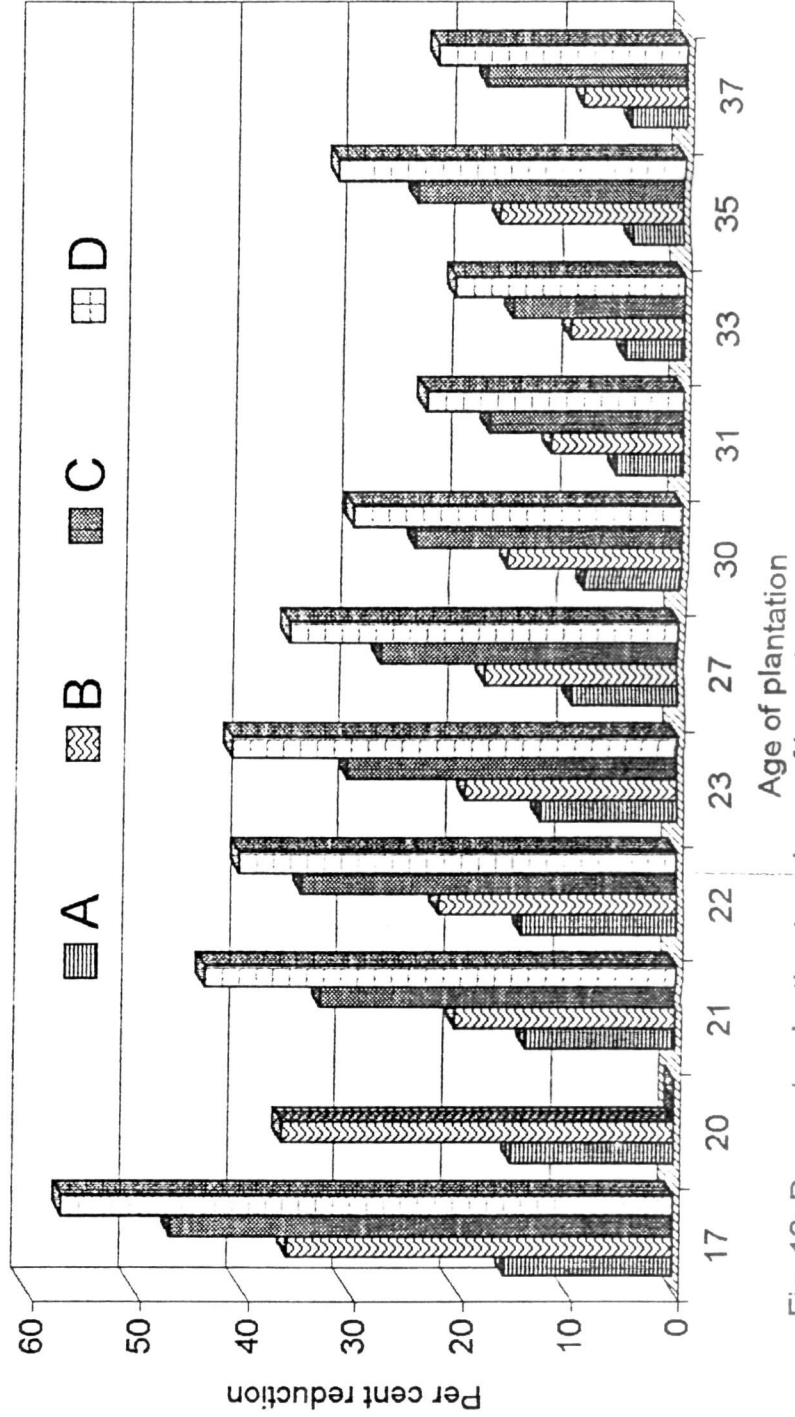


Fig 13: Per cent reduction in volume of borer infested trees as compared to healthy trees

4.2.1.2. Impact of borer infestation on economic value of teak

The impact of the borer infestation on trees leading to economic loss in teak was estimated by comparative value method. The borer damage status of the logs and the value fetched by the auctioned lots and poles in comparison with that of the undamaged ones are presented in Table 20. The borer damaged logs (Plate 9) though bigger in length and girth did find themselves only in the D-class which is the lowest class of timber in quality. The logs which were free from borer damage did fetch a value as high as Rs. 44,332/m³ compared to only Rs. 23,192/m³ for logs highly ridden with borer damage. A reduction of nearly 48% in economic value. The same case of reduction in economic value of borer infested logs as compared to good quality ones was evident in all length and girth classes. Sometimes logs very good length and girth did not bidders primarily due to borer damage. The only use of these borer infested was for handicrafts and tool handles. Even the poles ridden with the borer tunnels fetched poor value Rs. 210/pole as against good poles Rs. 750 to Rs. 950/pole, a reduction of more than 75%.

4.2.2. Alternate host

In the present study, teak trunk borer was noticed to attack *Butea monosperma* which grew naturally in infested teak plantations and also in adjacent places (Plate 10 and 11). This was the first incidence of *A. cadambae* attacking *B. monosperma* other than teak. It was remarkable to find that the trees of *B. monosperma* which were close to biotic influence like agricultural fields and roads were heavily attacked.

Table 20: Economic value reduction in trunk borer affected teak logs/poles sold in Govt. timber depot.

Logs			
Sl. No.	Quality class	Value/m ³ (Rs)	Remark
1	Cic	37,500	No borer damage
2	Cid	29,048	No borer damage
3	CIIb	44,332	No borer damage
4	CIId	24,926	No borer damage
5	CIVb	38,745	No borer damage
6	Dib	16,092	D score logs
7	DIIb	23,192	D score log
8	DIIc	No bid	D&C score logs
9	DIIIb	11,463	D score logs
10	DIIIc	18,518	D score logs
11	DIId	No bid	D&C score logs
12	DIId	16,803	B&C score logs
13	Rej	4,651	D score logs
Poles			
Sl. No.	Quality class	Value/pole (Rs)	Remark
1	IaSPL	750	No borer damage
2	Ia	952	No borer damage
3	Ia	210	Borer damaged
4	Ia	210	Borer damaged

Timber grading followed for teak logs in Govt. timber depots.

Quality class	Length class	Girth class
A - Best quality logs, Superior in all respects	I - > 6 m	a - > 2 m
B - Very good and free from defects	II - 5-6 m	b - 1.5-2 m
C - Medium to good quality, free from major defects	III - 4-5 m	c - 1-1.5 m
D - Poor quality, unsound logs with all or any of the major defects	IV - 3-4 m	d - < 1 m
	V - 2-3 m	
	VI - < 3 m	



Plate 8: A road-side teak tree heavily ridden with trunk borer holes.



Plate 9: A teak log in a timber depot heavily ridden with borer holes.



Plate 10: View of *Butea monosperma* tree infested by teak trunk borer.



Plate 11: Close-up view of infested trunk portion of *Butea monosperma*.

4.2.3. Natural Enemy Complex of Teak trunk borer

4.2.3.1. Bird predators

Only the woodpeckers were found to be actively digging into the stems of infested teak trees and extracting the larvae for feeding. Altogether three different species coming under the Order: Piciformes and Family: Picidae were identified as preying on trunk borer larvae. They are

- 1) Heartspotted Woodpecker – *Hemicircus canente* Lesson.
- 2) Lesser Golden Backed Woodpecker – *Dinopium benghalense* Linnaeus
- 3) Great Black Woodpecker – *Dryocopus javensis* Horsfield.

The characteristic feature of woodpecker predation *i.e.*, a rectangular excavation as deep as 2-3 inches (Plate 12) was followed as an indication of wood pecker trials. Heartspotted woodpecker though could not dig into the hard stem portion it was found to search and extract borer larvae from axils of primary and secondary branches. Whereas the lesser golden backed woodpecker was found to be most able in searching, extracting and feeding on borer larvae (Plate 13). The woodpecker trials for extracting the larvae were mostly found on the main trunk. Thus their feeding was most effective in controlling the larval population. The great black woodpecker was found rarely but found to prey similarly as compared to golden backed woodpecker.

Studies on the locations of woodpecker trials of all the infestation categories revealed that the birds tended to prey on borer larvae right from the base of the trunk extending to more than half the height of the trees. The trials were highly concentrated at 1 to 3m height of the trees, which is highly ridden with borer tunnels. The results on the predatory pattern of the woodpeckers on trees under various



Plate 12 and 13: A Golden backed Woodpecker working into borer holes and typical woodpecker trials found on heavily infested trees.

infestation categories are presented in Table 21. The per cent predation was highest in D score class (19.44%) followed by C score class (15.85%), B score class (9.38%) and A score class (8.57%).

4.2.3.2. Predatory/Parasitic insects

No parasitic or predatory insects are collected during the study period.

4.2.3.3. Microbial pathogens

Neither diseased larvae nor pupae were encountered during the study period.

4.3. Identification of resistant clones to teak trunk borer and biochemical studies

4.3.1. Characterization of clones in Clonal seed orchard

The results of the characterization of teak clones in Manchikeri and Karka CSOs with respect to trunk borer incidence is presented in Table 22 and 23. The percentage of infestation in Manchikeri CSO ranged from 0 to 11.12% whereas in Karka it ranged from 0 to 52%.

In Manchikeri, CSO 11 out of 24 clones were found to be infestation free. Interestingly, only 2 clones (MyHaV1 and MyHaV4) from Northern provenance, one clone (MySA1) from Central provenance and all the clones from Southern provenance (MyHuT1, MyHuT2, MyHuT3, MyHuT6, MyHuT7, MyHuT8 and MyMK3) were completely free from borer attack. These clones thus showed apparent resistance to teak trunk borer.

Only 13 clones in this CSO showed infestation by trunk borer and most of them having only initial level of infestation. Highest infestation in Manchikeri CSO was found in Clone No. 9 (MyHV5) (11.12%) (Plate 15) followed by Clone No. 33 (MyHaK2) (10.53%) and Clone No. 4 (MyHD4) (10.42%). Clone No. 4 and Clone No.

Table 21: Incidence of Woodpecker trials in various infestation categories.

Infestation category	No. of trunk borer holes observed	No. of holes worked by woodpecker	Predation (%)
A	70	6	8.57
B	320	30	9.38
C	492	78	15.85
D	720	140	19.44

Table 22: Characterization of clones with respect to teak trunk borer in CSO, Manchikeri.

Sl. No	Clone I. D.	Clone No.	Origin of the Clone (Division)	Origin of the clone (Range)	Infestation (%)	Percentage of trees affected under various health score class				
						H	A	B	C	D
1	MyHD1	1	Haliyal	Barchi	3.12	96.88	3.12	0.00	0.00	0.00
2	MyHD2	2	Haliyal	Barchi	7.50	92.50	2.50	5.00	0.00	0.00
3	MyHD3	3	Haliyal	Barchi	2.94	97.06	2.94	0.00	0.00	0.00
4	MyHD4	4	Haliyal	Barchi	10.42	89.58	4.17	2.08	0.00	4.17
5	MyHV1	5	Haliyal	Gundvamoli	0.00	100.0	0.00	0.00	0.00	0.00
6	MyHV3	7	Haliyal	Gundvamoli	4.17	95.83	0.00	0.00	0.00	4.17
7	MyHV4	8	Haliyal	Gundvamoli	0.00	100.0	0.00	0.00	0.00	0.00
8	MyHV5	9	Haliyal	Virnoli	11.12	88.88	0.00	11.12	0.00	0.00
9	MyHV6	10	Haliyal	Virnoli	4.76	95.24	4.76	0.00	0.00	0.00
10	MyHV7	11	Haliyal	Virnoli	5.88	94.12	5.88	0.00	0.00	0.00
11	MyHaK1	32	Haliyal	Kulgi	2.13	97.87	0.00	0.00	0.00	2.13
12	MyHaK2	33	Haliyal	Kulgi	10.53	89.47	7.89	2.63	0.00	0.00

Contd....

Sl. No	Clone I. D.	Clone No.	Origin of the clone (Division)	Origin of the clone (Range)	Infestation (%)	Percentage of trees affected under various score class				
						H	A	B	C	D
13	MyHaK3	34	Haliyal	Kulgi	8.33	91.67	2.78	5.56	0.00	0.00
14	MySA1	13	Shimoga	Arasake	0.00	100.0	0.00	0.00	0.00	0.00
15	MySA2	14	Shimoga	Arasake	0.00	100.0	0.00	0.00	0.00	0.00
16	MySS2	16	Shimoga	Sacrebyle	8.70	91.30	8.70	0.00	0.00	0.00
17	MyBL1	31	Lakkavalli	Bhadravathi	5.00	95.00	0.00	5.00	0.00	0.00
18	MyHuT1	17	Hunsur	Thithimathi	0.00	100.0	0.00	0.00	0.00	0.00
19	MyHuT2	18	Hunsur	Thithimathi	0.00	100.0	0.00	0.00	0.00	0.00
20	MyHuT3	19	Hunsur	Thithimathi	0.00	100.0	0.00	0.00	0.00	0.00
21	MyHuT6	22	Hunsur	Thithimathi	0.00	100.0	0.00	0.00	0.00	0.00
22	MyHuT7	23	Hunsur	Thithimathi	0.00	100.0	0.00	0.00	0.00	0.00
23	MyHuT8	24	Hunsur	Thithimathi	0.00	100.0	0.00	0.00	0.00	0.00
24	MyMK3	37	Mysore	Kakanakote	0.00	100.0	0.00	0.00	0.00	0.00

Table 23: Characterization of clones with respect to teak trunk borer in CSO, Karka.

Sl. No	Clone I. D.	Clone No.	Origin of the clone (Division)	Origin of the clone (Range)	Infestation (%)	Percentage of trees affected under various score class				
						H	A	B	C	D
1	MyHaD1	1	Haliyal	Barchi	23.08	76.92	11.54	7.69	3.84	0.00
2	MyHaD2	2	Haliyal	Barchi	52.00	48.00	12.00	8.00	16.00	16.00
3	MyHaD3	3	Haliyal	Barchi	15.38	84.62	7.69	0.00	3.84	3.84
4	MyHaD4	4	Haliyal	Barchi	0.00	100.0	0.00	0.00	0.00	0.00
5	MyHaV1	5	Haliyal	Gundvamoli	7.69	92.31	7.69	0.00	0.00	0.00
6	MyHaV2	6	Haliyal	Gundvamoli	30.77	69.23	11.54	7.69	7.69	3.84
7	MyHaV3	7	Haliyal	Gundvamoli	19.23	80.77	7.69	3.84	7.69	0.00
8	MyHaV4	8	Haliyal	Gundvamoli	11.54	88.46	7.69	3.84	0.00	0.00
9	MyHaV5	9	Haliyal	Virnoli	52.00	48.00	20.00	16.00	8.00	8.00
10	MyHaV6	10	Haliyal	Virnoli	26.92	73.08	15.38	7.69	3.84	0.00
11	MyHaV7	11	Haliyal	Virnoli	24.00	76.00	24.00	0.00	0.00	0.00
12	MyHaV8	12	Haliyal	Virnoli	4.35	95.65	0.00	0.00	0.00	4.34

Contd....

Sl. No	Clone I. D.	Clone No.	Origin of the clone (Division)	Origin of the clone (Range)	Infestation (%)	Percentage of trees affected under various score class				
						H	A	B	C	D
13	MySA1	13	Shimoga	Arasake	12.00	88.00	0.00	12.00	0.00	0.00
14	MySA2	14	Shimoga	Arasake	51.85	48.15	11.11	11.11	25.93	3.70
15	MySS1	15	Shimoga	Sacrebyle	19.23	80.77	11.54	7.69	0.00	0.00
16	MySS2	16	Shimoga	Sacrebyle	25.93	74.07	18.52	0.00	3.70	3.70
17	MyHuT1	17	Hunsur	Thithimatti	12.50	87.50	8.33	4.17	0.00	0.00
18	MyHuT2	18	Hunsur	Thithimatti	4.17	95.83	4.17	0.00	0.00	0.00
19	MyHuT3	19	Hunsur	Thithimatti	14.81	85.19	14.81	0.00	0.00	0.00
20	MyHuT4	20	Hunsur	Thithimatti	12.00	88.00	4.00	4.00	0.00	4.00
21	MyHuT5	21	Hunsur	Thithimatti	20.00	80.00	12.00	4.00	4.00	0.00
22	MyHuT6	22	Hunsur	Thithimatti	20.83	79.17	8.33	12.50	0.00	0.00
23	MyHuT7	23	Hunsur	Thithimatti	17.39	82.61	8.70	8.69	0.00	0.00
24	MyHuT8	24	Hunsur	Thithimatti	33.33	66.67	8.33	16.70	0.00	8.33

7 (MyHV3) had highest infestation in D-score (4.17% each) followed by Clone No. 32 (MyHaK1) (2.13%). Whereas Clone No. 9 had highest infestation in B-score (11.12%) followed by Clone No. 34 (MyHaK3) (5.56%), No. 31 (MyBL1) and No. 2 (MyHD2) (5% each). In case of A-score Clone No. 16 (MySS2) had highest infestation (8.7%) closely followed by clone No. 33 with 7.89%. From the observation there were no C-score trees and only few trees with D-score infestation. Overall it was found that only Clone No. 4 (Plate 14) had the heaviest infestation.

In Karka CSO almost all the clones except Clone No. 4 (MyHaD4) showed attack by the trunk borer in one or the infestation scores. Though all the clones except clone No. 4 showed incidence of borer attack some of the clones based on minimum infestation did show apparent resistance to the borer. Three clones (MyHuT2, MyHuT3 and MyHuT4) from Southern provenance, 3 clones (MyHaV1, MyHaV4 and MyHaV8) from Northern provenance featured light infestation. All the clones from Central provenance were moderately infested by the borer.

Highest infestation was found in Clone No. 2 (MyHaD2) (Plate 16) and Clone No. 9 (MyHaV5) (52% each) closely followed by Clone No. 14 (MySA2) (Plate 17) (51.85%) and Clone No. 24 (MyHuT8) (33.33%). Clone No. 2 had the highest infestation (16%) in D-score followed by Clone No. 24 with 8.33% and Clone No. 9 with 8%. Altogether 9 clones in the CSO featured in D-score with varying percentage. In case of C-score Clone No. 14 featured highest infestation (25.93%) followed by Clone No. 2 with 16% and Clone No. 9 having 8%. Altogether 10 clones were found to be in the C-score infestation with varying percentages. In B-score highest infestation was noticed in Clone No. 24 (16.7%) closely followed by Clone No. 9 (16%) and Clone No. 22 (MyHuT6) (12.5%). Altogether 16 clones featured in B-



Plate 14: Clone No.4 in CSO, Manchikeri heavily infested by teak trunk borer.



Plate 15: Clone No.9 in CSO, Manchikeri heavily infested by teak trunk borer.



Plate 16: Clone No.2 in CSO, Karka heavily infested by teak trunk borer.



Plate 17: Clone No.14 in CSO, Karka heavily infested by teak trunk borer.

score. Except 3 clones all other clones featured in A-score infestation. Highest infestation in A-score was recorded in Clone No. 11 (MyHaV7) (24%) followed by Clone No. 9 (20%) and Clone No. 16 (MySS2) (18.52%).

4.3.2. Performance of teak clones by provenance

Results on performance of teak clones by provenance with respect to trunk borer infestation are presented in Table 24 and 25. The results indicated that in CSO, Manchikeri there was significant difference among provenances in relation to trunk borer infestation and also for A-score infestation. Whereas in case of CSO, Karka there was no significant difference among provenances for either trunk borer infestation or for any of the infestation scores.

4.3.3. Influence of locality on the infestation levels in both the CSO

Results on the influence of locality on the infestation levels is presented in Table 26. According to the results there was significant difference between Manchikeri and Karka for percent infestation and all the infestation scores except for D-score.

4.3.4. Interaction of locality and provenance on trunk borer infestation

Results on the interaction of locality and provenance on trunk borer infestation in both the CSOs are presented in the Table 27. Clones common in both the CSOs were considered for knowing the influence of interaction of locality and provenance on incidence of trunk borer. Altogether 19 clones with 10 clones representing Northern Provenance, 3 clones from Central Provenance and 6 from Southern Provenance were analysed for their borer infestation status. According to two-way ANOVA the influence of provenances on the infestation status of the clones was non-significant at 5% confidence level whereas at a higher levels (10%) confidence limit

Table 24: Variation for teak trunk borer infestation among clones originated from different provenance in Manchikeri CSO.

Provenance	n	Infestation (%)	H	A	B	C	D
North	13	12.03 ± 6.5	77.95 ± 6.5	7.2 ± 6.2	4.9 ± 6.9	0	2.46 ± 4.8
Central	4	7.52 ± 8.90	82.48 ± 8.9	4.29 ± 8.6	3.23 ± 6.5	0	0
South	7	0	90	0	0	0	0
F Value		9.4	9.42	3.6	1.63	-	1.4
Probability		<0.01	<0.01	<0.04	NS	-	NS
C.V.		76.15	7.21	123.9	181.1	-	269

Table 25: Variation for teak trunk borer infestation among clones originated from different provenance in Karka CSO.

Provenance	n	Infestation (%)	H	A	B	C	D
North	12	26.04 ± 13.3	63.98 ± 13.3	16.94 ± 8.9	9.24 ± 8.7	8.83 ± 8.5	6.2 ± 8.3
Central	4	30.64 ± 10.9	59.28 ± 11.1	16.19 ± 11.1	13.96 ± 9.5	10.42 ± 14.4	5.55 ± 6.4
South	8	23.63 ± 6.70	66.37 ± 6.70	16.71 ± 3.7	12.12 ± 8.8	1.44 ± 4.08	3.54 ± 6.7
F Value		0.53	0.54	0.013	0.53	2.27	0.305
Probability		NS	NS	NS	NS	NS	NS
C.V.		42.80	17.45	48.06	80.50	128.6	145

Table 26: Location wise variation in infestation per cent of trunk borer.

Locality	Infestation (%)	H	A	B	C	D
Manchikeri	6.82±7.7	83.17±7.8	4.46±6.2	2.14±5.4	0	1.25±3.7
Karka	26.6±11.7	63.38±11.7	17.39±7.5	10.97±9.3	6.9±9.4	4.75±7.6
F Value	37.9	37.7	33.4	12.81	10.06	3.22
Probability	<0.01	<0.01	<0.01	<0.01	<0.01	NS
C.V.	59.2	13.5	63.11	115.9	193	200

Table 27: Interaction between locality and provenance in infestation status of different clones.

Provenance	n	Manchikeri (% infestation)	Karka (% infestation)	Sources of variation	F-value	Probability
North	10	11.27	28.42	Provenances (P)	2.94	NS
Central	3	5.88	32.18	Locality (L)	47.38	**
South	6	0	23.70	Interaction (P x L)	0.80	NS

n = Number of clones common to Manchikeri and Karka

there appears to be a significant influence. The influence of locality on the infestation status of the clones was significant at 5% confidence level. And for the interaction of locality and provenance there was no significant effect.

4.3.5. Bark thickness and trunk borer infestation

The results on the correlation between bark thickness and trunk borer infestation are presented in Table 28. In both the CSOs the correlation was insignificant while there was negative correlation when it was obtained for 29 clones combined over localities.

The performances of clones for bark thickness based on provenance from which they represented are given in Table 29. For the variation in bark thickness the clones from the Northern provenance had thinner bark whereas those from the Southern provenance had the thickest bark in both the CSOs. The Central provenance had moderate thickness in both the CSOs. The variation in bark thickness in CSO, Manchikeri was non-significant between the provenances whereas it was significant in CSO, Karka.

4.3.6. Bio-chemical analysis of bark contents of resistant/susceptible clones

In order to know the bio-chemical basis if any behind the resistance/susceptibility of teak clones to trunk borer infestation different contents like poly-phenols, proteins, total sugars and moisture present in bark samples were estimated by different methods as mentioned in Material and Methods. The results of one-way ANOVA are presented in Table 30. As per the results, there was significant difference for poly-phenols between healthy and infested category. The healthy category had the highest amount of poly-phenols (5.24%) when compared to infested category

Table 28: Correlation between clonal bark thickness in relation to trunk borer infestation in CSO, Manchikeri and CSO, Karka.

CSO, Manchikeri				CSO, Karka			
Prove-nance	Clone No.	Borer infesta-tion (%)	Bark thickness (cm)	Prove-nance	Clone No.	Borer infesta-tion (%)	Bark thickness (cm)
N	1	3.12	1.70 ± 0.12	N	1	23.08	1.51 ± 0.10
N	2	7.50	1.63 ± 0.14	N	2	52.00	1.12 ± 0.16
N	3	2.94	1.50 ± 0.10	N	3	15.38	1.46 ± 0.20
N	4	10.42	1.60 ± 0.16	N	4	0.00	1.55 ± 0.16
N	5	0.00	1.93 ± 0.18	N	5	7.69	1.48 ± 0.15
N	7	4.17	1.43 ± 0.16	N	6	30.77	1.52 ± 0.13
N	8	0.00	1.83 ± 0.14	N	7	19.23	1.87 ± 0.14
N	9	11.12	1.77 ± 0.18	N	8	11.54	1.51 ± 0.18
N	10	4.76	1.73 ± 0.20	N	9	52.00	1.58 ± 0.12
N	11	5.88	1.83 ± 0.10	N	10	26.92	1.68 ± 0.10
N	32	2.13	1.57 ± 0.16	N	11	24.00	1.64 ± 0.18
N	33	10.53	1.57 ± 0.10	N	12	4.35	1.62 ± 0.18
N	34	8.33	1.37 ± 0.18	C	13	12.00	1.81 ± 0.13
C	13	0.00	1.73 ± 0.16	C	14	51.85	1.64 ± 0.12
C	14	0.00	1.77 ± 0.18	C	15	19.23	1.60 ± 0.16
C	16	8.70	1.90 ± 0.20	C	16	25.93	1.84 ± 0.17
C	31	5.00	1.43 ± 0.14	S	17	12.50	1.76 ± 0.19
S	17	0.00	1.73 ± 0.16	S	18	4.17	1.81 ± 0.10
S	18	0.00	1.70 ± 0.14	S	19	14.81	1.60 ± 0.19
S	19	0.00	2.10 ± 0.12	S	20	12.00	1.70 ± 0.16
S	22	0.00	1.73 ± 0.10	S	21	20.00	1.76 ± 0.13
S	23	0.00	2.17 ± 0.18	S	22	20.83	1.81 ± 0.19
S	24	0.00	1.80 ± 0.12	S	23	17.39	1.96 ± 0.20
S	37	0.00	1.57 ± 0.12	S	24	33.33	1.63 ± 0.18
r = - 0.366 Probability = 0.07				r = - 0.328 Probability = 0.11			
Combined over localities							
r = - 0.331 Probability = 0.02							
Regression equation: y = 53.28-24.35x							

Table 29: Variation for bark thickness by provenance in Manchikeri and Karka CSO.

CSO, Manchikeri			CSO, Karka		
Provenance	n	Bark thickness (cm)	Provenance	n	Bark thickness (cm)
North	13	1.65±0.17	North	12	1.55±0.17
Central	4	1.71±0.20	Central	4	1.72±0.12
South	7	1.83±0.22	South	8	1.75±0.11
F Value		2.03	F Value		5.34
Probability		NS	Probability		<0.01
C.V.		10.99	C.V.		9.09

Table 30: One-way ANOVA for bio-chemical contents between susceptible and resistant clones.

Resistance category	Clone No.	Polyphenols (%)	Proteins (%)	Total sugars (%)	Moisture (%)
		Mean \pm S.D	Mean \pm S.D	Mean \pm S.D	Mean \pm S.D
Infested	2	3.60 \pm 0.19	8.40 \pm 0.40	14.50 \pm 0.35	68.16 \pm 0.76
	6	3.96 \pm 0.19	10.18 \pm 0.33	15.60 \pm 0.64	59.70 \pm 1.25
	9	4.40 \pm 0.20	13.25 \pm 0.41	18.93 \pm 0.92	70.10 \pm 0.85
	14	3.70 \pm 0.15	10.32 \pm 0.43	17.60 \pm 0.85	64.80 \pm 0.60
	Mean	3.92 \pm 0.36	10.54 \pm 2.01	16.66 \pm 1.99	65.69 \pm 4.55
Healthy	4	4.46 \pm 0.20	12.55 \pm 0.39	14.05 \pm 0.92	70.30 \pm 1.15
	5	6.45 \pm 0.18	8.97 \pm 0.25	12.66 \pm 1.27	69.50 \pm 1.00
	18	5.65 \pm 0.18	11.00 \pm 0.21	16.80 \pm 1.06	66.20 \pm 0.90
	19	4.38 \pm 0.19	9.65 \pm 0.23	11.05 \pm 0.49	66.60 \pm 0.87
	Mean	5.24 \pm 1.0	10.54 \pm 1.58	13.64 \pm 2.44	68.15 \pm 2.05
F-value		21.79	0.00	12.67	3.89
Probability		<0.01	NS	<0.01	NS
C.V.		15.16%	15.70%	13.74%	4.88%

(3.92%). For total sugars also there was significant difference between healthy and infested category with healthy category having lower (13.64%) than that in infested category (16.66%). For proteins and moisture content the healthy and infested category did not differ significantly.

According to two-way ANOVA as presented in Table 31 all the clones differed significantly with respect to bio-chemical contents of bark. Clone No. 5 had the highest percentage of poly-phenol content (6.45%) as compared to Clone No. 2 (3.6%). For proteins Clone No. 9 had the highest content (13.25%) while the least was 8.4% in Clone No. 2. Clone No. 9 also had the highest amount of total sugars (18.93%) while the least was in Clone No. 19 (11.05%). Moisture content did not vary much between the clones with maximum in Clone No. 4 (70.3%) while the least was found in Clone No. 6 (59.7%).

Table 31: Two-way ANOVA for bio-chemical contents for different clones.

Resistance category	Clone No.	Polyphenols (%)	Proteins (%)	Total sugars (%)	Moisture (%)
		Mean \pm S.D	Mean \pm S.D	Mean \pm S.D	Mean \pm S.D
Infested	2	3.60 \pm 0.19	8.40 \pm 0.40	14.50 \pm 0.35	68.16 \pm 0.76
	6	3.96 \pm 0.19	10.18 \pm 0.33	15.60 \pm 0.64	59.70 \pm 1.25
	9	4.40 \pm 0.20	13.25 \pm 0.41	18.93 \pm 0.92	70.10 \pm 0.85
	14	3.70 \pm 0.15	10.32 \pm 0.43	17.60 \pm 0.85	64.80 \pm 0.60
Healthy	4	4.46 \pm 0.20	12.55 \pm 0.39	14.05 \pm 0.92	70.30 \pm 1.15
	5	6.45 \pm 0.18	8.97 \pm 0.25	12.66 \pm 1.27	69.50 \pm 1.00
	18	5.65 \pm 0.18	11.00 \pm 0.21	16.80 \pm 1.06	66.20 \pm 0.90
	19	4.38 \pm 0.19	9.65 \pm 0.23	11.05 \pm 0.49	66.60 \pm 0.87
Mean		4.58 \pm 0.99	10.54 \pm 1.67	15.15 \pm 2.61	66.92 \pm 3.52
SEM \pm		0.028	0.124	0.319	1.228
C.D at 5%		0.134	0.286	0.461	0.905

Discussion

V. DISCUSSION

Teak has been prime plantation species, because of the commercial value of its excellent timber. Teak plantations have become important to help fill the gap between demand and supply of teakwood. It is attacked by a large number of insect fauna and suffers assiduously from insect damage. Among 8 species of trunk borers on teak, borer *A. cadambae* has posed serious concern as the value of the timber reaching the depots is reduced due to irregular holes and hollowness in the heartwood.

Any effort to protect the valuable heartwood of teak is worthwhile in the present scenario. Recently, the trunk borer has attained major pest status in teak growing areas of Karnataka especially the heavy rainfall tracts. The studies on the ecology and management aspect of this pest is very scanty especially in Karnataka. Therefore extensive investigations on the extent of spread, quantum of damage and population build up are necessary in formulating effective control measures. Presently no control operations are practiced, therefore a more detailed basic study of the pest and its ecosystem is necessary to plan out integrated method of management.

Studies on the insect ecology would help in formulating silvicultural operations for its control. Basic information on the economic losses caused by the borer would figure out the seriousness of damage. Survey on its alternate hosts and natural enemy complex could throw some light on the horizontal expansions of the host range and the possibility of using bio-control measures against the borer. Further more a preliminary information on the borer infestation of already chosen plus trees of teak in different CSOs would increase the possibility of identification of host

resistance as a tool in management of the pest. Hence the present study was taken with the following objectives:

1. To study the distribution pattern of teak trunk borer in space and time among the plantations of Uttara Kannada.
2. To assess economic losses due to teak trunk borer and to record alternate hosts and natural enemy complex of teak trunk borer.
3. To identify resistant clones of teak in different clonal seed orchards and study their bio-chemical characters.

The results obtained on these aspects are discussed in the following pages.

Distribution of teak trunk borer infestation in plantations

The borer infestation per cent in both the localities studied was uniform at around 32-35%. This may be due to occurrence of these localities in the same bio-climatic zone experiencing high rainfall and temperature. Similar observations were brought out by Lingappa (1991) that the occurrence of the pest is more in heavy rainfall tracts covering Yellapur, Dandeli and Honnavar taluks of Uttara Kannada district.

However, plantations at Gunjavathi had more number of heavily infested trees than those at Tatwala (19.77% Vs 16.43%).

These results are similar to the findings of Prasad Kumar *et al.* (2001) where they reported heavy infestation in Mundgod and Yellapur compared to other taluks of Uttara Kannada.

In both the localities, age-specific infestation level was observed. For instance, at Gunjavathi 20 year old plantation showed initial phase of attack, while older plantations (23, 27 and 31 year old) showed advanced phase. Similarly at Tatwala

also advanced phase of attack was observed in older aged plantations, while 17 year old plantation had only initial phase of attack. Further, the localities also differed with respect to the stages of infestation at plantation level.

The proportion of affected trees was more or less equal in both the localities and the localities differed with respect to potential risk in the future. The estimated mean for 'moderate level of infestation' (B-score) being high in Tatwala (0.0940) and higher for 'heavy infestation' (C and D-score) in Gunjavathi (0.1977) indicated that the pest pressure in Gunjavathi was higher and that the locality faced higher threat to trees being heavily attacked and leading to subsequent death. In general, the estimates of low and moderate level infestation were associated with lower variance indicating a greater certainty of attack. While that of heavy infestation suggested more uncertainty (*i.e.* more variance).

Since it was found that the probability of occurrence of low and moderately infested trees to be higher in Tatwala than in Gunjavathi suggests that the locality had higher incidence of trees suffering initial attack. Whereas in Gunjavathi which had the probability higher for heavily infested trees, shows that the locality had higher incidence of trees suffering economic damage levels. Hence plantations in Gunjavathi would be more prone to the spread of borer attack if left with heavily infested trees. These data form a crucial input for the intensive management of these plantations, 'selective felling' among the highly infested plantations in-fact may be important in checking the further spread of the infestation. We are aware of any study, which focuses on these issues in teak.

Distribution pattern of infested teak trees

There exists a definite pattern in establishment of the borer infestation within plantation and its gradual spread. Infested trees occur in distinct patch with the heavily infested (C and D-score) trees being their centers. The patches are as large as 6m radius and showed a tendency of increasing diameter since there was minimum occurrence of healthy trees even at distances of 6m. Low infestation trees exist on the periphery of these infested patches and the occurrence of a healthy tree within these patches being minimum shows the severity of the infestation. Hence the infestation in such plantations does show a transitory/intermediary stage when infested patches are large and about to coalesce, making the infested trees to be uniformly distributed in the entire plantation.

The above said pattern is further supported by the fact that the infested patches were more distinct among heavily infested plantations than among low infested plantations. This exemplified by the fact that among heavily infested plantations, there was a more tendency of infested trees being neighbours when compared to low infested plantations.

In sparsely infested plantation the infested trees did not show any pattern of establishment. The occurrence of mostly healthy ones or A-score trees near all infestation scores shows that the infested trees were randomly distributed in the entire plantation.

This study on spatial dispersion of the infested tree to understand the establishment pattern of the borer is perhaps, first of its kind to be followed in Karnataka.

These findings are in line with the findings of Mathew *et al.* (1989) who has reported from Kerala, that teak trunk borer infestation is usually confined to distinct patches in initial and second stage of infestation, while during the last phase, the infestation spreads at a faster pace leading to a more or less uniform distribution of attack in the plantation.

Similarly, Shibata *et al.* (1995) also reported a contagious distribution of the adults of Sugi borer *Semanotus japonicus* infesting *Cryptomeria japonica*. The distribution pattern of the adults reflected the contagious distribution of the damaged trees in the stand. He Fangliang and Alfavor (1997) reported spatial attack pattern of White pine weevil *Pissodes strobi* on white pine *Picea glauca* to be aggregated in the initial stages of the infestation, changing to random when the infestation reached intermediate levels but regular over the entire plantation when the infestation was at its peak.

Vertical distribution of borer infestation

From the results on the density and distribution of borer holes on trees under different infestation categories, it can be ascertained that the most frequently attacked and susceptible portion of the main trunk was from 1 to 2m height of the tree. Especially in case of C and D-score trees distribution of holes was noticed even up to 3m but much densely at 1 to 2m height of the trunk. This portion is highly susceptible to damage by human activities and fire incidence thus giving ample opportunity for the borer to establish itself. Once established, the previous infestation predisposed the same portion to be re-infested in the subsequent years. These findings are in line with the findings of Prasad Kumar *et al.* (2001) who recorded more number of holes per tree at 2m height.

Similar observations on the borer distribution on the tree trunks have been reported by Donley and Rast (1984) who found that nearly 75% of the attack by red oak borer *Enaphalodes rufulus* in the economically important basal 4m trunk portion in all size classes of trees. Mishra *et al.* (1985) reported stem borer *Aristobia horridula* attack on *Dalbergia sissoo* up to 4m from ground level. Harman and Harman (1990) also found that attacks of locust borer *Megacyllene robiniae* on black locust trees *Robinea pseudoacacia* were concentrated higher on the main stems and the upper extremities of trees were lightly attacked.

The trees with initial attack showed maximum borer holes at the base of coppice shoots or branches indicating that the initial attack starts mainly at these susceptible locations. In case of C and D-score trees the holes being highly frequent at damaged bark or callus formations shows that the initial attack has stimulated the trees to respond to the borer feeding with callus development. The callus making the bark distorted may be an ideal site for the borer to oviposit. This supplemented by bark damage by human and woodpecker makes the bark more susceptible to the borer infestation.

Temporal distribution of borer infestation

Most of the fresh infestation in both the localities occurred in the months of July to September. The new larval infestation during September 2000 could be the brood produced by the adults that might have emerged during May & June, 2000. The eventual establishment and feeding could only be visibly noticed in July 2000 and extending up to September 2000. Later on the new infestation could not be found in any of the season till May 2001. The new infestation in July 2001 could be the brood produced by the adults that emerged during May and June 2001.

Therefore it can be ascertained that the insect had overlapping generations throughout the year and reached their peak emergence during *pre-monsoon season*. Hence the plantations acquired new infestation specifically in the months of July to September. Routine silvicultural thinning during the month of November and later should include those trees highly infested by the borer so that most of the individuals in the new generation are removed from the existing borer population. further, if light-trap method to control the pest is to be tried, the best months are May and June.

These findings are in conformity with the findings of Nair (1987) who reported that most of the *cossids* adult female emerged in late April to May in the *pre monsoon* season in Kerala. Lingappa *et al.* (1991) also reported that adult females emerged more in numbers during the monsoon and emergence of first brood in the second week of July.

The occurrence of a single peak in present investigation may be due to the occurrence of only the south-west monsoon season bring some wetness to the soil necessary for pupation. The moth emergence through-out the year with two distinct peaks one in May to June and another in September to October as reported by Mathew (1990) may be attributed to the occurrence of both south-west and north-east monsoon in Kerala.

In both the localities the highest rate of progression of infestation is noticed in moderate to heavily infested plantations. This may be because of rapid transformation of A-score trees to B-score in a single year. Thus a regular rise in moderate level of infestation is noticed. In heavily infested plantations of both the localities there is almost equal rise in levels of moderate and heavily infested trees. This may possibly be due to large number of heavily infested trees building up the

pest pressure and subsequent re-infestation of already infested trees. In low infestation plantations of both the localities there is higher rise in low and moderate levels of infestation than in heavy infestation category. This can be attributed to the slow build up of infested trees and most of them acquiring initial attack before they get re-infested over the years.

These findings are in line with the findings of Mathew (1990) who reported the rate of progression of infestation of 14.5% in heavily infested plantation.

Pre-disposing factors

In both the localities most of the teak plantations existed near human habitation or agricultural fields. Fire and cattle menace a resultant of human interference in the forest were found to be the most evident factors in both the localities.

Principal Component Analysis grouped the plantations based on the influence of the disturbance factors. 'Grazing' and 'fire' in plantations were found to be most influential factors for infestations per cent. Almost all the plantations under study were under influence of one or the other kind of disturbance. Therefore both the localities contained huge number of heavily infested trees in the plantations and the existence of large teak plantations spread over a large area could also be a possibility for build up of higher pest pressure in the region.

These findings are in line with those investigated by Beeson (1941) who reported attack of this borer is limited to trees of poor quality that are unhealthy due to frequent fires in the plantations. Lingappa *et al.* (1991) also reported the incidence of the borer to be more in fire-affected areas and where cattle keepers are dwelling.

Mathew (1990) reported plantations adjacent to human habitations and trees growing in such areas are more susceptible to the attack by the borer.

Other workers also indicated fire as one of the pre disposing factors for borer attack such as Liu *et al.* (1989) reporting outbreak of stem borers on *Pinus sylvestris* and *Larix olgensis* and Ranjeet Singh *et al.* (2001) reporting heavy infestation by Coleopteran borers on Chir Pine (*Pinus roxburghii*).

The results on the distribution of infestation around disturbed locations revealed that the portion of the plantations that is very close to these locations contained several affected trees. The highest occurrence of C and D-score around human habitation indicated that the plantations suffer considerable stress especially due to human activities which involves frequent lopping of branches or plucking of leaves for various purposes. Similar heavy infestation near agricultural fields may be due to people lopping branches for minor utilization in cultivation practices or fencing the trees to save the crops from wild animals. Along the road where the trees are exposed to continued damage by passersby are also heavily infested. Thus a uniform pattern of distribution of highly infested trees near these locations could be seen in the transition portions of the plantations between the plantation interior and the disturbing location.

Reduction in heavily infested trees as we move from close to road to the interior of the plantation simultaneously the occurrence of healthy trees increased at increasing distance points out that the effect of busy road is considerable up to the extent of 20-40m from the road. Hence roadside trees/plantations were vulnerable to trunk borer infestation.

These findings are in confirmity with the observations of Mathew (1990) and Prasad Kumar *et al.* (2001) who reported that roadside teak trees suffer heavy trunk borer infestation. Rossem *et al.* (1978) has reported that increasing damage to roadside trees by *Cossus cossus* were attributed to damage to trunk by mowing machines.

Correlation between age of tree and borer infestation

The correlation coefficient between age and infestation categories was positive but weak. This may be possibly due to the narrow range of plantation ages (17 to 37 years) and all of them being in the most susceptible age to be infested by the borer. And also due to all the plantations were almost heavily attacked without showing much difference in distribution of infestation. The infestation status in the plantation being a result of other factors like disturbance and stocking levels and the pest pressure existing in the plantations therefore cannot be solely attributed to only the age of plantation.

These results are in partial accordance with the findings of Mathew (1990) who has reported based on the survey carried out in plantations of differing age groups which ranged from 10-56 years that as the age of the plantations increases the proportion of affected trees in the plantations also increased.

Impact of trunk borer infestation on growth parameters

In order to find out the influence of borer infestation on growth parameters, the infested and healthy trees were compared for their GBH and height and contrasted with each other. From the results it was evident that the infested trees showed a remarkable reduction in both GBH and height and subsequently there was reduction in volume. The reduction in volume of infested trees was highest in younger

plantations when compared to older plantations. This may be because the younger plantations suffer greater physiological stress when infested by the borers early in their age. The per cent reduction was less in A and B-score trees when compared to C and D-score trees (per cent reduction). This shows that higher the infestation greater was the its impact on the growth and development of the trees. The per cent reduction in volume ranged from 4.88 to 15.60 for A score, 9.65 to 36.36 in B score. This may be due to the initial attack of the borer being of little significance when the host can tolerate borer infestation to some extent.

The per cent reduction in volume ranged from 15.9 to 46.79 in C scores and 21.20 to 56.88 in D scores. This may be due to the fact that infested trees having suffered constant re-infestation by the borer leading to loss of vigour. The percentage reduction being higher in younger plantations aged when compared to older ones. This may be due to the presence of higher number of weakened trees and also because of trees being attacked early in their age, thus having stunted growth. But in case of older plantations the trees being fewer in number and attacked later in their age could have achieved similar growth and also that the older trees did develop large amount of callus growth. Thus the bark and wood get enlarged and distorted in response to insect feeding. Therefore the infested trees measured more or less equally to healthy ones.

These findings are in line with observations of Beeson (1941) who has reported attack of this borer is limited to trees of poor quality that are unhealthy. Gavioli (1984) also reported that carpenter moth (*Cossus cossus*) usually attacked trees weakened by age or other causes. Fearn (1985) reported that the adult females

of wood moth *Xyleutes liturata* oviposited on genus *Acacia*, and sickly or damaged trees being particularly prone to attack.

Economic loss due to trunk borer infestation

The information gathered on the loss in economic value in timber due to trunk borer damage shows that logs face a loss in economic terms to as high as 48% and the poles to the extent of more than 75%. As per the results on the status of infestation in plantations of both the localities, the proportion of trees in economic damage categories (C and D-scores) was high in almost all the plantations surveyed. This poses a serious threat to the state exchequer in the form of loss in economic value of timber extracted from these plantations. Most of the logs rejected or fetching poor value in the auction was due to deterioration of wood brought about by the borer infestation like strength and working qualities, hence were useless.

These results are in confirmation of the findings of Mathew (1990) who explained that planks sawn from borer damaged have numerous holes and are not cherished for use in building construction, furniture making etc. Mathew and Rugmini (1996) reported that trees very seriously damaged or dead due to infestation constituted 30% in Trichur, 39.6% in Kothamangalam and 32.25% in Nemmara Forest Divisions and that these trees were not useful for any commercial use.

Alternate host of teak trunk borer

The discovery of *Butea monosperma* as a new alternate host to trunk borer points out that trunk borer though confined itself largely to teak as its principal host, it succeeded in spreading to new host species which are naturally growing in the plantations. Similar reports of trunk borer spreading to new species has been reported by Bhandari and Upadhyay (1986) as a pest of tendu (*Diospyros*

melanoxylon) in Madhya Pradesh, Mathew (1990) on *Grewia tiliaefolia* and *Terminalia bellarica* growing naturally in affected teak plantations in Kerala and Prasad Kumar *et al.*, (2001) on *Terminalia tomentosa*. This horizontal expansion of host range by trunk borer has to be viewed seriously by the forest managers.

Natural enemy complex

Few workers have carried out the work on the discovery and application of natural enemies in controlling of teak trunk borer. Mathew (1990); Mathew and Mohamed Ali (1987). In the present investigation only bird predators on teak trunk borer was noticed.

The birds identified were the Heartspotted Woodpecker, the Lesser Golden Backed Woodpecker and Great Black Woodpecker. These findings are in line with the identification of woodpeckers preying on trunk borer by Mathew (1990), where he identified the same species of woodpecker (the lesser golden backed woodpecker) apart from an unidentified barbet to be feeding on the caterpillars after extracting them from the larval tunnels.

In the present study other than that identified by Mathew (1990) another two species of woodpeckers the Great Black Woodpecker and the Heartspotted woodpecker were identified as preying on borer larvae for the first time.

The observations on the number of woodpecker trials per hundred trunk borer tunnels indicated that per cent predation by woodpecker was highest in D-score trees (19.44%) followed by that in C score trees (15.85%). This shows that predation by woodpeckers was more frequent in C and D score trees than in A & B score ones. These results are similar to the findings of Spradberry (1990) who reported predation

of Siricid larvae in coniferous trees by woodpeckers was 28.8% of a total population of 3617 larvae in logs worked by woodpeckers.

But the low rate of predation by woodpeckers might not be a potential control agent against trunk borer larvae looking into the extent of teak plantations and the existing high pest pressure in the localities studies. Human inhabitation's nearer the infested plantation may further exclude the woodpeckers from completely operational.

The non-occurrence of insect predators and parasites during the investigation may be due to rarity of them if present, or because of non-existence due to poor vegetation mixture to shelter a wide diversity of natural enemies in the plantations which could have taken upon the larvae for food or parasitization. It may also be due to camouflaging of egg masses on the trunk and due to inaccessibility of larvae to predatory or parasitic insects. The non-occurrence of diseased larvae may be due to non-prevalence of any disease or due to the inaccessibility of the larvae to the outside since their collection posed a practical problem and heavily infested trees though present could not be split in good numbers in the field due to logistics. This calls for a further intensive study on these issues.

Clonal resistance to trunk borer infestation

In Manchikeri CSO 11 out of 24 clones were found healthy and free from trunk borer attack. Only 2 clones (MyHaV1 and MyHaV4) from Northern provenance, one clone (MySA1) from Central provenance and all the clones (MyHuT1, MyHuT2, MyHuT3, MyHuT6, MyHuT7, MyHuT8 and MyMK3) from Southern provenance were completely free from borer attack. These clones thus showed apparent resistance to

teak trunk borer. Therefore, these clones could have resisted borer attack or may be the phenomenon of escape of attack over the years.

Clone No. 4 and No. 7 only having highest infestation in D-score (4.17% each) followed by Clone No. 32 (2.13%) may be because some of the ramets of these clones might have been under stress and lost vigour either due to re-infestation by borer attack or due to unsuitability of locality. Whereas Clone No. 9 having highest infestation in B-score (11.12%) and in case of A-score clone No. 16 having highest infestation (8.7%) only is a reason that the trees are showing only initial attack and that the percentage of infestation in this category is also negligible as in case of D-score. Only 13 clones in this CSO showing infestation by trunk borer and most of them having only initial level of infestation depicts the status of infestation not to be in a level to put the clones to the real test of resistance.

Since the infestation was still in initial stages in this plantation, the results may be treated as preliminary and only suggestive; further monitoring of the CSO needs to be undertaken.

In Karka CSO almost all the clones except Clone No. 4 showing attack by the trunk borer in one or the infestation scores shows that none of the clones were completely free from attack by the trunk borer. Though all the clones except clone No. 4 (MyHaD4) showed incidence of borer attack some of the clones based on minimum infestation did show apparent resistance to the borer. Three clones (MyHuT2, MyHuT3 and MyHuT4) from Southern provenance, 3 clones (MyHaV1, MyHaV4 and MyHaV8) from Northern provenance featured light infestation. The intensity of borer attack being very low in these clones could be an indication that

they might have resisted borer attack either posing physical hardness to the borer or by chemical defence, the phenomenon of escape of attack being minimum.

Highest infestation in Clone No. 2 and Clone No. 9 (52% each) and in Clone No. 14 (51.85%), Clone No. 24 (33.33%) and the least infestation of only 4.17% in Clones No. 18 shows that there has been a continuous and regular infestation spreading in the entire CSO. Altogether 9 clones in the CSO featuring in D-score and 10 clones found to be in the C-score infestation with varying percentages shows that many of the clones were heavily infested over the years. Clone No. 2 having the highest infestation (16%) in D-score followed by Clone No. 24 with 8.33% and Clone No. 9 with 8%, where as in case of C-score Clone No. 14 featuring highest infestation (25.93%) followed by Clone No. 2 with 16% and Clone No. 9 having 8% shows that these clones have been heavily infested and may be that the clones are not vigorous enough to the borer attack or showing any resistance mechanism to the borer infestation. Clone No. 2, 6, 9 and 14 featuring in all the infestation categories is an indication that these clones might be highly susceptible to borer attack. Whereas Clone No. 4, 5, 11, 18 and 19 having only initial level of infestation may be due to apparent resistance to borer attack or may be due to escape of attack. The possibility of escape is minimum looking to the extent of damage the borer has caused and the presence of it in virtually all the clones. Therefore it can be opined that clones which showed highest infestation and in which most of them are suffering in the severe infestation category as being highly susceptible since only those clones which lack the required vigour and resistance mechanism could be potentially utilised by borers.

These results are in line with the findings of Lindeman (1988) reported that loss of resistance of *Fraxinus pennsylvanica* was indicated by normal larval

development of *Zeuzera pyrina*. Sharma and Bhatia (1996) similarly identified Poplar clones resistant to stem borer *Apriona cinerea* based on observations like minimum attack and maximum tolerance. Wang *et al.* (1998) have also reported that degree of damage caused by *Apriona germari* in 34 *Populus* clones varied considerably between the clones, and that the clones which exhibited an insect free percentage of 7.25%, and infestation index of 11.1-29.5 and insect density of <1.0 head/tree as resistant to the borer.

The infestation status in CSO, Karka depicts a situation as it occurs in a typical teak plantation featuring a number of trees within a small area being infested by trunk borer. Most of the clones being under attack of trunk borer shows that the entire plantation has been under the attack by the insect for quite long and the attack to be uniformly distributed. The clones have been subjected to high pest pressure due to its location in a drier locality as compared to Manchikeri CSO and where large territorial teak plantations highly infested with trunk borer infestation existing in close proximity.

Performance of teak clones by provenance

As per the results the provenances in CSO, Manchikeri had significant difference for trunk borer infestation and for the low levels of infestation (A-score). This may be due to the reason that none of the clones in the southern provenance were infested and completely free from attack of trunk borer. Most of the attack in heavy infestation or in low intensity was found the northern provenance clones and also in very low incidence. There was only light or moderate attack in central provenance. Hence the difference in status of infestation among the provenances though minute was significant.

As per the results the provenances in Karka CSO did not show significant difference for either percentage of infestation or for any of the infestation scores. This may be due to the distribution of infestation among all the provenances being more or less equal which is a result of the representative clones in these provenances being attacked in one or the other infestation score. Most of the heavy infestation did figure in Northern and Central provenances as compared to Southern provenances. Hence provenance did not have an influence in relation to attack by the trunk borer.

Influence of locality on the infestation levels in both the CSO

Both the CSOs differed significantly with respect to trunk borer infestation parameters. This shows that the locality had an influence the status of infestation existing in both the CSOs. This may be because of the pattern of distribution being widespread and higher in CSO, Karka and almost all the clones being attacked various levels of infestation, while in CSO, Manchikeri the infestation being sparse and only a handful of clones suffering in lowest levels of infestation. There may be a difference in exposure of these seed orchard to pest attack or may be the clones are more resistant to borer attack in Manchikeri than Karka.

Interaction of locality and provenance on trunk borer infestation

Overall the influence of locality was found to be stronger than the origin of the clones. While local conditions of Karka favoured a higher infestation level, the same in Manchikeri, CSO was not conducive for infestation. The influence of clonal origin was weak but suggestive of the fact that clones from Southern provenance were better in escaping or resisting the borer attack.

These findings are in line with those of Noh et al. (1992) who reported that Aspen clones (*Populus davidiana*) tolerance to poplar borers was more affected by

environment than by genotype, although there were significant differences among genotypes.

Bark thickness and trunk borer infestation

In both the CSOs the association between bark thickness and infestation was negative but weak, however data pooled over localities indicated a strong negative association between the two. The Northern provenance had thinner bark whereas those from the Southern provenance had thicker bark in both the CSOs and the Central provenance had moderate thickness in both the CSOs. This is an indication that bark thickness character was similar in both the CSOs. The variation in bark thickness in CSO, Manchikeri was non-significant between the provenances whereas significant in CSO, Karka. This may be the influence of a drier locality such as Karka when compared to moister location such as Manchikeri on the thickness of bark. The Northern provenance having thinner bark in Karka might have predisposed most of its clones to borer infestation while the Southern clones with thicker bark could have resisted borer infestation better in Karka specifically and in general in both the localities. This may be the first report in teak which records the correlation of bark thickness of teak and trunk borer infestation. Hence efforts may be made to include 'bark thickness' as one of the factors while selecting plus trees of teak.

Bio-chemical analysis of clones

As per the results, the healthy category had the highest amount of polyphenols (5.24%) when compared to susceptible category (3.92%) but total sugars was lower in healthy infested category (13.64%) compared to infested category (16.66%). Although in case of proteins and moisture content the healthy and infested category did not differ significantly. The difference in terms of phenols and sugar

content signifies that the healthy clones could have resisted borer attack over the years and those clones which are infested would have been highly susceptible to trunk borer attack. The high rate of susceptibility of this category could be attributed to low amounts of phenols (the aromatic compounds which are found to offer resistance) in trees and the higher amounts of sugars pre-disposing the trees to be mostly preferred by the borer, hence prone to regular re-infestation over the years. This study on the chemical basis of the teak clones for trunk borer infestation was the first of its kind to be carried out.

These results are in line with the findings of Jain *et al.* (1999) who reported the degree of resistance/susceptibility of teak resistance towards leaf skeletonizer *Eutectona machaeralis* to be directly correlated with poly-phenol and inversely with the protein contents of clonal leaves. Meshram *et al.* (1999) have similarly reported resistance of *Dalbergia sissoo* seedlings against defoliator *Plecoptera reflexa* to be related to high polyphenol content (6.24%) and low protein content (9.54%) in the leaves.

The work of Sun Li Yan and Han Yifen (1995) on resistance of *Populus deltoides* varieties to *Batocera horsfieldi* was also related to phenol and tannin contents of young shoots and bark rather than nutrient components.

Implication for management:

- 1) The existing plantations in both the localities are highly infested with trunk borer.

Therefore there is a need to bring down the pest population to avoid rapid transformation of infested trees ultimately leading to death of the trees. Hence all plantations badly affected by *A. cadambae* may be clearfelled since their

existence will only result in the deterioration of the affected trees spreading infestation to the healthy ones.

- 2) The affected trees and infested patches within plantations of low or moderate infestation may be extracted during the routine silvicultural thinnings.
- 3) Plantations, especially in areas prone to infestation may be kept free of mechanical injuries such as lopping of branches, plucking of leaves *etc.* Measures to reduce or avoid fires occurring inside the plantations may be practical.
- 4) Further host range expansion may be discouraged in order to avoid the pest seeking safe alternative hosts.
- 5) Biological control agents such as bird predators could be encouraged for effective control of the pest at larval stage itself.
- 6) Orchard sites could be established away from localities suffering heavily from trunk borer incidence to avoid the plus trees being infested by the borer.
- 7) Selecting plus trees or selection of seed stand for resistance to trunk borer in drier areas may be reliable.
- 8) Hybridization of trunk borer resistant teak clones may be thought of.

Summary

VI. SUMMARY

Distribution of trunk borer infestation was studied in plantations at Gunjavathi (Mundgod taluk) and Tatwala (Yellapur taluk) of Uttara Kannada district. The results revealed that plantations at Tatwala had lesser infestation (32.54%) than Gunjavathi (35.76%). Gunjavathi had higher percentage of heavily infested trees (19.77%) than Tatwala (16.43%).

Within the localities the plantations differed with respect to the stages of infestation. Moderate level of infestation (B-score) was higher in Tatwala while it was higher for heavy infestation (C and D-score) in Gunjavathi indicating that the pest pressure in Gunjavathi was higher. Gunjavathi differed more than that in Tatwala for C and D-scores in plantations since they suffered from different phases of insect attack.

Studies on spatial distribution revealed a definite pattern of trunk borer establishment in heavily infested plantation. The infestation featured a distinct patchy nature as large as 6m radius of infested trees with the heavily infested (C and D-score) trees situated in the center. In moderate to heavily infested plantations the infestation confined to smaller patches unlike larger ones in heavily infested plantations. Whereas in sparsely infested plantations the infested trees did not show any pattern of establishment and the infested trees were randomly distributed in the entire plantation.

Both the localities hence were found to be suffering heavily from trunk borer infestation. Hence there was a need to eliminate those plantations badly affected by trunk borer and extraction of infested trees or patches within the plantations.

Plantations acquired new infestation during the months of July to September in both the localities. The annual rate of progression was higher as expected, in moderate to heavily infested plantations when compared to heavily infested and low infestation plantations. In case of C and D-scores it was higher in heavily infested plantations. Extraction of borer infested trees during routine silvicultural thinnings during the months of November and December could possibly reduce the larval population that could complete their life-cycle and add up to the existing population.

Results on vertical distribution revealed that more number of holes in all the infestation category congregated at 1-2m height of the main trunk of the trees. In case C and D score trees the main trunk showed tunnels even up to 3m.

The occurrence of borer holes was highest at base of coppice shoots/branches in A & B-score trees. Maximum holes were found at bark damage or callus formation sites in C & D-score trees.

Pre-disposing factors were of vital relevance on the infestation status of the plantations. The observations on the disturbance factors influencing the plantation in both the localities revealed that the incidence of agricultural fields and fire in plantations had greater influence on the trunk borer infestation followed by grazing and human settlements.

Therefore the trees have to be kept free of mechanical injuries such as lopping of branches, plucking of leaves etc. Fire occurrence inside the plantations could reduce the physiological stress on trees.

There was no significant relation between age of plantation and infestation status except for A score, possibly due to the narrow range of plantation ages (17 to 37 years) and all of them being in the most susceptible age.

The per cent reduction in volume ranged from 4.88 to 15.60 for A score, 9.65 to 36.36 in B score. The per cent reduction in volume ranged from 15.9 to 46.79 in C score and 21.20 to 56.88 in D score. The data on economic loss due to borer infestation indicated that the logs that were highly ridden with trunk borer damage recorded a reduction of nearly 48% in economic value to their counterparts that were free from borer damage. Even the poles ridden with the borer tunnels fetched poor value with a reduction of more than 75% economic value fetched by good ones. The reduction in economic loss by the borer could be viewed seriously and suitable measures could be taken to reduce its influence.

In the present study, incidence of teak trunk borer was also noticed on *Butea monosperma* growing naturally in the teak plantations and near these localities. This is the first record on this tree species as alternate host.

Among natural enemy complex, only the woodpeckers were found to be actively pecking into the stems of infested teak trees and extracting the larvae for feeding. They were, the Heartspotted Woodpecker – *Hemicircus canente*, the Lesser Golden Backed Woodpecker – *Dinopium benghalense* and Great Black Woodpecker – *Dryocopus javensis*. Predation by woodpeckers was more in D-score and C-score trees. The identification of two species of woodpeckers, the Great Black Woodpecker and the Heartspotted Woodpecker as predators on teak trunk borer larvae is first to be reported from the present study. Woodpeckers could be encouraged in heavily infested localities as they could kill the larval population thus reducing the build up of borer population.

Observations for identifying resistant teak clones was recorded in two clonal seed orchards which are located in Manchikeri and Karka. In CSO, Manchikeri the

percentage of infestation ranged from 0 to 11.12% whereas in CSO, Karka it ranged from 0 to 52%.

Eleven out of 24 clones in CSO, Manchikeri were found healthy and free from trunk borer attack. Only 2 clones (MyHaV1 and MyHaV4) from Northern provenance, one clone (MySA1) from Central provenance and all the clones (MyHuT1, MyHuT2, MyHuT3, MyHuT6, MyHuT7, MyHuT8 and MyMK3) from Southern provenance were completely free from borer attack. These clones thus showed apparent resistance to teak trunk borer.

Highest infestation in Manchikeri CSO was found in Clone No. 9 (MyHV5) (11.12%) followed by Clone No. 33 (MyHaK2) (10.53%) and Clone No. 4 (MyHD4) (10.42%).

In CSO, Karka almost all the clones except Clone No. 4 (MyHD4) showed attack by the trunk borer in one or the infestation scores. Some of the clones based on minimum infestation did show apparent resistance to the borer. Clone Nos. 18, 19, 20 (MyHuT2, MyHuT3 and MyHuT4 respectively) from Southern provenance, Clone Nos. 5, 8, 12 (MyHaV1, MyHaV4 and MyHaV8 respectively) from Northern provenance featured light infestation. All the clones from Central provenance were moderately infested by the borer. Highest infestation was found in Clone No. 2 (MyHaD1) and Clone No. 9 (MyHaV5) (52% each) closely followed by Clone No. 14 (MySA2) (51.85%) and Clone No. 24 (MyHuT8) (33.33%).

Provenances in CSO, Manchikeri differed significantly for infestation per cent and low levels of infestation (A-score). Most of the attack in heavy infestation or in low intensity was found in clones from the Northern provenance.

Provenances in Karka CSO did not differ significantly for either percentage of infestation or for any of the infestation scores. Hence provenance did not have an influence in relation to attack by the trunk borer. Most of the heavy infestation was found in Northern and Central provenances.

Both the CSOs differed significantly with respect to trunk borer infestation parameters indicating the influence of locality on the status of infestation.

The provenances did not have a major influence on the borer infestation. Localities had a major effect on infestation status of the clones. The clones by provenances behaved in a similar trend in both the CSOs. The influence of clonal origin was weak but suggestive of the fact that clones from Southern provenance were better in escaping or resisting the borer attack. Therefore clones could be from Southern and Central provenance for better resistance to trunk borer.

Results on the bio-chemical analysis of resistant/susceptible clones in CSO, Karka revealed that there was significant difference for poly-phenols between healthy and infested category. The healthy clones (Clone No. 4, 5, 18 and 19) (MyHaD4, MyHaV1, MyHuT2 and MyHuT3) had the highest amount of poly-phenols (5.24%) when compared to infested clones (Clone No. 2, 6, 9 and 14) (HyHaD2, MyHaV2, MyHaV5 and MySA2) having 3.92%. For total sugars also there was significant difference between infested and healthy clones with infested clones having an average of 16.66% which was higher than that in resistant clones with 13.64%. In case of proteins and moisture content the infested and healthy clones did not differ significantly. Hence the resistance of the clones could be attributed to high poly-phenols and low sugar contents. Plus tree selection could include bio-chemical analysis of bark or wood portion as a measure of resistance to trunk borer.

FUTURE LINE OF WORK:

1. Further detailed studies on clonal resistance by screening the clones from their places of origin may lead to further meaningful data.
2. Study on clonal wood characters for their resistance to trunk borer attack.
3. Further exploration of natural enemies such as parasites, predators and microbes.
4. Development of management strategies including chemical and biological measures.
5. Suppressing the existing population by treating affected trees with fumigants.
6. Destruction of larvae in the soil at the time of pupation with suitable insecticides/ bio-pesticides.

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*Original not seen

Appendix

Appendix - I

Layout map of the Clonal Seed Orchard of teak at Manchikere. The number in each cell refers to the I. D. of Clone.

31	14	9	11	32	13	4	7	3	33	18	1	2	34	4	32	31	2	14	8	4	34	14	3	33
10	4	37	1	3	18	32	34	31	11	17	16	19	3	1	4	2	10	1	32	22	13	23	1	2
5	31	2	23	8	19	1	11	33	16	2	34	31	33	37	16	32	3	13	33	1	33	18	9	32
17	18	34	4	5	1	7	3	1	4	33	3	16	16	33	19	1	34	23	4	18	1	10	18	4
2	33	5	16	33	3	10	33	34	32	5	34	8	33	4	2	32	14	34	1	2	5	16	22	33
14	16	7	9	4	1	4	17	14	16	3	18	13	4	7	13	24	1	32	4	34	1	11	3	1
17	11	4	33	2	5	17	1	11	37	34	33	32	1	33	9	13	17	4	3	33	14	17	34	4
17	5	18	31	3	4	14	4	33	14	16	32	1	32	3	10	33	32	23	34	1	2	34	10	7
22	4	10	7	11	17	3	32	5	16	31	19	3	2	4	16	5	11	24	2	31	11	7	23	32
18	7	17	2	34	2	24	2	16	2	33	37	34	24	1	31	32	4	2	10	3	8	31	7	34
4	1	16	9	4	14	2	5	32	3	32	5	1	16	37	8	34	32	24	18	22	19	13	8	16
19	2	34	10	32	16	34	33	9	18	4	17	31	2	9	4	10	4	34	14	16	18	32	4	32
3	5	37	14	2	32	1	8	4	33	10	32	24	32	4	33	23	3	4	33	4	7	4	8	10
33	32	4	17	33	4	2	1	33	7	33	5	18	9	8	2	9	32	24	2	34	10	11	3	9
23	37	24	23	22	7	10	32	2	4	34	14	16	3	32	5	31	10	3	33	13	4	32	33	7
11	5	34	8	23	1	13	4	1	10	9	22	37	32	34	3	11	1	32	11	32	17	1	18	31
32	23	10	23	31	14	7	16	32	37	18	13	34	3	9	13	4	32	9	18	10	24	33	11	4
2	22	23	32	2	13	14	31	7	32	2	3	32	19	33	17	1	1	24	33	13	8	4	2	7
10	18	2	19	14	3	22	23	33	2	14	11	9	4	14	7	22	16	3	8	10	4	19	4	11
31	19	32	1	24	2	34	4	1	5	32	9	34	16	4	8	5	31	34	4	31	23	5	13	1
23	11	23	22	11	34	23	10	31	3	2	33	7	31	33	7	10	34	32	2	17	13	2	14	33
24	32	34	7	37	9	3	37	14	34	3	9	33	11	1	5	4	32	17	7	33	3	37	16	3
5	7	1	14	4	32	14	34	4	9	33	4	9	23	31	32	16	7	4	1	4	14	37	19	32
22	23	18	10	34	2	5	31	32	22	4	2	31	14	3	14	34	1	32	3	23	7	13	32	2
13	32	37	23	1	16	18	32	34	23	18	32	3	2	8	5	11	34	2	10	2	32	33	1	5

Appendix - II

Layout map of the Clonal Seed Orchard of teak at Karka. The number in each cell refers to the I. D. of Clone.

24	1	10	12	2	20	8	24	16	17	7	20	11	22	21	16	34	14	8	18	21	9	13	11	12
18	2	14	19	4	13	22	3	1	5	3	10	6	19	17	15	12	3	4	15	2	6	8	21	16
13	7	5	21	24	18	19	9	10	18	9	5	24	23	6	20	13	23	6	9	17	7	1	4	20
12	21	1	12	8	17	16	7	11	23	1	17	20	22	14	3	19	16	2	11	24	21	13	12	9
1	14	19	23	4	2	3	18	14	20	2	8	10	15	17	5	22	6	4	12	10	17	6	16	23
22	8	9	21	18	3	12	1	24	8	3	7	13	5	11	24	13	11	10	14	20	22	1	21	3
5	15	10	2	19	8	5	7	6	9	22	16	14	18	16	4	3	19	7	21	18	4	15	8	6
14	7	17	23	9	13	16	9	17	14	12	23	11	2	15	1	10	24	20	12	23	17	20	22	2
9	4	13	6	18	10	20	11	3	15	5	8	1	24	19	22	12	18	17	11	15	19	6	5	17
11	5	1	24	3	8	7	1	21	2	13	20	14	21	23	4	16	15	7	9	22	14	13	18	10
23	19	9	5	4	24	23	6	10	22	11	2	10	3	12	21	18	6	4	2	24	21	22	9	14
10	17	12	19	20	15	10	16	5	19	18	7	13	9	1	13	17	14	11	19	16	20	23	17	12
14	6	7	22	3	11	21	2	23	8	4	3	5	18	6	15	3	23	8	1	15	14	4	24	2
2	8	11	21	16	9	8	17	18	9	13	10	1	17	12	21	19	13	20	4	2	9	21	15	23
16	22	5	10	9	6	15	16	1	24	14	22	17	19	1	8	2	7	11	12	22	7	5	12	8
3	18	6	17	18	19	6	3	23	10	19	6	23	9	11	14	5	3	10	18	13	15	8	20	16
7	9	13	24	4	22	20	17	21	7	16	13	5	4	10	7	6	24	2	14	16	4	6	2	5
4	10	12	1	20	3	18	24	11	3	12	11	15	21	6	8	23	19	8	1	17	10	9	14	4
23	17	6	19	2	13	21	22	5	19	3	1	20	12	15	24	16	17	9	7	23	12	3	16	1
1	20	4	22	15	19	11	2	17	4	9	21	10	8	18	14	5	7	15	2	20	5	24	7	18
5	19	7	8	3	18	23	10	1	23	15	11	5	13	4	2	13	18	6	12	14	17	9	21	24
6	22	16	24	14	7	21	19	13	14	8	6	18	15	20	12	1	2	4	5	10	3	13	8	4
11	20	5	1	9	2	14	11	12	17	16	3	22	23	3	15	17	16	18	19	24	7	20	11	17
15	3	6	7	4	12	18	23	24	22	19	20	9	5	1	16	24	13	10	8	2	21	14	15	6
13	2	10	15	19	7	22	20	13	7	2	24	15	21	8	12	23	4	3	22	11	16	9	24	14