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DECAY OF STANDING TREES IN NATURAL FORESTS

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ABSTRACT

Ocular appraisal on occurrence of decay in living trees in natural stands in the State employing external decay indicators revealed an average incidence of 20.7%. Highest percent incidence of decay of 23.6 was recorded in the evergreen forest at Aramba (Achenkoil Forest Divn.) and lowest in the semi-evergreen forest at Kottiyoor (Kannur Forest Divn.), while in wet-evergreen forest at Panthanthodu (Silent Valley National Park), it was 18.71 %. Among the seven categories of decay indicators viz., swollen knot, swollen bole, punk knot, canker and open wound, hollow in the bole, sporophore, branch stub and rotten branches, all the indicators except punk knot occurred in comparatively high frequency. Altogether 44 polypores belonging to 18 genera were found associated with decay in living trees. Nine polypores caused brown-rot, while all the rest were associated with white-rot.

Detection and estimation of decay in standing trees in natural stands at Aramba (SFC III) were made by non-destructive as well as destructive methods. Ocular appraisal of 139 trees belonging to 12 species viz., *Vateria indica, Palaquium ellipticum, Dipterocarpus indicus, Disoxylum beddomei, Mesua nagassarium, Persea macrantha,* Bombax *ceiba, Hopea parviflora, Terminalia bellerica, Artocarpus hirsutus, Syzygium cumini* and *Bischofia javanica,* revealed that 66% of the trees contained decay. Direct probing into the wood of *V. indicu, P. ellipticum, Persea macrantha* and B. *javanica* for measuring the electrical resistance of the wood using pulsed electric current (Shigometer) proved less reliable in detecting the decay in living trees.

In ocular appraisal, a total of 794 external decay indicators belonging to seven Categories were recorded on 139 trees and in destructive sampling 495 indicators belonging to all the seven categories were found associated with decay, entailing a total loss of 129.63 m^3 of timber. Swollen bole and sporophore were associated with decay in cent percent cases. Hollow in the bole, canker and open wound and swollen knot were the other indicators which showed high percentage association with decay. Though, branch stub and rotten branches exhibited high frequency of occurrence (376), they showed least association (26.33%) with heartrot in trees. For detecting and estimating the heartrot in trees, swollen bole and sporophore were found to be the most reliable indicators, followed by hollow in the bole, and canker and open wound. Among the twelve tree species studied, V. *indica* exhibited highest number of external decay indicators (264) belonging to all the seven categories and an average of 3.42 m^3 decay volume per decayed tree.

Regression analysis revealed sporophore, canker and open wound, tree dbh, hollow in the bole and swollen bole as the most reliable variables in predicting the decay volume in mixed stand, whereas hollow in the bole, tree dbh and swollen bole were the reliable variables in natural stands of *V. indica.* Decay prediction equations were generated separately for *V. indica* and mixed natural stand.

1. INTRODUCTION

Kerala State situated between latitudes 8°18' and 12°48', longitudes 74°52' and 77°22', has an area of 38,863 Km^2 which is about 1.2% of the geographical area of India. The State has typical tropical warm-humid climate with an average annual rainfall of 3,020 mm and mean monthly temperature ranging from 17.5 to 29.5°C. Forests cover an area of 9400 Km^2 in the State which is about 1.26% of the total forest area of India and 24% of the land area of the State. The forests of Kerala are distributed in three distinct altitudinal zones. The lower zone is an undulating narrow belt up to about 300m (above m.s.1.) comprising tropical moist deciduous forests. The intermediate zone reaches up to 1500m (above m.s.l.), consisting of tropical semi-evergreen and tropical wet-evergreen forests. This zone culminates in upland plateau, which is the high altitude zone comprising sub-climax savanna of high ranges. The evergreen and semi-evergreen forests of the State have been the major source of timber.

In natural forests, among the various factors responsible for the loss to the standing crop, decay is the most important. Decay of the central core of heartwood in living tree is termed as heartrot. Usually, decay does not set in till the heartwood is formed. Some trees develop visible heartwood earlier, while in others the process is much delayed. In tropical trees, heartwood develops between 10 to 25 years of age, depending on the tree species. Heartwood comprised of dead tissues is formed by the aging and death of parenchymatal cells in centrally located xylem. It develops centripetally and may or may not involve a pigmentation change. Accumulation of gas emboli in adjacent conductive cells and isolation of parenchyma cells have been proposed as the cause of death of cells (Zimmermann and Brown, 1971).

In trees, the central core of dead heartwood is protected from the decay fungi by the outer living sapwood and the bark. However, when the heartwood becomes exposed due to injuries, decay may establish in the heartwood as heartrot which becomes progressive. Concepts of wood decay are still being formulated and tested. Robert Hartig's original idea that infection occurs only through branch stubs and wounds that expose the heartwood is no longer fully accepted (Haddow, 1968; Merril *et al.*, 1975; Shigo and Man, 1977). Much of the extensive research on invasion of stem tissues by decay fungi was stimulated by Shigo's (1984) concepts of organism succession and compartmentalization developed to explain the patterns and progress of decay observed in living trees. Heartrot fungi normally develop only in living trees; when the tree dies, they are replaced by fungi which are better adapted to a saprobic system. Heartrot fungi can be classified as causing either white-rot or brown-rot. The two types of decay differ markedly in physical and chemical characteristics (Cowling, 1961; Kirk, 1977). White-rot fungi degrade cellulose and the hemicellulose at approximately the same rates relative to the original amount present, whereas lignin is decomposed at a similar rate, or usually somewhat faster on a relative basis (Ander and Erikson, 1978;

Kirk *et al*, 1979). Brown-rot fungi utilize the hemicellulosearid cellulose of the cell wall at approximately the same rate leaving the lignin essentially unaffected (Kirk, 1975; Kirk and Alder, 1970). As the decay occurs in the heartwood, tree is not killed outright but it continues to grow and may exhibit all the external appearance of a healthy tree, as the living wood remains mostly unaffected. A considerable volume of standing timber is thus destroyed by the heartrot fungi. In aged natural stands, the trees containing advanced heartrot exhibit certain signs usually known as decay indicators. These indicators include swollen knots, swollen bole, punk knots, branch stub and rotten branches, sporophores, cankers and open wounds, early forking, resin flow, etc. (Thomas and Thomas, 1954; Boyce, 1961; Bakshi *et al.*, 1963). While many of these signs indicate an extensive decay, others indicate only slight one.

Detection and estimation of heartrot in living trees are usually made by destructive and non-destructive methods. The non-destructive methods include direct probing of the wood by measuring the electrical resistance of the wood (Skutt *et al.*, 1972; Shigo and Shigo, 1974; Shigo and Berry, 1975; Wilkes, 1983), increment boring (Dimitri, 1968; Perrin and Delatour, 1976), radiography (Miller, 1964), transmission of ultrasonic sound (Waid and Woodman, 1957), borescope (Dowden, 1970), ocular observations on the external decay signs (Cervinkova and Temmlova, 1966; Hinds and Hawksworth, 1966; Lavallee and Lortie, 1968; Roth and Hepting, 1969, Lachance, 1979), etc. The destructive method is by felling, billeting, dissecting and measuring the decay. Detection of decay in standing trees by employing simple, non-destructive methods is useful and helpful to foresters for determining the profitable harvest for specific purposes as well as for effective utilization of the available timber resources. In India, though, an overall appraisal on decay in natural forests has not so far been made, Bakshi *et al.* (1963) recorded about 73% of decayed trees in a sal forest in Uttar Pradesh, entailing a loss of 10% ofthe merchantable timber. Since, so far, no other quantitative data are available on decay in natural stands in other partsof the country, studies were undertaken on decay of standing trees in natural forests of Kerala. Knowledge on the extent of decay of the heartwood of different tree species in natural forests may serve as a reliable basis for predicting the decay volume in the stands as well as for the preparation of a cull manual of commercially important timber species.

2. MATERIALS AND METHODS

2.1. Prevalence of decay

Initially a reconnaissance was undertaken to select the plots that could be representative of the area on the basis of a good distribution of defective trees, as evidenced by the prevalence of visible decay indicators. Three sample plots of 0.5 ha (50 x 100 m) each were selected in the natural forests at Aramba

(Achenkoil Forest Divn.), Chalakkayam (Ranni Forest Divn.), Kottiyoor (Kannur Forest Divn.) and Panthanthodu (Silent Valley National Park). Within each plot, trees of girth >40 cm were observed for the presence of external evidence of decay. Tree with apparent decay were scored for the presence of external decay indicators viz., swollen bole, swollen knot, punk knot, canker and open wound, branch stub and rotten branches, hollow in the bole, sporophore, etc. Girth of the tree (gbh), tree species, number, nature and relative position of decay indicators, decay fungal species associated, occurrence of snags, etc. were also recorded.

Survey was also made in various disturbed and less disturbed natural forests in the State. These forest areas includ: Gurunathanmannu, Nilakkal (Ranni Forest Divn.), Aryankavu (Thenmala Forest Divn.), Arippa, Kulathupuzha (Trivandrum Forest Divn.), Pothupara (Nenmara Forest Divn.), Kollathirumedu, Sholayar (Vazhachal Forest Divn.), Ambumala, Karulai (Nilambur Forest Divn.), Begur (Wynad Forest Divn.), Kalluchal, Peechi (Trichur Forest Divn.), Peruvannamuzhi (Kozhikkode Forest Divn.) and Galazy (Mannarkkad Forest Divn.). Observations on the presence of external decay indictors and their intensity were recorded. Decay fungal sporocarps associated with standing trees were collected. General stand composition and frequency of occurrence of decay fungi were recorded. Data on gbh of the tree, approximate height, tree species, number, nature and relative position of the heart rot indicators, nature of decay, incidence of fire in the stands, etc. were recorded.

2.2. Detection and estimation of decay

A study area was selected in the selection felling natural forest at Aramba (SFC III, Achenkoil Forest Divn.). A total of 139 trees belonging to 12 commercially important tree species viz. *Vateria indica* L., *Palquium ellipticum* L., *Dipterocurpus* indicus Bedd., *Disoxylum beddomei* Hiern., *Mesua nagassarium* (Burm. f.) Kosterm., Persea macrantha (Nees) Kosterm., Bombax ceiba L., Hopea parvifora Bedd., Terminalia *bellerica* (Gaertn.) Roxb., *Artocarpus hirsutus* Lamk., *Syzygium cumini* (L.) Skeels, and *Bischofia javanica* Bl. were selected from the Tree Marking Register randomly on the basis of their relative occurrence in the area. The selected marked trees were located in the forest. Pre-felling observations viz. tree number, tree species, gbh (girth at breast height, i.e. 1.37 cm from ground level), approximate tree height, etc. were recorded on a data sheet. Ocular observations on presence of external decay indicators exhibited by the trees, their nature, number and position, identity of the decay fungus, if possible, etc. were recorded. A separate code was provided for each indicator and relative positions of the external decay indicators on the marked trees were also diagrammed.

2.2.1. Electrical resistance of the wood

Electrical resistance of the wood of trees suspected to be decayed was measured using a Shigometer 02-67. A total of 19 trees belonging to *V. indica* (12), *P. ellipticum* (3), *P. macrantha* (2), and *B. javanica* (2) were tested. Probe holes were drilled into the bole using a battery operated drill and the twisted wire probe was inserted into the probe hole and the resistance measured at one centimeter intervals along the radius. A 75% decrease of the highest value was taken as the success rate (Shigo and Shigo, 1974).

2.2.2. Destructive sampling

As and when the observed trees were felled, post-felling data were collected. Girth under the bark at the base and top of the merchanatable bole was measured. After billeting into four to five metre in length, the girth of each log was measured at both the ends. Wherever possible, dissection was made by bucking and making deep wedge shaped cuts in the log to confirm the association of an external decay indicator with the decay column in the heartwood and its intensity. To determine the decay volume, observations were recorded on: average length and diameter of decay column including associated discoloured areas due to incipient decay, extent of decay along the bole above and below the decay indicators, hollow in the central core, its diameter and length, termite and other insect associated with the decay column, etc. In the case of severely decayed billets, the location and extent of decay were also diagrammed for each billet for ascertaining the probable point of entry of decay fungi in standing trees and the mode of spread of decay in the heartwood.

The following methods were used for the measurement of decay column. A value of 2.5 cm was added to the measured visible decay, taking into account of incipient decay to make the actual length of decay column. All the irregular patterns of decay at the cut end of logs were converted into circular pattern by taking two measurements, each passing through the geometric centre of observed decay at right angles to each other. The mean of the two readings was taken as the diameter of the decay column. When sound wood existed between the areas of apparently similar decay in the cross section of the timber or when decayed wood completely encircled the narrow central core of apparently sound wood, the entire area was converted into a circular pattern of decay (Fig.1). When decay occurred throughout the length of the log, the diameter of the decay column was recorded as mean diameter of the decay at both ends. When decay was seen at one end only and the other end was sound, the length of decay column was determined by sawing lengthwise (only in rare cases) and ascertained the actual decay column. Log volume as well as decay volume were calculated as follows:

$$V = \frac{(s1 + s2)1}{2}$$

where, V= volume of decay or log volume (m^3); sl= cross sectional area of large end of the log or area of decay at the large end (m^2); s2= cross sectional area of small end or decayed area at the small end of the log (m^2); I= length of log or length of the decay column (m).

2.3. Collection of decay fungal sporophores, decayed wood samples, determination of nature of decay and identification of associated decay fungi

Decayed wood samples were collected from the trunk and branches. The decay samples werecategorized on the basis of their nature as white-rot, white spongy rot, pocket rot, brown rot, brown cuboidal rot,etc. Whenever, the sporophores were absent, identification of the fungi causing heartrot was attempted by isolation of fungus on malt extract agar (1.5%) or Sabouraud maltose agar (1%) medium. The hyphal characteristics of the fungus were compared with that of known decay fungi (Nobles, 1958; Bakshi, 1971). The morphological and physical details of the decayed wood samples were studied, the nature and type of decay ascertained and decay fungi associated with the particular decay confirmed.

Morphological characters of the sporophores collected from the sample plots as well as from the natural stands in various localities surveyed were studied. Sporophores were initially air-dried and then oven dried at 60°C for two days and preserved with proper labeling for further studies. Microscopic characters of thesporophores were studied using free hand sections mounted in 10% KOH and stained with 1% aqueous Phloxine-Bin 1% cotton blue. Identification of the decay fungi was made up to species level as far as possible based on macro and microcharacters, hyphal system (Teixeira, 1962; Pegler, 1973; Ryvarden and Johansen, 1980) and by comparison with authentic herbarium specimens available at FRI, Dehra Dun and Calicut University, Calicut.

2.4. Estimation and prediction of decay volume

The pre-felling and post-felling data collected from the stands were subjected to appropriate statisticalanalyses. Gross volume,decay volume and net merchantable volume of wood were deduced separately for each tree species. Frequency of decay indicators and their relationship with the observed decay column in each log, reliability of the indicators and their relative significance for estimating the decay volume,etc. were worked out both at tree and log levelseparately for each tree species. The reliability of all the variables including tree dbh for predicting the decay volume was analyzed. Decay prediction equations were generated by employing a stepwise regression technique. All the analyses were carried out using SPSS/PC+ ver.2.0 (Norusis, 1988).

3. RESULTS AND DISCUSSION

3.1. Prevalence of decay in natural stands

In natural forests, prevalence of decay in living trees and the quantity of wood decayed depend largely on age of the stand, environmental conditions, biotic pressure on the stand as well as various abiotic factors including occurrence of successive annual forest fires. Usually, the tree becomes vulnerable to attack by heartrot fungi as soon as the heartwood develops. In tropical trees, heartwood is formed between 10 to 25 years of age, depending on the tree species, and various site factors. Data on prevalence of heartrot collected from the selected plots in natural stands at four localities viz. Aramba (evergreen forest), Chalakkayam (evergreen forest), Kottiyoor (semi-evergreen forest), Panthanthodu (wet-evergreen forest) and various other natural stands in the State revealed that occurrence of heartrot and its intensity varied to a great extent from area to area.

Though, all the trees above 40cm gbh in the plots were observed, usually, visible decay indicators were exhibited only by the trees above 60cm gbh. Among the four sample plots, highest percent incidence of decay of 23.6 was observed at Aramba and lowest (17.6) at Kottiyoor (Table 1).

Table 1: Prevalence of decay in natural stands

Locality	Forest type	No. of Trees observed	Trees with decay indicator	Frequency of decay indicators 11	12	I3	I4	15	I6	17
Aramba	Evergreen	432	102	45	20	18	41	21	17	3
Chalakkayam	Evergreen	326	61	29	19	**11**	37	13	19	**1**
Kottiyoor	Semi-evergreen	284	50	**27**	19	5	30	13	13	2
Pathanthodu	Wet-evergreen	299	65	27	21	4	33	18	15	1

'11: swollen knot, 12: swollen bole, 13: canker and open wound, 14: branch stub and decayed branchJ5: hollow in bole, I 6 sporophore, I 7 punk knot

Among the affected trees *Dipterocarpus indicus, Disoxylum beddomei, Mesua nagassarium, Vateria indica* are the commercially important species. Of the 432 trees belonging to 28 genera and 34 species observed in the evergreen forest at Aramba, heartrot indicators were evident in 102 trees belonging to 21 tree species (Table 2).

Table 2 Prevalence of decay in natural stands at Aramba

Sl. No.	Tree Species	Localname	No. of trees observed	Trees showing decaysign No.	%
1.	*Anacolosa densiflllora* Bedd.	Kalmanikyam	12	2	16.66
2.	*Artocarpus hirsutus* Lamk.	Anjili	7	2	28.57
3.	*Bischofia javanica* Bl.	Mlachethayan	4	1	25.00
4.	*Bombax ceiba* L.	Ilavu	12	2	16.66
5.	*Chukrasia tabularis* A.Juss	Chuvannakil	8	3	37.5
6.	*Cullenia exarillata* Robyns	Vetiplavu	3	0	0
7.	*Carallia brachiata*	Vallabum	2	1	50.0
8.	*Cinnamomum riparium* Gam.	Vayana	7	1	14.29
9.	*Calophyllum polyanthum* Wall.ex	Punnappa	1	0	0
10.	*Diospyros candolleana* *Wt*.	Karimaram	27	7	25.93
11.	*Dipterocarpus indicus* Bedd.	Karanjili	50	13	26.0
12.	*Dysoxylum beddomei* Hiern.	Akil	18	11	61.11
13.	*D. ficiforme* (Wt.) Gam.	Karakil	3	0	0
14.	*Elaeocarpus tectorius* (Lour.) Poir.	Kara	2	0	0
15.	*Holigarna beddomei* Hk.f.	Cheru	19	2	10.53
16.	*Hydnocarpus pentandra* (Buch-Ham) Oken	Marotty	1	0	0
17.	*Kingiodendron pinnatum* (Roxb.exDc) Harms	Kulavu	3	0	0
18.	*Knema attenuata* Warb.	Chorapine	23	1	4.35
19.	*Mesua nagassarium* (Burm.f.) Kosterm	Nangu	30	13	43.33
20.	*Neolitsea cassia* (L.) Kosterm	Venkana	3	0	0
21.	*Polyalthia fragrans* (Dalz.) Bedd.	Nedunar	6	2	33.33
22.	*Persea macrantha* (Nees.) Kosterm	ooravu	1	0	0
23.	*Palaquium ellipticum (Dalz.)* Engl.	Pali	22	4	18.18
24.	*Melia dubia* Cav.	Malaveppu	2	0	0
25.	*Hopea parviflora* Bedd.	Thampakam	12	4	33.33
26.	*Syzygium cumini* (L.) Skeels	Jnaval	8	2	25.0
27.	*Syzygium hemisphericum* (Walp.) Alston	Tholjnaval	10	2	20.0
28.	*Terminalia bellerica* (Gaestn.) Rex.	Thanni	9	0	0
29.	*Terminalia paniculata* Roth.	Maruthu	1	0	0
30.	*Terminalia travancorensis* Wt. Arm.	Pekkadukka	3	1	33.33
31.	*Vateria indica L.*	Vellapine	116	25	21.55
32.	*Vateria malabarica* Dc.	Kunthirikkapine	5	3	60.0
33.	*Vepris bilocularis* (Wt.) Arn.) Engl	Moothasari	1	0	0
34.	*Vitex altisima* L.	Myla			0
	Total		432	102	23.61

In the evergreen forests at Chalakkayam and wet-evergreen forests at Panthanthodu, prevalence of decay was 18.71% and 21.52% respectively. The average percent decay in all the four representative natural stands in the State was recorded as 20.68. All the seven categories of decay indicators were observed in all the four areas. Sporophore of the decay fungi, usually considered as a sure indicator of decay (Bakshi, 1976; Eusebio, 1987) were found associated with about 4.76% of the observed trees in all the four areas. Usually, sporophores are produced from decayed tissues of advanced stage. A good percentage of decayed trees showing sporophores indicates the advanced stage of decay in a large number of trees. Certain species of fungi develop sporophores abundantly soon after the decay is established in the heartwood, while others develop sporophores less frequently or very rarely even when decay is extensive (Thomas ad Thomas, 1954; Bakshi and Singh, 1970). However, under the tropical humid climate prevailing in the State, most of the decay fungi produced their fructifications on the affected tissues. Sporophores of *Phellinus* spp., *Fomitopsis* spp. and *Tramates* spp. were the most commonly encountered ones. Among the seven visible decay indicators, swollen knots were recorded in highest frequency in the plots at all the four localities and ranged from 41 to 54%. Ordinarily, a knot indicates the position of the base of a branch that has become embedded in the wood during the growth of the tree. Swollen knot is formed when living wood grow over a knot in which sporophores are forming (Boyce, 1961). Such knots are considered a reliable indicator of decay (Thomas and Thomas 1954; Bakshi *et al.*, 1963).

Occurrence of swollen bole ranged from 20 to 38% in the plots at four areas in natural stands. Swollen bole indicates an advanced stage of heartrot and is regarded a reliable decay indicator (Bakshi *et al.,* 1963; Toole 1959). Trees infected with heartrot fungi show perceptible swelling at the region of decay in advanced stage. Usually, the swollen region of the bole gives a hollow sound when struck hard. Occurrence of cankers and open wounds in trees was low and varied from 6.5 to 18.5%. Punk knots, cylindrical core of punky tissue of the wood decayed by the fungus, embedded in the sapwood up to different depths and opening upon the bark as oval hard structures, were recorded only in a few trees.

Heartrot in standing trees are often categorized into different ecological groups, based on the position and spread of the decay, namely root and butt rots, and trunk rots. In the former, decay fungi may enter the tree through butt region and the decay spread to the roots and the trunk or they may enter through roots and spread to the butt region. Trunk rots become established in two ways, namely, wounds, branch stubs and knots. Injuries caused by fire, lightning, mechanical injuries caused by logging, wind damage, etc. may serve as the infection courts or the entry points of decay fungi in standing tree (Mohanan, 1992). In advanced cases these openings may become into hollow in the bole. The position of these hollow in the bole indicate the nature of the infection courts and also the decay.

The percent occurrence of such openings ranged from 21.6 to 27.6 in the natural stands surveyed. Branch stub and rotten branches were also observed as indicator of decay. Their frequency of occurrence varied from 42 to 60% in all the four localities surveyed. However, this indicator was usually considered as a least reliable one, as their mere occurrence often may not be associated with any detectable decay in the log (Toole, 1959; Bakshi *et al.*, 1963; Bakshi, 1976). In all the four areas, decay indicators such as cankers and hollow in the bole at the top of the trunk, broken trunk and main branches occurred in high frequency which may indicate the earlier logging activities in the stands. Similarly, occurrence of open wounds, hollow at the base of the trunk in many trees in all the four areas may indicate the incidence of severe ground fire.

In natural stands, presence of snags, decayed and dead standing trees, indicates the decay potential of the stand, since they serve as a reservoir of the decay fungal inoculum. The number of snags ranged from 2 to 7 per hectare in the four areas.

3.2. Fungi associated with decay in natural stands

Quite a large number of decay fungi were collected from natural forests in different localities of the State. Only a few were found associated with heartrot of standing trees, while many of them caused decay of small branches and twigs (sapwood rot). A total of 44 fungi belonging to 18 genera were identified as associated with decay of various tree species and the nature of decay caused by them was ascertained (Table 3; Figs.3-6).

Most of the fungal species, found widely distributed in the semi-evergreen, evergreen and wet-evergreen forests, showed a wide host range. While a few species like *Fomitopsis palustris, Hexagonia sulcata, Rigidoporus lineata,* etc. exhibited restricted distribution and very narrow host range. White-rot fungi were the most widespread in all the three types of forests of the State. Altogether 35 fungi were identified as causing white-rot in various tree species. Ten species of *Phellinus* caused white-rot in different tree species and among these *P. troyanus, P. fustuosus, P. gilvus* and *P. rimosus* were the most widely encountered ones. *Polyporus auriculiformis*, *Tramates scabrosa* and *Lenzites* spp. were the other common white-rot (sapwood rot) fungi encountered in the natural forests of Kerala. *Microporus affinis, M. xanthopus, Coriolopsis spp., Flavidon flavus,* etc. were also common in all the areas surveyed which caused mainly white-rot of branches and twigs (sapwood rot). Nine fungi were associated with brown-rot in standing trees. Four species of *Fomitopsis,* three species of *Rigidaporus* and one species each of *Hexagonia,* and *Pyrofomes* caused brown-rot of various tree species. Among the *Fomitopsis* spp., *F. dochmius* and *F. rhodophaeus* were the most widespread in occurrence as well as they exhibited a wide host range. *F. dochmius*

Table 3: Decay fungi collected from natural forests in various localities in Kerala

SI.No.	Decayfungi	Nature of decay	Important tree species
1.	*Coriolopsis caperata* (Berk.) Murr.	white rot	HP,MD,KP,XX
2	*C. sanguinaria* (K.I.) Tenz.	white rot	BJ,CE,DBO,PC,MN,XX
3.	*Cyclomyces setiporus* Berk &Pat.	white rot	AH,MN,PE
4.	*C. tabacinus* Mont.) Pat.	white rot	CE,PE,VI
5.	*Flavidon flavus* (Kl.) Ryv.	white rot	DBD,PE,TP,TT,VI
6.	*Fomitopsis dochmius* (berk. & Br.)Ryv.	brown rot	AI,CE,DI,MN,PE,PM,SC,TB,VB
7.	*F. palustris*	brown rot	CE,DI,KP
8.	*F. rhodophaeus* (Lev.) Imaz.	brown rot	CE,GT,MN,XX
9.	*Fomitopsis sp.*	brown rot	PE,MN
10.	*Ganoderma applanatum* (Fr) Pat.	white rot	AH,DB,SC,HB,MN
11.	*G. lucidum* (Curt. ex Fr.) Karst.	white rot	AH,BJ,CE,DB,DI,PM
12	*Hexagonia apiaria*	white rot	AH,BC,CE,VI,PE
13.	*Hexagonia sulcata* Berk.	brown rot	CE,PE
14.	*H. tenuis* (Hook.) Fr.	white rot	AH,BC,CE,VI,PE
15.	*Irpex lacateus* (Fr. ex Fr.) Fr.	white rot	DB,DI,HP,VI
16.	*Lenzites acuta* Berk.	white rot	BJ,DBE,GT
17.	Lenzites spp.	white rot	DB,PM
18.	*Loweporus wahlbergii* (Fr.) Reid.	white rot	TB,VI,SE
19.	*Microporus xanthgus* (Fr.) Kuntz.	white rot	CE,DBE
20.	*M. affinis*	white rot	DBE,BC
21.	*Nigroporus vinosus (Berk.)*Murr.	white rot	TP,PE
22.	*Phellinus allardii* (Bres.) Ryv.	white rot	BJ,TB
23.	*P. contiguus* (Pers. ex Fr.) Pat.	white rot	BJ,GT,VI,XX,U
24.	*P. fastuosus* Lev.)Ryv.	white rot	DI,PE,PM
25.	*P.* ferreus (Pers.)Bourd & Herr.	white rot	PE,MN,VI
26.	*P. gilvus* (Schw.) Pat.	white rot	VI,TC
27.	*P. pseudosenex (Murr.)*Bond & Herr.	white rot	KA,DB
28.	*P. rimosus* Berk.) Pilat	white rot	AH,AT
29.	*P. senex* (Nus.& Mont.) Imaz.	white rot	AH,HB,KP,PE
30.	*P. troyanus* (Murr.) Sacc.	white rot	DB,DC,GT,PE,MN,XX
31.	*P. wahlbergii* (Fr.) Reid.	white rot	DB,SE
32.	*Phellinus* sp.	white rot	VI,CE
33.	*Polyporus auricularius* (Batsch.)Fr.	white rot	BJ,DB,HB
34.	*Polyporus* sp.	white rot	GT,PM
35.	Pycnoporus *sanguineus* (Linn. ex Fr.) Murr.	white rot	AH,DBE,PM
36.	Pyrofomes *albomarginata* (Zipp.ex Lev) Ryv.	brown rot	MN
37.	*Rigidoporus lineatus* (Pers.) *Ryv.*	brown rot	BJ,HC
38.	*R. microporus* (Fr.) Overeem	brown rot	BJ,MD,XX
39.	*R. ulmarius* (Sow. ex Fr.) Imaz.	brown rot	DB,TC,PM
40.	*Tramatus cingulata* Berk.	white rot	DBO,CE,HP,TP
41.	*T. hirsuta* (Wulf. ex *Fr.)* Lloyd.	white rot	AF,DBE,GT
42.	*T. scabrosa* (Pers.)G.H. Cunn.	white rot	MN,PE
43.	*Tramatus* sp.	white rot	CE,HC
44.	*Trichaptum byssogenus* (Jungh) *Ryv.*	white rot	DB0,XX

AF:*Acrocarpus fraxinifolius*, AH:*Artocarpus hirsutus*, AT *Antaris toxicaria*, B C *Bombax ceiba*, BJ: *Bischofia javanica*, CE *Cullenia exarillata*, DB *Diospyros bourdillonii*, DBE *Disoxylum beddomei*, DBO: *Dipterocarpus bourdilloni*, GT: *Grewia telifolia*, HA: *Holigarna arnottiana*, HB *H. beddomei*, H P *Hopea parviflora*, HC *Haldinia cordifdia*, MN:*Mesua nagassmium*, MD:*Meliadubia*, PM *Persea macrantha*, PC: *Polyalthia ceasoides*, P E *Palaquium ellipticum*, SC: *Syzygium cumini*, TB: *Terminalia bellerica*, TP. *T. paniculata*, TT:*T.travancorensis*, T C : *Toona ciliata*, VI: *Vateria indica*, XX:*Xylia xylocarpa* had the largest fruitbody collected, measuring about 80 cm dia. from Gurunathanmannu (Ranni Forest Divn.). *H. sulcata* restricted its occurrence in wet-evergreen forests of Silent Valley National Park, whereas *H. tenuis* was widespread in the forest with a wide host range. Of the 44 species of polypores associated with decay in standing trees in the natural forests, nine were found causing brown-rot. In tropical forests white-rot fungi dominate over brown-rot fungi (Ryvarden and Johansen, 1980; Cunningam, 1965). However, comparatively high percentage occurrence of brown-rot fungi'in the present study may be due to the fact that decay fungi associated with living trees only were studied.

3.3. Detection and estimation of decay

Decay in heartwood is progressive and, hence, the volume of decay increases in the living trees with age. From the ecological point of view, decaying trees which undergo a series of successive biological deterioration processes serve as a niche for diverse micro as well as macroorganisms. However, from the pathological point of view, decaying trees are reservoir of inoculum and consequently a source of infection to adjoining healthy trees in the natural stands. Therefore, early detection of decayed trees in the natural stands is important. So that, trees in advanced stages of decay can either be excluded from felling in order to reduce the logging expenses, or maximum merchantable timber can be salvaged from them at the earliest and the stand can be protected from excessive decay loss. In the present study, for detecting and estimating the decay in standing trees, both non-destructive and destructive methods were employed. Non-destructive method included ocular appraisal on external decay indicators exhibited by the trees and direct probing into the wood of the trees using pulsed electric current (Shigometer). The destructive method was felling, billeting and dissecting the logs of the observed trees and measuring and estimating the decay volume.

3.3.1. Non-destructive sampling

i. ***External decay indicators***

In relatively aged and disturbed natural stands ocular observation on external decay indicators has been employed for detecting the decay in standing trees. External decay indicators have been shown to be useful to detect and even estimate decay in living trees in several cases. In natural stands, where several such indicators are present, as in the case of present study, the detection of decay in the stand becomes more reliable. Altogether seven categories of decay indicators viz. swollen knot, swollen bole, canker and open wound, branch stub and rotten branches, hollow bole, sporophore and punk knot were used for scoring the trees containing decay (Fig.2). Of the 139 marked trees belonging to

12species observed in thenaturalstandat Aramba, all the treesexcept four trees of *Vateria indica* exhibited one or the other of seven visible decay indicators. However, the frequency of occurrence of each of these indicators varied from zero to seven per tree. Often two to five categories of the decay indicators were found in a single tree, and their number and relative position of occurrence in trees varied. The data clearly indicate that most of the trees that exhibited decay indicators had heartrot which may vary from very incipient to advanced stage, depending on the nature and frequency of occurrence of the decay indicators (Table 4).

Table 4: Frequency of various decay indicators in different tree species

Tree species	No. of trees		Frequency of indicators**							Decay volume(m^3)	
	Total	With decay	I1	I2	I3	14	I5	I6	I7	Total	Per tree average
V. indica	52	24	40	43	30	97	31	18	5	82.18	3.42
P. ellipticum	17	15	16	5	19	41	15	2	0	5.20	0.35
D. indicus	21	17	20	12	12	59	15	11	2	16.98	0.99
D. beddomei	7	7	7	7	9	29	3	0	2	13.32	1.90
M. nagassarium	9	7	18	1	11	41	10	1	1	4.20	0.60
P. macrantha	9	4	4	1	5	32	1	0	0	0.31	0.08
B. ceiba	6	4	2	1	1	21	1	0	0	3.14	0.79
H. parviflora	3	2	2	0	4	12	0	0	0	0.06	0.03
T. bellirica	2	2	1	0	1	5	2	0	0	0.07	0.03
A. hirsutus	4	1	1	0	0	9	1	1	0	0.02	0.02
S. cumini	5	4	4	2	2	16	4	0	1	1.17	0.29
B.javanica	4	4	4	3	0	14	3	1	2	2.99	0.75
Total	139	91	119	75	94	376	86	34	13	129.63	

ii. *Electrical resistance of the wood*

Twelve trees of *V. indica*, three of *Palaquium ellipticum*, two each of *Persea* macrantha and *B. javanica* were probed for measuring the electrical resistance of the wood by using twisted wire probe of Shigometer (Fig.3d,e). The magnitude and patterns of radial variation in the electrical resistancediffered substantially among the species. In *V. indica*, the readings for the outer heartwood were often "off scale" (+500 Kohm), whereas pulse resistance failed to exceed even 100 Kohm in *P. ellipticum* and *P. macrantha*. However, in all the tree species except *B. javanica,* pulse resistance tended to be "off scale" in the outer sapwood. Usually, the pulse resistance decreased in the inner heartwood of all the four treespecies.

A decrease of 120 to 200 % of the highest value was obtained only in two trees of *V.indica* out of 12 trees tested. A decrease of 70 to 80% of the highest resistance reading was recorded in one tree each of *B.javanica* and *P.ellipticum;* while in *P. macrantha,* only 55 to 65% decrease of the highest resistance reading was obtained. Resistance readings of more than 75% decrease of the highest value were taken to score the tree as contained decay (Shigo and Shigo, 1974).

In general, the data on electrical resistance of wood measured using Shigometer were not reliable to detect the decay in standing trees, as considerable radial variation in electrical resistance occurred in sound wood of the tree belonging to the same species as well as different species studied. Furthermore, often a success rate of 75 %'decrease of the highest resistance reading was not obtained even on severely decayed trees. The data obtained from destructive sampling method also showed that decay originated at the top of the bole (trunk decay) and spread up to the middle of the bole was not detected by the device. As different tree species under the observations covered a wide range of wood properties as well as considerable radial variation in their wood and difficulty in drilling the probe holes, especially in trees with large basal girth and dense wood, also pose problems for practical application of Shigometer for detecting the decay in tropical hardwoods.

3.3.2. Destructive sampling

Detection and estimation of decay was also carried out by felling and billeting the observed trees. Of the logs of 139 trees observed, 91 trees contained decay which ranged from incipient to advanced stage. Both white-rot and brown-rot were observed in the heartwood of differeent tree species. Decayed wood tissues exhibited various physical features viz. white spongy rot, white pocket rot, brown cuboidal rot, etc. depending on the decay organisms associated and also level of degradation of the wood tissues. Gross volume of 139 felled trees measured was 1821.58 m^3 and the total decay volume 129.63 m^3 (Table 5).

Table 5: General data on tree species sampled, gross volume, decay volume and percentage of decay, etc.

No. of tree species sampled	12
No. of trees sampled	139
No. of trees with decay	91
No. of trees without decay	48
Gross volume (m^3)	1821.58
Decay volume (m^3)	129.63
Net merchantable volume (m^3)	1091.96
Percentage of trees without decay	3453
Percentage of trees with decay	65.47
Percentage of decay	7.12

About 66% of theobserved trees contained decay with an average decay volume of 7.12 m^3. Among the twelve tree species studied highest number of decayed trees (24)and highest percentage decay (12.23) wereobserved in *V. indica* (Table 6). Whereas lowest number of decayed trees (1) as well as the least percentage of decay of 0.03 was in *A. hirsutus*. In *Dipterocarpus indicus*, out of 21 trees observed, logs of 17 trees contained decay of 16.98m^3. Whereas in *Disoxylum beddomei*, all the seven trees observed were decayed and the gross volume and decay volume were 120.89 m^3 and 13.32 m^3, respectively; the percentage decay was 11.02 which falls near to that of V. *indica.*

Even though, the number of trees observed belonging to a particular tree species ranged from two to fifty two, decay was observed in all the twelve species. However, the percentage occurrence of decay as well as intensity varied from species to species. *B. javanica* showed cent percent decay incidence and comparatively high percent decay (6.73). While *T. bellerica* recorded cent percent incidence, decay volume (0.07 m^3)and percentage decay (0.27)were comparatively less. S. cumini, H. *parviflora* and P. *macrantha* were less affected by decay. *M. nagassarium* had a decay volume of 4.20 m^3 with 7.27% decay (Table 6).

Table 6: Extent of decay observed in different tree species

Tree Species	Mean gbh (cm)	No. of trees		Volume (m^3)			
		Total	with decay	Gross volume	Decay volume	**Net merchantable**	% decay
V. indica	326.7	52	24	671.84	82.18	589.61	12.23
P. ellipticum	293.8	17	15	184.99	5.20	179.80	2.81
Dipt. indicus	363.5	21	17	374.23	16.98	357.25	4.54
Dis. beddomei	364.3	7	7	120.89	13.32	107.58	11.02
M. nagassarium	282.0	9	7	57.86	4.20	53.66	7.27
P. macrantha	273.3	9	4	74.91	0.31	74.60	0.41
B. ceiba	396.6	6	4	125.82	3.14	122.68	2.49
H. parviflora	280.0	3	2	28.09	0.06	28.03	0.22
T. bellarica	310.0	2	2	24.54	0.07	24.48	0.27
A. hirsutus	311.3	4	1	56.09	0.01	56.07	0.03
S. cumini	313.0	5	4	57.80	1.17	56.63	2.02
B. javanica	300.0	4	4	44.50	2.99	41.51	6.73
Total		139	91	1821.56	129.63	1691.9	7.12

3.3.3. Decay in relation to external decay indicators

A total of 794 visible decay indicators belonging to seven categories were recorded on 139 trees belonging to 12 species. In destructive sampling method, altogether 495 indicators of all the seven categories were found associated with decay in the logs. A success rate of 62.34 % indicated that most of the visible decay indicators are dependable for detecting the decay by ocular observation. Among the decay indicators, swollenbole and sporophore were associated with decay in all cases. While hollow bole, canker and open wound, swollen knot were the other indicators which showed high percentage association withdecay (Table 7). However, branch stub and rotten branches exhibited in highest frequency (376), showed very low percentage association (26.33) with decay.

Table 7 : Decay indicators, their frequency of occurence and association with decay in various tree species

Sl. No.	Decay indicator	Frequency of occurrence	No. of indicator associated with decay	Percentage of indicator with decay
1	Swollenknot	**119**	**105**	**88.23**
2	Swollen bole	**72**	**72**	**100.00**
3	Canker and open wound	**94**	**89**	**94.68**
4	Branch stub and rotten branch	**376**	**99**	**24.33**
5	Hollow bole	**86**	**77**	**89.53**
6	Sporophore	**34**	**34**	**100.00**
7	Punk knot	**13**	**7**	**53.85**
	Total	**794**	**495**	**62.34**

Among the twelvespecies, *V. indica* exhibited highest number of external decay indicators (264) belonging to all the seven categories and an average of 3.42 m^3 decay volume per decayed tree (Table 7). *P. ellipticum* showed a total of 98 external decay indicators of six categories and a total of 5.20 m^3 decay volume was detected. In *Dipterocarpus indicus* and *Disoxylum beddomei*, 131 and 55 external indicators respectively belonging to all the seven categories were observed, however, per tree decay volume detected was comparatively high (1.90 m^3) in the latter than in the former (0.99 m^3). Though, in *M. nagassarium,* a total of 83 indicators belonging to all the seven categories were exhibited, total decay volume (4.20 m^3) and per tree average decay volume (0.60 m^3) were less. The results revealed that the extent of decay associated with each category of external decay indicator varied depending on the nature, number and relative position as well as the tree species affected. Also, all the external decay indicators used in the study were not equally reliable in detecting the decay and estimating the decay volume.

Sporophore, with a frequency of occurrence of 34, in six out of twelve tree species studied, was found associated with decay in all the observed cases. It was rated as the most reliable indicator among the seven categories. *Phellinus ferreus, P. gilvus, P. troyanus, P. fastuosus, Fomitopsis palustris, F. dochmius* and *Rigidoporus* spp. were the most common polypores associated with the decay in trees.

Swollen bole, with a frequency of 72, observed in nine out of twelve species was also found associated with all decay cases and was rated as another reliable indicator. Hollow in the bole, observed in all the twelve but one species with a frequency of occurrenceof 86 showed 89.53% association with decay and it can be rated as a reliable indicator. In many cases decay was found spreading from the base of the tree to the top (butt rot). In this case, usually a hollow in the bole at the base of the trunk was observed; wound caused by severe ground fire or due to mechanical injury may have served as the infection courts of the decay fungi. In *V. indica, P. ellipticum* and *D. beddomei* association of termite with the decay in thecentralcoreofthebole whichresultedinlargehollowwasobserved. Spread of decay from top of the trunk to the base (trunk rot) was also not uncommon. In such cases, decay was extended throughout the bole in a very narrow column or without any portion entirely free from decay. Hollow bole at the top of the trunk or a broken trunk/main branch indicates theearlier logging injury caused to the residual trees or the injury caused by lightning, heavy wind, etc., which might have served as the infection courts to the decay fungi. Trunk decay which originated from the broken trunk or branches at the top and the large decay column often extending to the base of the trunk was observed in *M. nagassarium, V.indicu* and *P. ellipticum*. Canker and open wound which observed in all the twelve tree species with a frequency of 94 also gave good percentage of association with decay (94.68). Punk knot, recorded only in six tree species with very low frequency of occurrence (13), showed only 53.85% association with decay. Similarly, branch stub and rotten branches, though recorded in highest frequency (376) showed only 26.33 % association with decay and was rated as the least reliable among the decay indicators studied.

3.3.4. **Decay in relation to tree girth**

Girth and age of tree are useful variables for the effective utilization as well as management of the stands. In natural forests, where age of the trees cannot be determined, girth forms an important variable in the classification as well as management of the stands for different purposes. An arbitrary classification of 139 trees belonging to12 speciesbased on their girth (gbh) into five girth classes viz. I to V, indicated that incidence of decay was more prominent in trees belonging to the girth classes IIto IVi.e., from 251to 400 cm gbh. A total of 71 decayed trees i.e., about 79.1 % of the decayed trees belonging to these girth classes were observed. In the girth class I, only 6.6 % decayed trees were observed whereas in class V all the 13 trees were decayed which comes to about 14.28% of the total decayed trees. Of the 139 trees observed, only 13 trees belonged to the girth class I and of this 6 had decay. In genera1, incidence of decay increased with the increase in treegirth, irrespective of the tree species studied. However, the relation of decay volume and treegirth was more pronounced in *V. indica*, where comparatively large number of trees (52) were observed with a total of 589.61 m^3 net merchantable volume and 82.18 m^3 decay volume (Table 6).

3.4. Prediction of decay

Prediction of decay volume in individual tree as well as in the stands is important for determining the net volume of merchantable timber and also for the proper management of the forest. Data on ocular appraisal on decay indicators as well as on detection of decay in the logs by destructive sampling method revealed that decay indicators such as sporophore, swollen bole, hollow bole, swollen knot, and canker and open wound which showed high percentage association with decay, are more reliable decay indicators. Branch stub, rotten branches and punk knot showed only low percentage association with decay and were found least dependable variables. The relative significance of these indicators in predicting the decay in standing trees also showed a similar trend (Table 8).

Table 8 : Relation between various decay indicators used in predictiong the decay in standing trees

Indicator	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**
I1	1.0000	**0.2944'**	**0.3866****	**0.0180**	**0.1686****	**0.1925****
I 2	**0.2944***	1.0000	**0.2212****	**-0.1104**	**0.2122****	**0.2257***
1 3	**0.3866****	**0.2212****	1.0000	**-0.0187**	**0.2777***	**0.1614****
I 4	**0.0180**	**-0.1104***	**-0.0187**	**1.0000**	**-0.0601**	**0.0282**
1 5	**0.1686****	**0.2122****	**0.2777****	**-0.0601**	1.0000	**0.3692****
I 6	**0.1925****	**0.2257****	**0.1614**	**0.0282**	**0.3692"**	**1.0000**
1 7	**0.0463**	**0.1039***	**0.0949**	**-0.0097**	**0.5510**	**0.0798**

* Significant at P =0.01; ** Significant at P =0.001

11 :Swollen knot; I2 : Swollen bole; I3 : Canker and open wound; I4 : Branch stub and decayed branch; I5 :Hollow in bole; I6 :Sporophore; I7 :Punk knot

Presence of swollen bole, canker and open wound, hollow bole, and in different combinations was found highly significant in predicting the decay volume. While swollen knot, a decay indicator found in high percentage association with decay, only in combination with other indicators such as canker and open wound, hollow bole and sporophore was found significant in predicting the decay volume.

Heartrot is progressive and therefore the volume of decay increases in the tree and in the stand asmoreand more heartwood isdecayed withage.The incidence as well as volume of decay increased in all the twelve tree species with increase in girth of the trees. This indicates that aged trees contain higher decay volume, since, girth size is directly related to the age of the tree. As the tree grows, opportunities for the infection also increase, the rate of healing of wounds becomes slow, the relative proportion of heartwood increases with a consequent decrease in the resistance to decay. With the age, the increment of new wood slows down while decay progresses, so that at a particular stage the volume of wood decayed overtakes and then surpasses the new wood added to the tree. From thisstageonwards the treesuffers fromanincreasingnet loss year after year. This indicates that the girth of tree is an important variable in estimating the decay in a standing tree irrespective of the tree species.

A stepwise regression analyses of the variables including all the seven decay indicators observed and diameter at breast height (dbh) of the trees indicated hollow bole as the most reliable variable for predicting the decay volume in *V. indica* (Table 9).

Table 9 : Estimated coefficient of the prediction equation for decay volume in *Vateria indica*

Variable	Coefficient	Standard error of the coeffi-cient	Standardized coeffi-cient	T value
I5	**0.3162**	**0.1584**	0.2546	**0.0516'**
D	**1.5265**	**0.5816**	**0.2613**	**0.0116***
I2	**0.4266**	**0.1366**	**0.4455**	**0.0030'**
Constant	**-1.4237**	**0.5773**		0.0173

* Significant at P = 0.01; 12 : Swollen bole; 15 : Hollow in bole; D : dbh

Thevariables, tree dbh and swollen bole ranked as second and third dependable indicators, respectively. Other variables viz. sporophore, canker and open wounds, though,associated with decay in high percentage and their occurrence was highly significant in relation to decay were found less significant for predicting the decay in *V. indica,* (Table 9).

In the stepwise regression analyses of data obtained from 139 trees belonging to 12 tree species using all the variables studied including tree dbh, a different picture emerged (Table l0). The variables,sporophore,canker and open wounds, tree dbh were the first,second and third ranked reliable variables respectively for predicting the decay volume. The variables, hollow bole and swollen bole, which were the first and second ranked variables for predicting the decay volume in *V. indica* became fourth and fifth ranked variables for predicting the decay volume in a mixed natural stand (Table 10).

Table 10 : Estimated coefficient of the prediction equation for decay volume in natural stand (pooled data of 139 trees belonging to 12 species)

Variable	Coefficient	Standard error of the coeffi-cient	Standardized coeffi-cient	T value
I6	0.24541	0.07503	0.19358	0.00 14*
I3	0.22194	0.5018	0.24429	0.0000*
D	0.73331	0.20871	0.19272	0.0006*
I5	0.11254	0.05951	0.11459	0.0608*
I2	0.37320	0.0532	0.44024	0.0000*
Constant	-0.69994	0.21565		0.0015*

* Significant at P = 0.01; I2 : Swollen bole; I3 : Canker and open wound; I5 : Hollow in bole; I6 : Sporophore; D : dbh

3.4.1. **Decay prediction equation**

The success in predicting decay volume accurately lies in identifying reliable decay indicators. Decay prediction equations were generated separately for mixed natural stand as well as for V. indicustand following stepwise regression taking all the decay indicators and tree dbh. Decay volume of *V. indica* can be predicted employing the following formulae:

$$\sqrt{DV} = \underset{(.57733)}{-1.4237} + \underset{(.15836)}{0.316215} + \underset{(.581561)}{1.5265D} + \underset{(.13660)}{0.426612}$$

where DV = decay volume (m^3),15 = hollow bole (number), D = dbh of tree (cm) and I2 = swollen bole (number). Adjusted $R^2 = 0.64197$.

The decay prediction equation generated for the mixed natural stand included more variables.

$$
\begin{array}{lcccccc}
\sqrt{DV} = & -0.6999 & + \; 0.2454116 & + \; 0.2219413 & + \; 0.73331D & + 0.1125415 & + \; 0.3732012 \\
 & (.21565) & (.07503) & (.05018) & (.20871) & (.05951) & (.05320)
\end{array}
$$

where DV = decay volume (m^3), I6 = sporophore (number),I3=canker and open wound(number), D dbh of the tree (cm), I5 = hollow bole (number), I2 = swollen bole (number). Adjusted R^2 0.65127.

4. GENERAL DISCUSSION AND CONCLUSIONS

In natural forests, decay is the most important single factor responsible for considerable loss to the standing crop. The 1956 Timber Resources Review conducted by the United States' Forest Service ranked heartrot as the major loss factor in sawn timber, accounting for 80% of the total loss through diseases (Hepting and Jemison, 1958). In India, though, such an appraisal on decay and diseases in natural forests has so far not been attempted, the timber trend study (Anon., 1958) projected combined loss in forest wealth due to causes like fire, decay, disease, insect and wind fall as 13 %. A study in sal forests (Shmea robusta Gaertn.f.) in Uttar Pradesh (Bakshi *et al.*, 1963) recorded about 73 % of decayed trees in the stands resulting in 10% loss of timber. So far, there is no information available on heartrot in natural forests in Kerala State.

Heartrot is common in relatively-aged stands and the intensity as well as the extent of decay depended upon various factors such as stand composition, age, degree of biotic and abiotic interference, site factors, etc. Usually, trees affected with heartrot exhibit almost all the outward appearance of healthy growth, which often result in faulty marking of trees for timber extraction. However, trees affected with heartrot may also exhibit certain external visible signs of decay which are called as decay indicators. In a natural stands, where trees belonging to different genera and species, age and diameter classes and containing heartrot of various extent may exhibit many of these external decay indicators. Depending on the nature, position and frequency of occurrence of these decay indicators, a well experienced forester can detect the potential defective trees in the stand. Thus, the trees suspected to contain extensive decay can either be excluded from the felling list in order to obtain a better out-turn as well as to reduce the logging expenses, or included for salvaging maximum wood and also for saving the stands from excessive loss due to decay, whichever is desirable. However, usually, the significant role of heartrot along with other cull factors in reducing the net merchantable volume of wood has been often overlooked in timber extraction in the State, and hence, the expected out-turn is not always obtained.

The foundation for tree decay studies was laid over a century ago by Robert Hartig (Merril *et al.*, 1975) who gave rise to the classical concept that most decay in standing trees originates by saprophic growth in dead heartwood. According to this concept, presence of wounds large enough to expose the heartwood allows entry of heartrot fungi which directly results in decay (Boyce, 1961; Merril and Shigo, 1979; Shigo, 1974; Shortle, 1979; Manion and Zobel, 1979). Over the past 30 years numerous studies on discoloration and decay associated with wounds, particularly of living hardwood trees have been made and the subject has frequently been reviewed (Shigo, 1974, 1984; Shigo and Hillis, 1973; Shigo and Marx, 1977; Boddy and Rayner, 1983). These studies have shown that colonization can also occur in other than heartwood by microorganisms including bacteria, non-hymenomycetes and hymenomycetes. As a result, the classical heartrot concept has been challenged and an expanded concept of tree decay has been proposed in its place (Shigo and Marx, 1977; Shigo and Hillis, 1973; Merril and Shigo, 1979). In India, Bakshi (1957) initiated the studies on heartrot in natural stands and made a quantitative account of heartrot in a sal forest (l3akshi et al., 1963). Though, a large number of polypores associated with decay of trees in natural forests in different parts of the Kerala State have been reported, so far, no quantitative as well as qualitative data on heartrot in standing trees are available. In the present study, the quantitative as well as qualitative data on the prevalence of heartrot obtained from the representative areas in evergreen, semievergreen and wet-evergreen forests of the State reveal that occurrence of decay is very high ranging from 17.6 to 23.6% in all the areas. Apart from the role of stand composition and site factors, the occurrence and the extent of loss due to decay is found to be mainly influenced by the level of biotic interference, especially the earlier logging operations carried out in the area. The nature and position of the decay indicators exhibited by the trees, especially hollow, canker and open wound of the bole, rotten branches, etc. show that many of the infection courts of the decay in standing trees may be traced back to the earlier logging injuries.

Despite the diversity of the microbes associated with heartrot of living trees, the degradation of the cell wall components is still ascribable to hymenomycetes. Of the several thousands of wood decaying fungi recorded so far, only a few hundred can cause decay in heartwood of living trees (Wagener and Davidson, 1954; Highley and Kirk, 1979). Though, quite a large number of decay fungal sporophores were collected from various localities in natural stands surveyed, only 44 polypores belonging to 18 genera were found associated with decay in living trees. Among these, only nine were causing brown-rot and all others were associated with white-rot. Among the white-rot fungi, a large number were associated with sapwood rot. Generally, in tropical forests, white-rot fungi dominate over the brown-rot fungi; brown-rot fungi are widely distributed in the coniferous forests (Ryvarden and Johansen, 1980).

Detection and estimation of heartrot in living trees in natural stands is important for exploiting the available timber resources judiciously as well as for a fair and honest deal in logging contracts. The ideal method for detecting and appraising heartrot in living trees should be rapid, simple, accurate and nondestructive. Earlier, destructive sampling methods by felling and dissecting the trees were employed for studying the decay process in trees. Ocular observations on visible external decay indicators exhibited by the treesas well as direct probinginto the heartwood of the trees were the nondestructive methods usually employed for detecting and estimating the decay in trees. Reliability on the external decay indicators for detecting the decay in different tree species has been reviewed by various workers (Foster et al., 1954; Cervinkova and Temmlova, 1966). However, such data on tropical hardwood species are meagre. Of the seven decay indicators observed in the present study, all except branch stub and rotten branches, and punk knot were found reliable estimates in detection of decay in all the twelve tree species studied. Swollen bole, sporophore, hollow bole, canker and open wound, and swollen knot are reliable indicators and these variables should be considered during marking the trees for felling.

Direct probing methods, earlier employed for detecting and appraising the heartrot include: increment boring (Dimitri, 1968; Perrin and Delatour, 1976), radiography (Miller, 1964), video processor image analyses (Blanchette, 1982), measuring the electrical resistance of wood (Skutt et al., 1972; Tattar et al., 1972; Shigo and Shigo, 1974; Shigo and Berry, 1975; Wilkes and Heather, 1982; Wilkes, 1983), transmission of ultrasonicenergy (Waid and Woodman, 1957) and borescope (Dowden, 1970), etc. The direct probing device used in the present study is a Shigometer, an electrical device for quantifying progressive stages of discolouration and decay in wood by measuring the resistance to a pulsed electric current which decreases with increase in concentration of cation due to the discolouration in the wood. A decrease in resistance of at least 75 % of the highest reading indicates the deterioration of wood tissues. Though,. Shigometer has been successfully used to detect decay in softwood as well as hardwood species in plantations (Tattar *et al.,* 1972; Shigo and Shigo, 1974), the data from the present study show certain limitations in the practical application of the device in tropical hardwood species. Drilling of probe holes in dense wood encountered difficulty and also found more time consuming. The success rate in detection of decay is much lower than that obtained from ocular observations on external decay indicators. Moreover, the use of the technique as a means of detecting decay in living trees, generally has also been questioned (Wilson *et al.,* 1982; Wilkes, 1983).

Nearly 66% of the marked trees belonging to 12 species were found affected with heartrot, entailing a loss of 7.12 % of timber. The actual loss in volume may be greater than as indicated, since gross volume of only main bole is accounted. Though, all the 12 species were affected with heartrot, the intensity and extent of volume decayed differed among the species. *V. indica* showed the highest percentage of decayed trees as well as decay volume, while *H. parviflora*, *T. bellerica* and *A. hirsutus* showed comparatively low decay percentage as well as decay volume. These observations reveal that there exists a great variation in decay resistance of wood of different timber species. Variation in decay resistance even in individual trees within a species has been recorded. This variation is possibly controlled genetically and is also due to differences in growth rate, age, size of the tree and deposition of toxic natural extractives like stilbenes in the heartwood. In natural stands, as age of the trees cannot be determined, girth of the trees forms an important variable in the selection of trees for felling. There is a direct relationship between girth of the trees and gross volume as well as decay volume. Since, heartrot is progressive, more and more wood becomes decayed with an increase in tree diameter.

Accurate prediction of decay in trees in the natural stands employing non-destructive methods will be of great help in the effective management of forest stands as a whole, as well as for deducing the net out-turn from a particular logging operation. Ocular appraisal employing decay indicators viz. swollen bole, sporophore, hollow in the bole, canker and open wound, etc. was found simple, accurate and reliable for detecting and estimating the decay in trees in the natural stands. Dbh of the tree is also found to be a dependable variable in predicting the decay volume. The relative significance of these reliable estimates may vary depending upon the tree species as observed in the case of *V. indica*. However, in a mixed natural stand, all the five ocular estimates including dbh of the tree may be used for predicting the decay volume more accurately. The prediction equations generated separately for *V. indica* stand and for the mixed natural stand will be of much use in predicting the decay volume and deducing the net merchantable volume.

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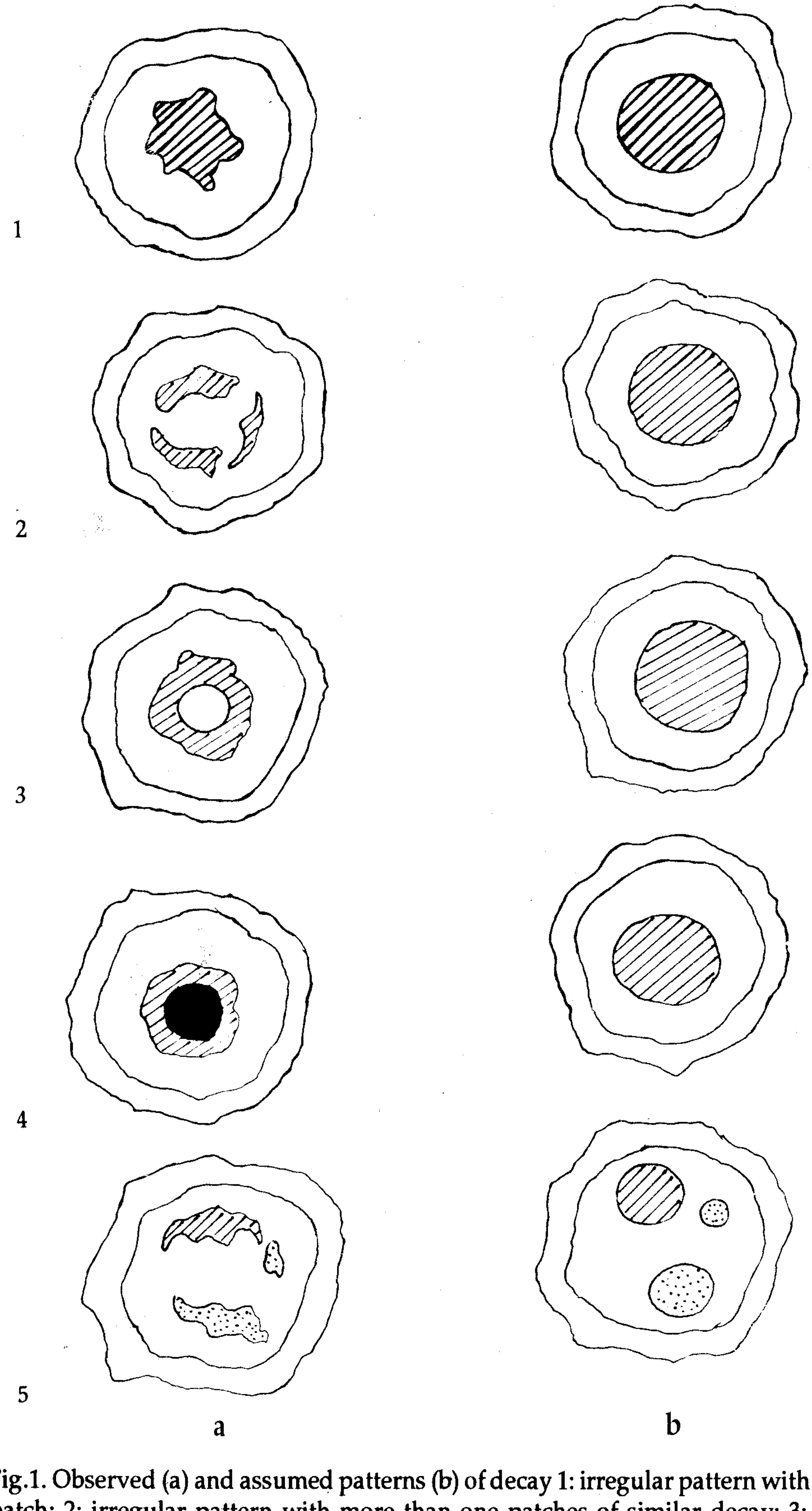

Fig.1. Observed (a) and assumed patterns (b) of decay 1: irregular pattern with single patch; 2: irregular pattern with more than one patches of similar decay; 3: decay encircling sound wood; 4: decay encircling a central hollow; 5: patches of different decays.

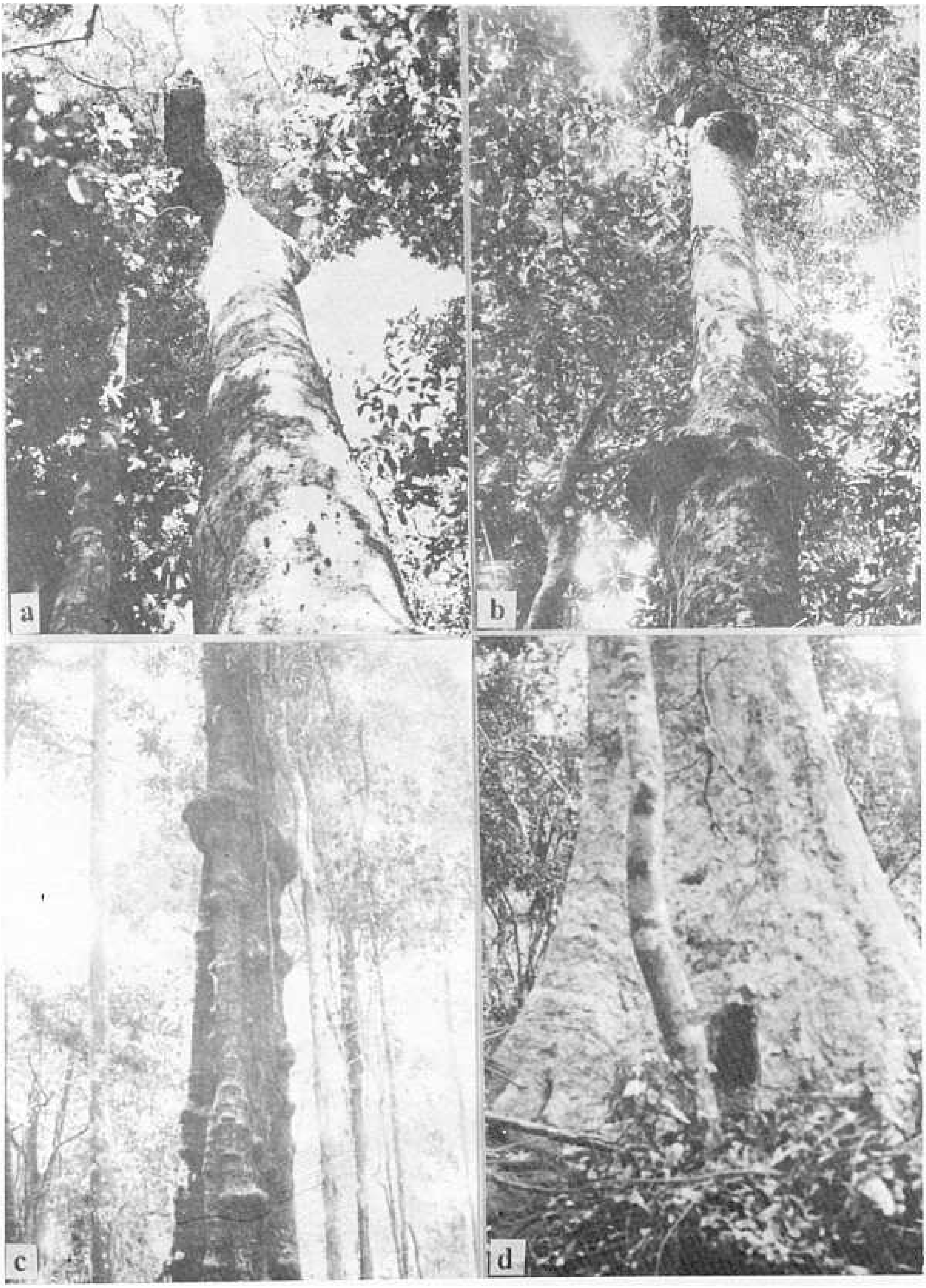

Fig.2.a-d: Trees in natural stands showing heart rot indicators. a: trees with swollen knot and decayed branch; b: tree with swollen knots; c: tree showing swollen knots from base to top of the trunk; d: hollow at the base.

Fig.3.a-c: Tree showing decay indicators (sporophores of decay fungi) a,b: trees exhibiting sporophores of *Phellinus* spp. on top (a) and basal parts of the trunk. c: Fruticification of *Lenzites* sp. on the decayed branch. d-e: detection of decay by measuring the electrical resistance of the wood; d: drilling the probe hole using battery operated drill; e: recording the electrical resistance of the wood using Shigometer.

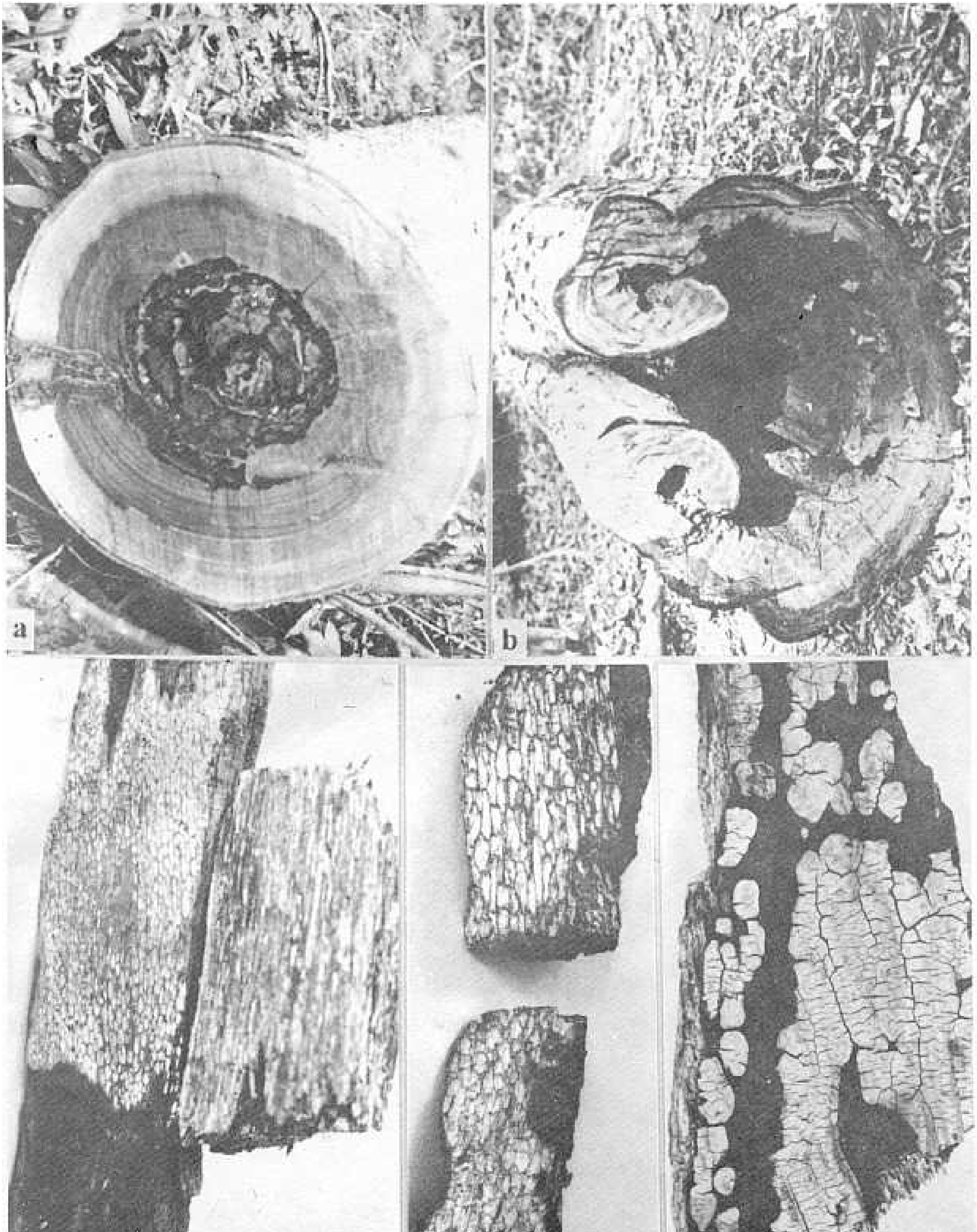

Fig.4a: Heart rot in *Vateria indica* b: heart rot in *Mesua nagassarium*; c-e: wood showing different stages of decay (white rot and brown rot).

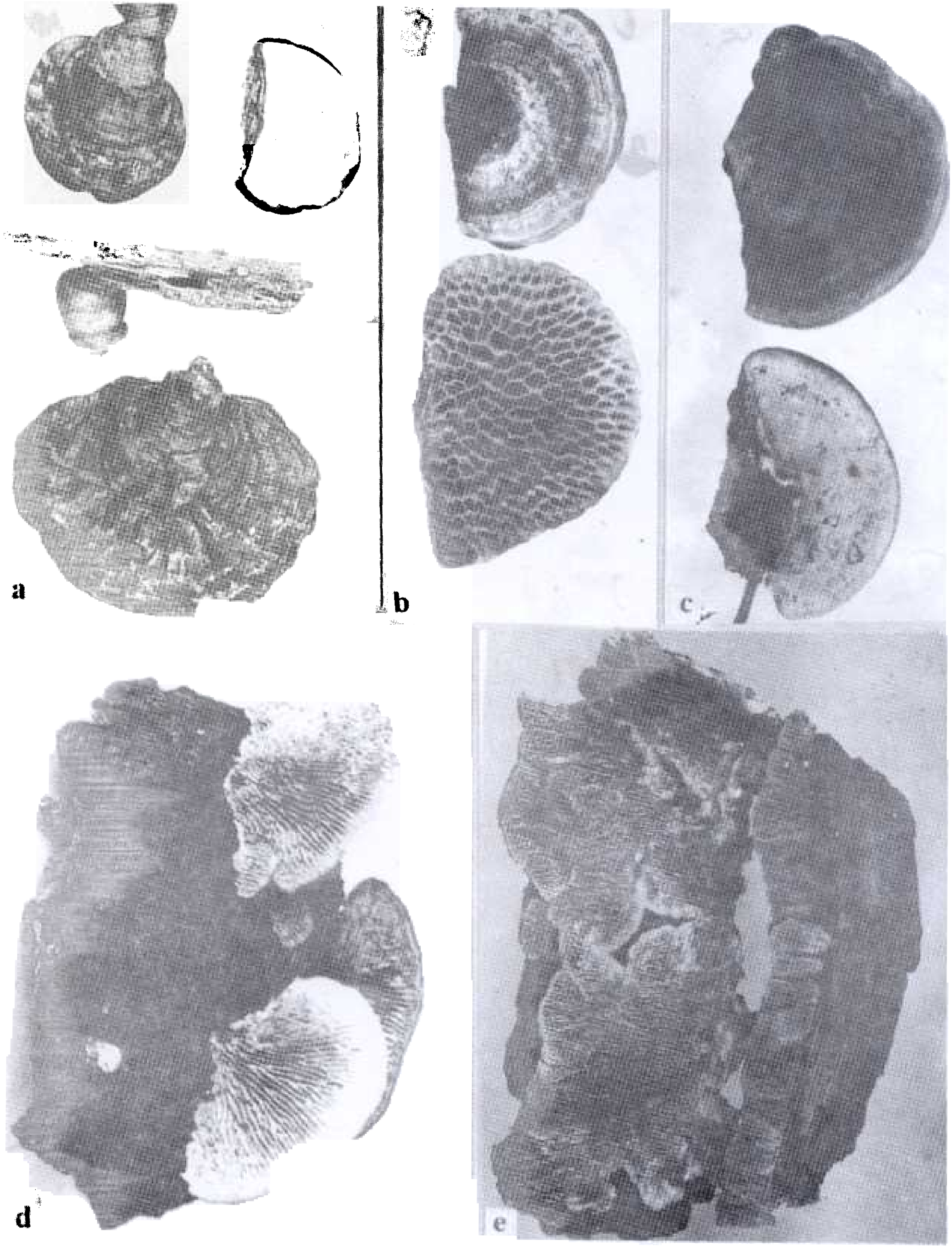

Fig.5.a-c: Decay fungal sporophores. a: *Ganoderma lucidum*; b: *Hexagonia apiaria*; c: *Fomitopsis dochmius* ; d: *Lenzites acuta* e: *Tramatus hirsuta*.

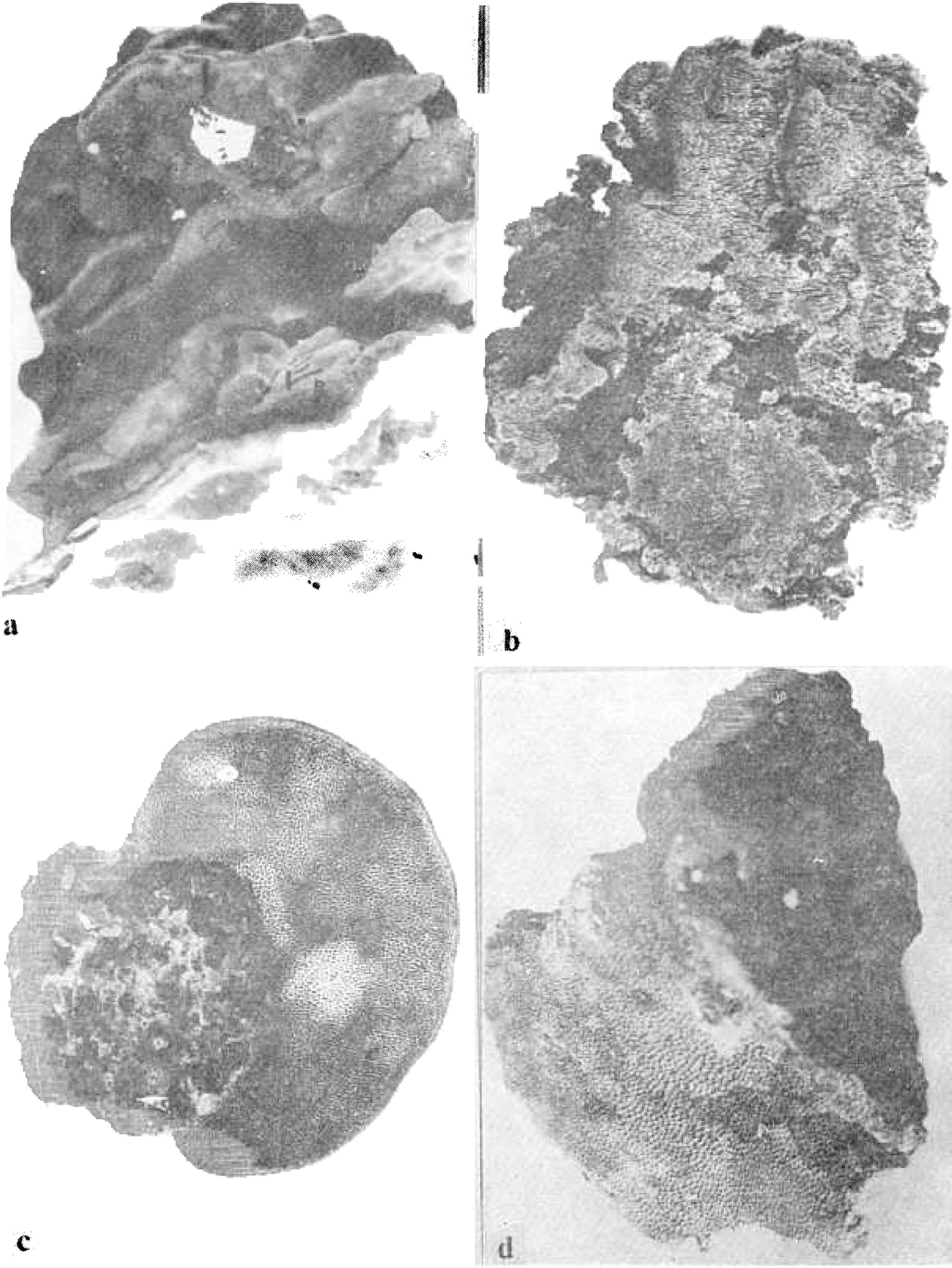

Fig.6.a-d: Sporophore of decay fungi: a: *Fomitopsis rhodophaeus;* b: *Phellinus contiguus,* c: *Phellinus rimosus* d: *P. ferreus.*