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NATURAL DECAY RESISTANCE OF SOME GHANAIAN TIMBERS AND WOOD DECAY HAZARD POTENTIAL FOR GHANA

BY

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M.Sc.F. Thesis

Submitted in partial fulfilment of the requirements for the degree of

Master of Science in Forestry

Faculty of Forestry
Lakehead University
Thunder Bay, Ontario
Canada
July, 1996.

DEDICATION

This work is dedicated to Victoria Kumi-Woode (Mrs) whose love and endurance remains my inspiration. To you darling wife I say, cheers.

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ABSTRACT

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Key words: decay resistance, agar-block, soil-block, *Coriolopsis polyzona*, *Oligoporus placentus*, *Pycnoporus sanguineus*, *Trametes versicolor*, decay index.

The natural decay resistance of 30 Ghanaian wood species, the decay capacity of four wood decay fungi, the effect of test method on fungal decay ability, and the wood decay hazard potential in Ghana were determined. Five of the wood species were rated as highly resistant, six as resistant, eight as moderately resistant and 11 as non resistant. Of the four decay fungi, *Coriolopsis polyzona*, *Oligoporus placentus*, *Pycnoporus sanguineus* and *Trametes versicolor*, only the strain of *C. polyzona* (004) induced adequate weight loss in the birch reference wood in either test methods (agar- and soil-block) for use in decay resistance rating. The two methods significantly influenced the performance of the fungi after 6 weeks of exposure with the white rot fungi showing higher decay ability in soil- than agar-block method, the converse was true for the brown rot fungus (*O. placentus*) using *Betula alleghaniensis* as substrate. However, after 12 weeks of exposure the test methods did not seem to have any effect on the performance of the fungi and resultant decay rating. Wood decay hazard in Ghana varies from areas of moderate, to those of very high potential. Generally the western part of the country has higher hazard potential than the eastern portions and the south has higher potential than the north, except for the southeastern corner which has the lowest hazard potential. Rainfall amounts, and to some extent the relief of the area, were the paramount determinants of the decay index in Ghana rather than temperature.

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CHAPTER 1

1.0 INTRODUCTION

Ghana is richly endowed with natural resources which are vital for the country's development and future prosperity. Timber has traditionally ranked third as a foreign exchange earner, and this is beside the various non-timber forest products (NTFP's) that contribute to the welfare of the people (MLF, 1993).

However, the timber trade is not without problems. As a result of rapid exploitation of commercial timber species from the forests of Ghana and the difficulty involved in the natural and artificial regeneration of some tree species, the country will in the coming years rely on the lesser utilized timber species to supply the wood needs of the country and for export. There are about 680 timber species in the natural forest of Ghana out of which only 20 are utilized economically (Hawthorne, 1990 ; Ofosu-Asiedu, 1976). Therefore there is the urgent need to shift from concentration on a few primary timber species to a broader range of species, and to divert from the traditional log and lumber production as the main export commodities from the sector to value-added products, among other initiatives. To accomplish this will require promotion of the lesser known timber species. However, a major constraint is a lack of knowledge about their distribution, stocking and wood properties (Ofosu-Asiedu, 1976).

The need for information on the distribution and stock of these timber species led to the national forest inventory project (Nolan, 1989). With the completion of inventory of the country's timber resource base, the next pressing issue is to assess the wood properties of the lesser utilized species. One important wood property is its natural durability against decomposers. Currently, research investigations into the density, physical and mechanical properties, average stem dimensions, seasoning properties, working properties and major uses of some Ghanaian timbers are being conducted while others are yet to be evaluated. Species are grouped into superior quality, high quality and lesser utilized species (Okoh, 1977a). However, few research investigations seem to have been done on the decay resistance of these species.

As is well known, some timber species are naturally durable while others are not, and therefore are very susceptible to agents of biodeterioration. Decay resistance has implications on end-use of any given species, since it determines its service-life and replacement cost. Naturally toxic compounds from durable woods may lead to the development of more effective wood preservatives, while naturally durable woods may also become an important option where there are concerns for environmental safety of wood preservatives (Zabel and Morrell, 1992). Hence resistance to fungal attack is a very desirable quality for wood utilisation.

Accelerated laboratory test of natural decay resistance is a useful method in determining the relative decay resistance between various species of wood . It is an initial means of estimating the ability of a wood species to resist severe microbial attack and for qualifying the performance level of a wood species. Ofosu-Asiedu (1976)

recommended the use of the fungi *Pycnoporus sanguineus*(L:Fr.) Murr and *Coriolopsis polyzona* (Pers.) Ryv. among others for use in evaluation of natural decay resistance of wood and preservatives due to their dominance as wood decay fungi in the country. There is the need to assess their decay ability and performance relative to fungi used in the standard decay test (ASTM, 1991) to make their use appropriate.

With the public's current environmental awareness and the decreasing resource availability, there is the need to maintain a balanced perspective on resource utilisation and conservation. To enhance the service-life of wood to facilitate efficient use of the forest resource, the biologist and wood preservers must know the decay potential at the end-use location. The extent to which most fungi decay wood depends on temperature and rainfall as the two most important climatic factors. As noted by Scheffer (1971), wood structures above ground and exposed to the weather, if not of a naturally durable species or not of a preservative-treated wood, may in certain climates be subject to decay. This is especially true of wood in ground contact. Hence, a quantitative measure of decay potential is needed to estimate needs for protective measures, especially preservative treatment. Also a knowledge of the relationship between vegetation and decay hazard potential will be useful in the estimation of one when the other is known.

This study seeks to evaluate the natural decay resistance of 30 Ghanaian timbers (14 lesser utilized and 16 primary species). Other aims will be :

1. to determine the suitability of *Pycnoporus sanguineus* and *Coriolopsis polyzona* as fungi for standard decay resistance test of tropical hardwoods,

2. to assess the effect of soil-block and agar-block cultures on decay resistance of wood, and

3. to determine the decay hazard potential for the various ecological zones in Ghana based on Scheffer's Climate Index Formula (Scheffer, 1971).

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 THE TROPICAL HIGH FOREST OF GHANA

Ghana formerly known as Gold Coast is situated on the south-central coast of West Africa and lies 850 km between latitude, 4^0 45' North and 11^0 11' North. The country is narrowly situated between longitudes 3^0 07' West and 1^0 14' East. The country covers an area of 238,539 km^2 and is bounded on the north, east and west by the Republics of Burkina Faso, Togo and Cote d'Ivoire, respectively. To the south lies the Atlantic Ocean. The country has a 560 km long coastline, and its territorial waters extend 200 nautical miles into the sea (Dickson and Benneh, 1988).

The high forest of Ghana now covers 82,000 km^2, about a third of Ghana's land area. Ghana's forests are part of the Guinea-Congolean phytogeographical region; the flora and fauna have strong affinity with the forest of Cote d'Ivoire, Liberia and Sierra Leone and to a lesser extent with the Nigerian Forest, from which they are separated by the arid "Dahomey Gap" (Sargent *et al.*, 1994).

Timber from the tropical high forest has traditionally ranked third as a foreign exchange earner, while fuelwood, bushmeat, medicinal plants and other natural products have continued to contribute to the welfare of local people (Falconer, 1992; MLF, 1993).

Nolan (1989) noted that general uses of Ghana's forest could be classified as quantifiable and non-quantifiable uses. The quantifiable ones include wood, fuel, employment, food and drink, medicines, shelter, canes, poles, chewing sticks and marantaceae leaves (wrappers). The non-quantifiable uses include environmental conservation, soil conservation, water purification, climate stability, genetic resource and wildlife habitat.

The history of forestry in Ghana dates back to 1906 when legislation was first enacted to control the felling of commercial tree species. This was soon followed by the creation of the Forestry Department in 1908. The demarcation and reservation of the forest estate was largely completed by 1939, and a Forest Policy for the entire country was adopted in 1948 (MLF, 1993).

In Ghana, the reserved forest area is divided into three "working circles" over which different management objectives are pursued. The working circles (WC) are: the Production WC, over which logging is permitted and the forest is managed for sustainable yield of timber; the Protection WC, in which no logging is permitted and the forest is managed solely for environmental protection; and the Research WC in which the forest is managed for the purposes of scientific research. The Protection WC is generally all steep slopes and all "watershed" areas including headwater catchments and river banks. Of the high forest area of 1.6 million ha., 1.1 million ha. (73%) is designated Production WC and 0.4 million ha. (27%) is designated Protection WC. The Research WC is insignificant (Ghartey, 1989).

While forest reservation has created a permanent forest estate for the welfare of

the people, protection of the water supplies, and maintenance of favourable climatic conditions for agricultural crops and soil stability, it has promoted exploitation and eventual demise of unreserved forest (MLF, 1993). However, some patches of forest outside reserves (sanctuaries) are protected locally for religious reasons (Hawthorne, 1990).

2.1.1 GHANA'S FOREST RESOURCE BASE

In the Ghanaian forests about 680 tree species are known which attain 5 cm dbh (Hall and Swaine, 1981; Hawthorne, 1990). About 420 species of these have been identified and recorded in the recent forest inventory (Ghartey, 1989). This covers all the common trees in Ghana . The remaining species are those that are rare or confined to limited habitats.

The recent forest inventory data estimates the gross national standing volume at 188 million m^3. This is made up of about 102 million m^3 in trees > 70 cm dbh (this was the lowest cutting limit as of 1989) and about 86 million m^3 in trees < 70 cm diameter (Ghartey, 1989).

2.1.2 SPECIES CLASSIFICATION

The first classification of commercial tree species in Ghana was made in the 1950's. Species were grouped into four classes depending on their economic value and growth rate of the actual and potential commercial species of the time (Ghartey, 1989). Table 1 shows the classification of the selected species under that system. Since then

many more species have come onto the market, including some which were formerly unclassified. A new classification comprising three classes was therefore proposed under the forest inventory project of 1989 (Ghartey, 1989), reflecting present-day trends in species utilisation.

Class one species are tree species recorded as having been exported from Ghana between 1973-1988. It includes the traditionally popular species of major economic importance, and those of lesser economic importance whose promotion has to be vigorously pursued. About 66 of the lesser trees in this class have been exported at least once. This class includes species used in this study except for *Albizia adianthifolia* and *Aningeria altissima* which are class two species. Class two species are those not exported but are > 70 cm dbh, and occur at a density of more than one tree per square kilometre. This class constitutes about 60 species. Class three trees involve all other species. Some species in the class were recorded as having diameters greater than 70 cm , but are considered to be anomalies *e.g.* strangling figs.

Class one and two species constitute the timber potential of the Ghanaian forest. However, all species allocated to Class one do not enjoy the same marketability. An example is *Ceiba pentandra*, which accounts for 12 per cent of the national volume of trees > 70 cm dbh, but is not currently a favoured export species. The Forest Inventory Project Classification is yet to be ratified by the Forestry Department; hence the old classification is still in use (Ghartey, 1989).

Table 1. Some economically important Ghanaian timber species.

Latin Name	Local Name	Forestry Dept. Class
Afzelia africana	Papao	3
Albizia adianthifolia	Awiefosamina	3
Amphimas pterocarpoides	Yaya	*
Aningeria altissima	Asanfena	*
Antiaris africana	Kyenkyen	2
Bombax brevicuspe	Onyinakoben	*
Canarium schweinfurthii	Bediwonua	3
Ceiba pentandra	Onyina	*
Celtis mildbraedii	Esa	3
Chrysophyllum albidum	Akasaa	3
Daniella ogea	Hyedua	*
Disthemonanthus bensamianus	Ayan	3
Entandrophragma angolense	Edinam	1
Entandrophragma cylindricum	Sapele/Penkwa	1
Entandrophragma utile	Efobrodedwo	1
Heretiera utilis	Nyankom	1
Khaya anthotheca	Krumben	1
Lophira alata	Kaku	2
Lovoa trichiloides	Dubinibiri	1
Milicia excelsa	Odum	1
Nesogordonia papaverifera	Danta	2
Pericopsis elata	Kokrodua	1
Piptadeniastrum africanum	Dahoma	2
Pterygota macrocarpa	Kyere/Koto	*
Pycnanthus angolensis	Otie	3
Strombosia glaucescens	Afena	3
Terminalia ivorensis	Emire	1
Terminalia superba	Ofram	3
Tieghemella heckelii	Baku	1
Turraeanthus africanus	Avodire	2

* Unclassified Source: Ghartey, 1989.

2.1.3 OVERVIEW OF GHANA'S TIMBER INDUSTRY AND PROSPECTS FOR FUTURE WOOD SUPPLY

Although there was a considerable decline in all sectors of the timber industry in the 1970's in logs, sawn timber and processed wood products, a dominant feature of Ghana's economy is still the production of timber for export. Ghana earned US$ 44.6 million from the timber trade in the first half of 1987. This amount accrued from the export of 267,000 m^3 of wood products. The increase in production and consequently the increase in financial returns stem from substantial resources pumped into the industry between 1983-1986 as a result of the Economic Recovery Program introduced in 1983 to provide equipment and spares, and better access and haulage facilities (Frimpong-Mensah, 1989). Table 2 shows the structure of the timber industry and indicates that the industry is mainly involved in processing of structural timber as reported by Osborne (1970).

Table 2. The structure of the timber industry in Ghana.

Type of firm	Number
Logging units	250
Furniture firms	200
Sawmills	100
Veneer slicing plants	13
Plywood mills	9
Moulding plants	7
Door manufacture	6
Chipboard plants	1

Source: Frimpong-Mensah, 1989.

Many formidable obstacles however hamper the rate of growth and development of the timber industry. The main constraints derive from environmental, management, economic, social and institutional requirements. The forests, both reserved and unreserved are being destroyed by burning (bush fires), illegal felling, and over exploitation. Although it is estimated that 101 million m^3 of marketable volume of timber is available in these forests, only a few species are being exploited, some seriously so (Baidoo, 1987; Frimpong-Mensah, 1989).

Johnson (1991) reported that by the turn of the century, half of Ghana's forest will have been lost unless present trends in exploitation are sharply reversed. The 1989 forest inventory results indicate the need to diversify species utilisation, from concentration on the traditional ones to substitutes, since the future of the industry will rely on the lesser utilised species (Ofosu-Asiedu, 1976; Ghartey, 1989). Sargent *et al.* (1994) reported that most of the primary timber species are likely to show a fall in standing volume of about 26% over the next 20 years with only very few species avoiding commercial extinction in the long run, unless there is a shift in demand for the less utilised species.

2.2 RESEARCH TRENDS IN WOOD MICROBIOLOGY IN GHANA

Timber trade in Ghana, as is the case in most developing countries, is export oriented; consequently, research into wood microbiology as with all research in the sector has been geared towards boosting the trade (Moor, 1940; Freas *et al.*, 1973).

Descriptive studies of tree species in Ghana began around the 1930s and were

revised in 1961 by Irvine (1961). Voorhoeve (1979) reported on taxonomy, uses, description and geographical distribution of timber species in West Africa. Reports on investigation of reasons for the under-utilisation of a number of secondary timber species in tropical countries where relatively few species enter the trade, particularly Colombia, Ghana, Nigeria and the Philippines, concluded that the immediate problem was lack of readily available information on the properties of these little known species (Freas *et al.*, 1973).

To address this problem with Ghanaian timbers the Forest Products Research Institute in Ghana, now Forest Research Institute of Ghana at Kumasi, embarked on a series of research programs into mechanical wood properties (Ashiabor, 1967; FPRI, 1967; Bentum, 1969; Bentum, 1970), wood seasoning characteristics (Ofori, 1985a), electrical resistivity of wood species with moisture (Okoh, 1977b), anatomical properties (Ayensu and Bentum, 1974; Ocloo and Laing, 1991), pulp and paper qualities (Smith and Primakov, 1977 ; Smith, 1978; Twimasi, 1991), uses (Bolza and Keating, 1972; Ayensu and Bentum, 1974), weathering performance (Bentum and Addo-Ashong, 1977) and corrosion resistance (Ofori, 1987).

Wood microbiology research in Ghana has mainly involved investigations into wood decay resistance (Findlay, 1942; Findlay, 1957; Puri, 1960; Amponsah, 1980), resistance to marine-borers (Rancurel, 1967; Barnacle and Ampong, 1975; Safo-Sampah, 1977; Gambetta and Orlandi, 1978; Ampong, 1977; Ampong, 1979; Saussier, 1982), wood-wool resistance to termite attack (Atuahene, 1972), resistance to termites (Bultman *et al.*, 1979; Ocloo, 1975) and field test of wood durability (Abankwa, 1970;

Ocloo, 1978; Usher and Ocloo, 1979). These tests have so far looked mainly at the traditional species and resistance to termites, ambrosia beetles and powder post beetles seems to be the main basis for durability classification as reported by Ayensu and Bentum (1974). Ofosu-Asiedu (1976) also reported on a survey of wood decay fungi in Ghana, and concluded with a proposal on pantropical fungi which may be used in accelerated laboratory test.

2.3 NATURAL DECAY RESISTANCE OF WOOD

Natural decay resistance, although often used synonymously with natural durability, is a restrictive term denoting resistance to deterioration by fungi and other microorganisms, while durability reflects resistance of wood to other deteriorating agents like insects, marine borers and weathering as well as micro-organisms (Zabel and Morrell, 1992). These terms are being used synonymously in this paper.

The benefits of using naturally durable woods have long been known (Graham, 1973). Phoenician boat builders routinely employed naturally durable cedars of Lebanon or oaks, the overuse of which contributed to the decline of natural forests along the Mediterranean (Zabel and Morrell, 1992).

With the decline in supply of naturally durable woods, interest in these species continue for many reasons including: the need to include decay resistance in tree improvement programs, knowledge of naturally toxic compounds in durable woods leading to development of effective wood preservatives, and importance of naturally durable woods in situations where environmental safety is a concern (Zabel and Morrell,

1992).

Laboratory assays to evaluate natural durability began in the 1940s in an attempt to explain further the nature of durability and identify the toxic compounds (Anderson *et al.*, 1963; Scheffer, 1957; Zabel, 1948, and Scheffer and Hopp, 1949).

Accelerated laboratory test gives useful comparison of decay resistance between timber species, which to date, have not been contradicted by the few service data and grave yard test results which are available (Osborne, 1970). The method has been used not only to evaluate the durability of various timbers, but also to assess the toxicity of wood preservative chemicals. Osborne (1970) noted that decay resistance rating is more related to above ground structural timber and is relevant to tropical timber trade. This is because interest in these rain-forest timbers lie in their use as general building timbers more than poles or posts in ground contact. Hence durability classes *viz.* highly resistant, resistant, moderately resistant and susceptible (non-resistant) classes are based on slightly less severe service conditions.

Natural decay resistance test have in some cases involved the assessment of both the resistance of the wood species to wood decay fungi and the toxicity of the wood extractives to those fungi. In most cases, warm water, ethanol, or other solvents were used to remove extractives from wood. These extractives were then tested for activity against a variety of decay and non-decay fungi (Findlay, 1957; McDaniel, 1989; Zabel and Morrell, 1992). Most tests were performed in petri dishes or decay chambers using nutrient agar. Although such tests provide a relative guide to chemical toxicity, they cannot evaluate more subtle effects such as variation in deposition of extractives in

wood and interactions between different extractives that must also play roles in natural durability.

In general, wood decay resistance has been evaluated through accelerated laboratory test by exposing wood samples to decay agents for various periods and rating the resultant degree of degradation. More elaborate tests employ grave yard test and other field tests. This allows the resistance of a given species to all wood deteriorating agents especially termites and fungi to be assessed.

Macrofungi have frequently been used as decay agents in accelerated laboratory test (Findlay, 1942; Findlay, 1957; Rudman and Da Costa, 1958; Puri, 1960; Osborne, 1970; Amponsah, 1980). The ASTM (1991) established the use of two brown-rot fungi, *viz. Gloeophyllum trabeum* (Pers. Fr.) (ATCC No. 11539) and *Poria placenta* (Fr.) Cke. (ATCC No. 11538) for determining decay resistance of softwoods and the white-rot fungus, *Trametes versicolor* (L.:Fr.) (ATCC No. 12679), was recommended for testing hardwoods. White-rot fungi , particularly *T. versicolor*, have been reported as effective hardwood decayers and have been used in several tests (Findlay, 1942; Findlay, 1957; Rudman and Da Costa, 1958; Seeham, 1976).

2.3.1 MECHANISM AND VARIATION OF WOOD DECAY RESISTANCE

Wood consists of several natural polymers and a wide range of cell-wall extractives, which are primarily localised in the heartwood. Hawley *et al.* (1924) were the first to report wood extractive toxicity as the cause of wood decay resistance. Many research investigations have confirmed wood extractives as the main mechanism for

wood decay resistance (Hart and Hillis, 1974; Hart, 1981; Deon *et al.*, 1980; Deon, 1984; Nault, 1988; Ejechi and Obuekwe, 1993), although some species with less extractive content are durable. Systemic poisons volatilising from wood were suggested by Coaton and Sheasby (1972) to kill termites in test chambers. Apart from wood extractives playing a chief role in durability, other factors like lignification, growth characteristics, organisms to which wood is exposed, and handling procedures, all play a role in wood durability.

Zainal (1976) reported that resistance of softwoods to soft-rot attack may be negated by partial delignification. Lignification is the important step in higher plant evolution that provided stiffness to stem tissues facilitating stem aerial development and protection against destruction by microorganisms (Zabel and Morrell, 1992).

Some species exhibit extreme hardness or contain large quantities of silica or calcium carbonate (Taniguchi *et al.*, 1986) which makes them resistant to marine-borer attack due to the hardness, and also alter the moisture-holding capacity, making it more difficult to wet, thereby limiting the microorganisms that can colonize them (Southwell and Bultman, 1971). However, natural durability commonly involve production of toxic chemicals during heartwood formation.

Growth factors like nitrogen content, as a result of fertilisation or site quality, are often correlated with increased susceptibility to fungal attack. Fertilisation may also produce a wider band of decay-susceptible sapwood (Merrill and Cowling, 1965). Reports on effect of density on durability is conflicting. van der Drift and Laming (1979), working with *Shorea spp.*, found a strong relationship between durability class

and density. Zabel and Morrell (1992) noted that wood density is poorly correlated with decay resistance. Findlay (1957) reported variation in decay resistance between Nigerian and Ghanaian timbers of the same species. He believed that growth conditions affected durability.

Scheffer (1936) and Scheffer and Eslyn (1961) reported that heat treatment can either volatilize or denature wood extractives, and thereby decrease natural durability. Rudman and Da Costa (1958) however, did not find kiln seasoning of wood to cause significant variation in decay resistance. Exposure to gamma radiation can adversely affect natural durability (Scheffer, 1963). Johnson and Cserjesi (1980) reported that exposure to excessive wetting led to leaching of water-soluble extractives and reduced natural durability.

Heartwood durability, as with that of any natural product , is characterised by wide variability both among species and among individuals of the same species (Scheffer and Cowling, 1966). This variation reflects both the genetic potential of a tree and the environmental conditions under which the tree is grown. The heartwood durability of a species may vary dramatically as with the difference exhibited between highly durable old-growth redwood and moderately durable second-growth timber of the same species (Clark and Scheffer, 1983), particularly, highly durable species.

The sapwood of all species, with a few exceptions is highly susceptible to decay regardless of the durability of the heartwood. White oak sapwood in the transition zone between recently formed heartwood and inner sapwood is more decay resistant than recently formed sapwood. Sapwood in the vicinity of wounds where prior injuries have

been walled off (reaction wood) is more decay resistant than the surrounding sapwood (Shigo, 1965). In those species in which true heartwood is not found, the inner stem tissues are somewhat more resistant to decay than newly formed sapwood. This may be a consequence of less nutrition, especially nitrogen.

In general, decay resistance increases from the cambium to the sapwood-heartwood interface. In many species, durability is highest near the sapwood-heartwood interface and declines toward the pith (Zabel, 1948; Scheffer and Hopp; 1949, Scheffer *et al.*,1949; Gardner and Barton, 1958; Gardner, 1960; Behr, 1974; Hillis, 1985; Hillis,1987). This decline is believed to reflect either biological detoxification, natural oxidation of heartwood extractives, or continued polymerisation of extractives to produce less toxic compounds (Anderson *et al.*, 1963). Durability may vary with stem height in that the most durable wood occurs at the base of the tree (Zabel and Morrell, 1992). Microbial activity may also reduce heartwood durability with age (Jin *et al.*, 1988; Rayner and Boddy, 1988), through fungal succession. Although variation in decay resistance in red cedar appears to be well correlated with distribution of wood extractive thujaplicin (Nault, 1988), Jin *et al.* (1988) found that thujaplicin can be converted through oxidative dimerisation and isomerisation by a *Sporothrix* isolate into thujin which is non toxic to *Poria rivulosa* (B. and C.) Cooke , a common decay fungus of western red cedar.

2.4 WOOD DECAY HAZARD

Wood is a remarkable material of great value and importance in the world economy, being used extensively as a structural material, fuel, or industrial raw material in many parts of the world (Zabel and Morrell, 1992).

One of the major drawbacks associated with the use of wood products is their susceptibility to biological deterioration. The replacement of decayed wood alone has been estimated to consume 10% of the timber cut annually in the United States (Boyce, 1961, and Zabel and Morrell, 1992). Zabel and Morrell (1992) noted that whereas wood decay results in substantial losses, labour costs involved in replacing structures, productivity losses, or liability that stems from poorly maintained wood, far exceed the raw value of the wood.

In most interior uses and many structural applications where wood is kept dry, there is no decay hazard, and this material will last indefinitely. Decay hazards are related to exterior uses of wood subjected to atmospheric wetting or other moisture sources such as soil contact (Zabel and Morrell, 1992). Scheffer (1971) noted that climatic conditions are the principal determinants of service life of wood. In a warm damp climate, for example, wood items are more prone to decay than they are in a dry or cold climate. Thus, the need for protective measures is greater in a humid than it is in a dry or a cold climate (Scheffer, 1971).

Setliff (1986), stressed the need for biologists and wood preservers to have an overall understanding of the decay potential in assessing wood decay problems in a given environment. This is due to the fact that most fungi that decay wood do so more rapidly at higher average temperatures and under moist conditions. Scheffer (1971) reported that since climatic conditions differ, the types of protective measures needed for wood items exposed to the weather differ.

The fact that preservative treatment must relate to climate objectively is an awareness that is increasing (Scheffer, 1971). The United States Federal Housing Administration recognised this for wood-frame dwellings and included in their standards a map of the continental United States showing relative decay hazards of three regions as a guide for the amount of preservative protection needed for wood structures used above ground in different regions. The United States Department of the Navy also expressed the need not only for a map, but also a formula that would quantify decay potentials of climates in localities in which temperature or rainfall varies comparatively over short distances (Scheffer, 1971; De Groot, 1982). This led to the development of a formula by Scheffer (1971).

Based on the fact that climate determines the service life of wood exposed to the weather and the assumption that temperature and rainfall are the principal factors, Scheffer (1971) developed a climate index formula. This was later referred to as a decay index formula by Setliff (1986). It is an index of the relative potential of a climate to promote decay of off-the-ground wood structures with possible adaptation of the formula to meet conditions of wood in contact with the ground. Scheffer (1971) used

the formula to determine the decay potential in the United States, while Setliff (1986) determined that for Canada. The area covered applies to temperate North America and the subtropics. This gives the decay potential for areas with moderate temperatures, and exposed to cold and or rainfall. Tropical areas of relatively high temperature and exposed to periodic rainfall, such as in Ghana, have not yet been assessed in this manner.

Ofori (1985b) reported on the Equilibrium Moisture Content (EMC) variations for various towns in Ghana as a guide of desired moisture content levels for wood preservers in seasoning wood to be used in various locations. With the current rural electrification project being undertaken in Ghana, using preservative treated teak poles as carriers, and the extensive use of wooden poles and other wood products outdoors, establishing the decay hazard potential of various regions in Ghana is deemed a worthwhile endeavour.

2.4.1 VEGETATION AND RAINFALL PATTERNS OF GHANA

Vegetation patterns and ecological zones are closely related to the distribution and incidence of rainfall and this may indicate rainfall hazard as well. The vegetational zones include: Coastal savannah, Coastal strand and Mangrove, Evergreen forest, Semi-deciduous forest and Savannah (Guinea and Sudan types).

Baker (1989) noted that the great importance of temperature in determining the distribution of vegetation on the surface of the earth is obvious from the contrast in character between the plant covers of the tropical, sub-tropical, temperate and arctic regions which enjoy similar rainfall . However, many climatologists consider rainfall

factors to be of paramount ecological significance in lowland tropical regions, particularly in determining the boundaries between forest and savannah. Again, there are variations both in amount and in distribution through the year which is ecologically important Baker (1989).

In the wettest south-western parts of the country the annual rainfall may exceed 3,000 mm falling off eastwards (Accra receives only a quarter of this) and northwards to less than 1,000 mm in the far north. Areas around the shores of Ghana experience two "peaks" of rainfall (May-June and October-November) separated by two unequal drier seasons. Passing northwards, the second peak diminishes progressively while the shorter interval between peaks also becomes constricted until at roughly $8^0 30'$ N the rainfall becomes a 'one peak' type (actual peak being in August-September) (Baker, 1989).

CHAPTER 3

3.0 METHODOLOGY

This study involved two main aspects: natural decay resistance test and wood decay hazard potential assessment. This chapter presents methods used in these two categories of the study.

3.1 NATURAL DECAY RESISTANCE TEST

The standard ASTM (1991) method of accelerated laboratory test of natural decay resistance of wood was adopted with some modification in the block size and type of lid closure. The decay resistance rating based on per cent weight loss was done in accordance with the standard where 0-10% are ranked as highly resistant, 11-24% as resistant, 25-44% as moderately resistant, and ≥45% as non resistant. The natural decay resistance test involved three series of experiments. The first experiment involved the assessment of decay ability of the wood decay fungi used. This was followed by a determination of the performance of the decay fungi in agar-block and soil-block tests and finally the assessment of the decay resistance of 30 Ghanaian timber species.

3.1.1 TEST PROCEDURE

Test fungi: Four species of wood decay fungi were used in all decay resistance tests carried out in this study. Two of the fungi were chosen in accordance with standard test for hardwoods (ASTM, 1991); *Oligoporus placentus* (Fr.) Gilb. & Ryv. (ATCC 11538), a brown rot fungus, and *Trametes versicolor* (L.: Fr.) Pilát (ATCC 12679), a white rot fungus. Both strains were recommended by the standard (ASTM, 1991) and were obtained from the Center for Forest Mycology Research (CFMR) in Madison, Wisconsin. The other two were based on the recommendation by Ofosu-Asiedu (1976): *Coriolopsis polyzona* (Pers.) Ryv. (Culture 004) and *Pycnoporus sanguineus* (L.:Fr.) Murr. (Culture 007), white rot fungi. Table 3 shows the history of the fungal isolates from Ghana. Appendix I shows the history of fungal isolates collected from Ghana and deposited at CFMR in Madison, Wisconsin.

Table 3. History of Ghanaian fungal isolates used in study.

Collection date	Culture number	Place of collection	Substrate	Deposition	Name of fungus
8 May, 1994	BKW 004	Mango Rd. Kumasi	Hardwood Stump	CFMR-Madison	*C. polyzona*
12 May, 1994	BKW 007	Buburo Rd. Kumasi	Hardwood Stump	CFMR-Madison	*P. sanguineus*

Fungal growth media : Malt agar was used as the nutrient medium for maintaining the fungal stock test tube cultures and establishing petri dish cultures of the test fungi. The medium was sterilized at 121^{0}C for 15 min. A supply of loam soil was provided as a substrate for the fungus in each soil-block test set up. The soil had a pH of 6.2 and a moisture holding capacity of 39%. The moisture content of air-dry soil, after being passed through a 3 mm sieve, was 15%. The culture chambers were 250 ml French square bottles.

Soil block test: For each soil-block jar in experiment 1, 69.4 g of water was measured into 250 ml capacity bottle (Fisher Sci. Co. AP 2105) to make up 130% of the water holding capacity of the soil. Next, 90 g of soil was added and levelled, after which a 3 x 29 x 35 mm maple (*Acer rubrum*) wood feeder strip was placed on the soil. The bottles were sterilized at 121^{0}C for 30 min. and then, after cooling, inoculated.

Agar block test: For each of the malt agar-block jars, 120 ml of 1% malt extract agar (about the same level as the soil in the soil-block set-up), sterilized at 121^{0}C for 15 min, was measured into the test bottles of 250 ml capacity. The feeder strips were sterilized under steam at 100^{0}C for 20 min and placed on the malt agar (MEA) after the latter had solidified. The jars were then inoculated by placing a piece of mycelium adjacent to the sides of the feeder strips.

Inoculation of bottles: After application of feeder strips to the bottles, fungal inoculum was cut from the petri dish culture and placed on the soil next to and in contact with the edge of the feeder strip. The bottles, with lids closed, were incubated at 24^{0}C and 70 % relative humidity for three weeks, by which time all the feeders were covered with

mycelium. The test blocks were then placed on them after their initial weighing.

Lid closure: Culture bottles were covered with lids with 5 mm air exchange holes bored through them that were sealed with autoclavable filter paper of coarse porosity (No. 4). The filter papers were glued to the lids with epoxy cement. The lids were wet-heat sterilised under pressure at 121^{0}C for 15 min and used to seal the bottles to prevent infection by mites and other insects during the experimental period (Smith, 1978).

Test blocks: The test blocks used in all investigations under this study were 14 x 14 x 14 mm in size. The test blocks were oven-dried overnight at 105^{0}C after which their initial weight (W_1) was taken to the nearest 0.01 g. The weighed blocks were then sterilised under steam at 100^{0}C for 20 min. After cooling, the blocks were placed two to a bottle, with cross section face down on the feeder strips in the prepared test bottles. The test blocks as well as the bottles were labelled to avoid losing their identities.

Incubation stage: The test blocks were then incubated at 26^{0}C ± 2 and about 70% relative humidity for the entire period of decay.

Termination of experiment and final response measurement: At the end of the exposure period, the test blocks were removed from the bottles, and carefully brushed of any surface mycelium. The blocks were then oven-dried at 105^{0}C for 24 hours and the final weight measured to the nearest 0.01 g and recorded as W_2.

Per cent weight loss in the individual test blocks was calculated as follows;

$$\text{Weight loss, \%} = \{(W_1 - W_2)/ W_1\} \times 100$$

3.1.2 EVALUATION OF NATURAL DECAY RESISTANCE OF THE SELECTED GHANAIAN TIMBERS.

Wood species: Thirty Ghanaian timber species (14 lesser utilised and 16 primary species) were selected based on their relative abundance, history of local utilisation, performance in the Ghanaian timber trade and literature on potential use(s).

Samples were taken randomly from yard piles in sawmills at Takoradi (Western region), Kumasi (Ashanti region) and Mim (Brong Ahafo region) in Ghana, because they are located in the forest zone where about 90% of the timber industries are located. Samples for each species were selected randomly from sawn lumber piles (samples from each pile were assumed to come from different tree sources). Table 4 shows the sources and economic rating of the various species.

Table 4. Economic rating and source of selected Ghanaian timber species.

Wood Species Latin Name (Local Name)	**Economic Rating**	**Source of Sample**
Afzelia africana SM. (Papao)	Major	Takoradi
Albizia adianthifolia (Schum.) Wight (Awiefosamina)	Minor	Kumasi
Amphimas pterocarpoides Harms (Yaya)	Minor	Kumasi
Aningeria alitissima Aubrev. & Pellegr. (Asanfena)	Minor	Kumasi
Antiaris africana Engl. (Kyenkyen)	Major	Takoradi
Bombax brevicuspe Sprague (Onyinakoben)	Minor	Takoradi
Canarium schweinfurthii Engl. (Bediwonua)	Minor	Takoradi
Ceiba pentandra (L.) Gaertn. (Onyina)	Minor	Takoradi
Celtis mildbraedii Engler (Esa)	Minor	Takoradi
Chrysophyllum albidum G. Don (Akasaa)	Minor	Mim

Daniella ogea (Harms) Rolfe ex Holl. (Hyedua)	Minor	Kumasi
Disthemonanthus bensamianus Baill. (Ayan)	Minor	Mim
Entandrophragma angolense (Welw.) DC. (Edinam)	Major	Takoradi
Entandrophragma cylindricum Sprague (Sapele)	Major	Takoradi
E. utile (Dawe & Sprague) Sprague (Efodrodedwo)	Major	Takoradi
Heretiera utilis Sprague (Nyankom)	Major	Takoradi
Khaya anthotheca (Welw.) DC. (Krumben)	Major	Takoradi
Lophira alata Banks ex Gaertn. F. (Kaku)	Major	Kumasi
Lovoa trichiloides Harms (Dubinibiri)	Major	Takoradi
Milicia excelsa A. Chev. (Odum)	Major	Kumasi
Nesogordonia papaverifera (A. Chev.) Caparon (Danta)	Major	Takoradi
Pericopsis elata (Harms) V. Meeuwen (Kokrodua)	Major	Takoradi
Piptadeniastrum africanum (Hook F.) Brenan (Dahoma)	Major	Kumasi
Pterygota macrocarpa K. Shum. (Kyere)	Minor	Kumasi
Pycnanthus angolense (Welw.) Warb. (Otie)	Minor	Kumasi
Strombosia glaucescens Engler (Afena)	Minor	Kumasi
Terminalia ivorensis A. Chev. (Emire)	Major	Kumasi
Terminalia superba Engl. & Diels (Ofram)	Minor	Kumasi
Tieghemella heckelii (A. Chev.) Roberty (Baku)	Major	Takoradi
Turraeanthus africanus (Welw. ex DC.) Pellegr. (Avodire)	Major	Takoradi

Sample quality and replication: Only clear heartwood samples were used. Wood blocks were cut into 14 x 14 x 14 mm sizes as experimental units. The number of block replications per test variable (fungus and sample) was six.[1]

[1] Much of the wood material to be used in this study disappeared from the wood shop the night before they were to be cut (September 10, 1994); samples were taken from single pieces of heartwood that remained for the various species hence six replicates were used instead of 20. This serves as the main limitation for the work and makes it a preliminary assessment of the decay resistance of the 30 species.

Response variable: Per cent weight loss in wood blocks after 12 weeks was the response measure. Mean per cent weight loss was used to rank decay resistance of the various wood species.

Reference blocks: Sixteen blocks of birch sapwood were used to test the decay ability of each fungus i.e. 64 blocks for the four fungi species. The test was run for 6 and 12 weeks to establish an approximate time wherein the birch sapwood reference blocks would have lost 60% of their initial weight.

Feeder strips: Strips of quarter sawn 3 x 29 x 35 mm maple (*Acer rubrum*) wood were used as feeder strips for the brown rot fungi, *Oligoporus placentus,* set-ups, while filter paper of coarse porosity (No. 4) 29 x 35 mm was used for the white rots (Highley, 1978).

3.1.3 DETERMINATION OF THE PERFORMANCE OF *CORIOLOPSIS POLYZONA* AND *PYCNOPORUS SANGUINEUS* AS FUNGI FOR STANDARD DECAY RESISTANCE TEST.

Clear *Betula alleghaniensis* (Birch) wood, *Strombosia glaucescens* (Afena) sapwood and *Celtis mildbraedii* (Esa) heartwood blocks of 14 x 14 x 14 mm dimensions were used to determine decay ability of *Coriolopsis polyzona* (Culture 004) and *Pycnoporus sanguineus* (Culture 007) as well as preliminary assessment of their comparative performance in decay resistance testing with *Oligoporus placentus* (ATCC 11538) and *Trametes versicolor* (ATCC 12679) .

Factors considered for the preliminary assessment include: test fungi and wood

species with six replicates. Per cent weight loss after 12 weeks of exposure was the response variable.

Their performance in decay resistance test was compared to those of *Oligoporus placentus* (ATCC 11538) and *Trametes versicolor* (ATCC 12679) for the 30 selected Ghanaian timbers after 12 weeks of exposure.

3.1.4 A COMPARISON OF THE EFFECT OF SOIL-BLOCK AND AGAR-BLOCK CULTURES ON DECAY RESISTANCE RATING

Non-decay resistant hardwood species of *B. alleghaniensis*, *S. glaucescens* sapwood and *C. mildbraedii* heartwood blocks were exposed to the four decay fungi in agar-block and soil-block cultures for 12 weeks. The fixed factors are wood species, fungi and culture media with six replicates per treatment combination. The response variable was per cent weight loss after 12 weeks of exposure.

3.1.4 VERIFICATION EXPERIMENT (EXPERIMENT 2)

A series of supplementary experiments (experiment 2) were carried out to verify the results obtained from those above to determine the source of variation in blocks of the same wood species exposed to the same fungus. A 6-week agar- and soil-block test using *B. alleghaniensis* and *C. mildbraedii* exposed to all four fungi species was carried out. The soil used in this test has water holding capacity of 26% and moisture content of air-dry soil of 14% with pH 6.2.

The decay resistance of the various wood species was verified using four of the

species determined from the 12-week soil-block test to be highly resistant, three of the resistant, three of the moderately resistant, all 10 of the non resistant species and the reference wood (*Betula alleghaniensis*) exposed to two wood decay fungi (*Coriolopsis polyzona* and *Oligoporus placentus*). In the case of *Bombax brevicuspe* and *Ceiba pentandra* all four fungal species were used since there was indication of higher decay ability of all the fungi when exposed to these wood species. Experimental duration in this test was 10 weeks. All other conditions were similar except for the shorter duration, cutting of inner lid seal around the hole before glueing the autoclavable filter paper into the lid to seal the hole, *i.e.* to ensure a clear seal. Moisture content in this test was the same as in experiment 1, except that 4 ml of water was added to each soil-block test jar after 6 weeks of exposure when some jars showed signs of drying out.

3.2 WOOD DECAY HAZARD POTENTIAL IN GHANA

Rainfall and temperature data for 10 years (1986-1995) from Ghana Meteorological Services records for 23 towns were selected randomly to represent their respective vegetational zones and wood decay hazard potential assessed for these zones using Scheffer's climate index formula (Scheffer, 1971). Five vegetational zones were identified based on the classification by Boateng (1966) as shown in Fig. 1.

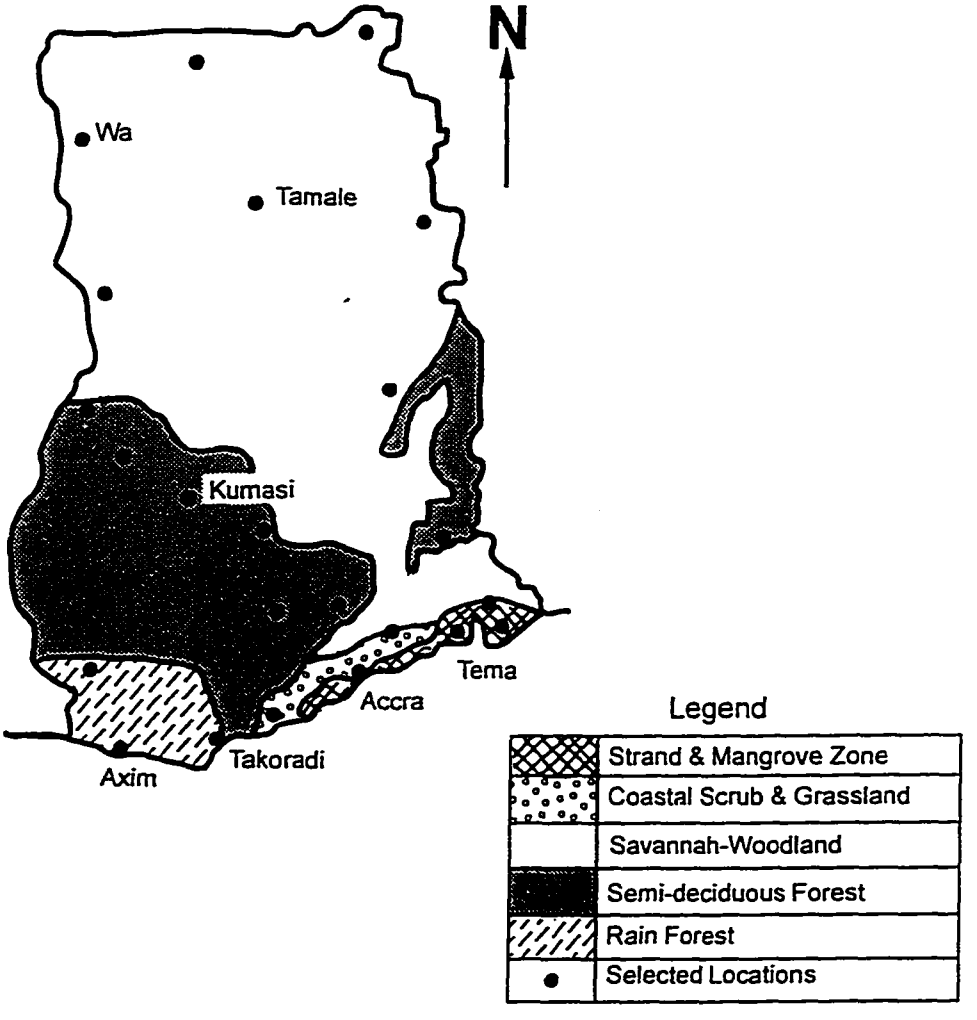

Figure 1. Vegetational map of Ghana showing selected locations .

Source: Modified from Boateng (1966)

Three towns each were chosen to represent the three relatively smaller zones (Rain Forest, Coastal Scrub and Grassland, and Strand and Mangrove Zone) and seven towns each were chosen to represent the larger (Semi-deciduous Forest and Guinea Savanna-Woodland) zones.

The climate (decay) index was calculated by using Scheffer's formula:

$$Decay-Index=\frac{1}{17}\sum_{JAN}^{DEC}(T-2)(D-3)$$

where T is the mean monthly temperature (°C), and D is the mean number of days in the month with 0.25 mm or more of precipitation.

CHAPTER 4

4.0 RESULTS

The two main study categories are wood decay resistance test and the wood decay hazard potential in Ghana. Results are presented under these two headings.

4.1 WOOD DECAY RESISTANCE TEST

Assessment of the decay resistance for the various wood species (main objective) began after preliminary assessment of the decay ability of test fungi and determination of a suitable time period for establishing decay resistance with the soil- and agar-block methods. The mean per cent weight loss of birch *(Betula* sp.), as a reference wood, was established after 6 (two experiments) and 12 weeks of exposure to four fungal species. The test also involved assessing two test methods: agar- and soil-block tests. In another test the performance of the various wood decay fungi in agar- and soil-block test were assessed using three wood species (including the reference wood) under exposure time of 12 weeks.

Table 5 shows the mean percentage weight loss of the reference wood to the four fungal species using the two test methods over 6 weeks of exposure in two experiments,

including *Celtis* sp. in the second test and together with two other wood species after exposure to the various fungi for 12 weeks. Table 5 indicates that all the fungal species caused mean percentage weight loss of less than 60% in the reference wood after 6 weeks of exposure in both test methods.

Table 5. Mean per cent weight loss of wood blocks exposed to four different fungi for 6- and 12-week duration in two culture media (agar and soil).

Duration	Culture medium	Wood species	C. polyzona		O.placentus		P.sanguineus		T. versicolor	
			Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
6 weeks	Agar	*Betula sp.*	29.4	15.9	49.4	43.2	7.0	5.1	3.8	4.3
	Soil	*Betula sp.*	56.7	11.6	12.7	15.0	11.7	8.0	4.3	1.6
	Agar	*Celtis sp.*		17.8		0.9		2.7		3.2
	Soil	*Celtis sp.*		21.5		18.8		28.3		3.9
12 weeks	Agar	*Betula sp.*	65.8		58.8		14.7		6.9	
	Soil	*Betula sp.*	85.1		14.2		25.2		4.5	
	Agar	*Celtis sp.*	58.4		8.1		12.0		3.8	
	Soil	*Celtis sp.*	65.1		18.2		19.3		2.9	
	Agar	*Strombosia sp. (Sapwood)*	51.6		3.8		11.4		2.6	
	Soil	*Strombosia sp. (Sapwood)*	51.2		12.5		16.5		1.8	

The weight loss caused by *Coriolopsis polyzona* was highest followed by *Oligoporus placentus, Pycnoporus sanguineus* and *Trametes versicolor*. The ability of the fungi to decay the test blocks varied with test method. After six weeks of exposure all the white rots (C. *polyzona and P. sanguineus)* except *T. versicolor* caused

relatively higher per cent weight loss in the soil-block method than in the agar-block test using both *Betula* sp. and *Celtis* sp. *Oligoporus placentus,* a brown rot fungus, on the other hand showed greater decay ability in agar-block test using *Betula* sp., as shown in Table 5, after six weeks of exposure in both experiments. The fungal species all showed different decay abilities in both agar- and soil-block methods. *C. polyzona* showed the highest decay ability in both media followed by *O. placentus and P. sanguineus,* T. *versicolor* showing the lowest performance. Decay rate was slower in the second experiment after 6 weeks of exposure.

Table 5 indicates that after 12 weeks of exposure to the reference wood (birch) only C. *polyzona* could cause appreciable decay (up to 60%) to merit use in assessing wood decay resistance using the soil block method, although all of the fungal species showed a common trend of increasing decay resistance from birch *(Betula sp.), Celtis* sp. *to Strombosia* sp. Only *C. polyzona* caused per cent weight loss greater than 60% in both agar and soil block tests. *O. placentus* which showed the second highest decay performance caused mean per cent weight loss of 58.8% in the agar block method and 14.2% in soil block.

Table 6 shows the decay resistance of the 30 Ghanaian timbers. The decay resistance of 30 Ghanaian timber species were assessed by exposing wood blocks to the four wood decay fungi for 12 weeks and in a repeat experiment using two fungi for 10 weeks. The decay resistance rating was based on the resistance of the various wood species to *Coriolopsis polyzona* because (Table 5), there was significant variation in the decay ability of the fungi (Table 6). Only C. *polyzona* caused significant weight loss

(over 60%) in the reference wood and other wood species rated as non-resistant in the preliminary assessment (Table 5).

Based on their resistance to *C. polyzona,* five of the selected species *(P. elata, A. Africana, L. alata, E. utile* and *T. heckelii)* were rated as highly resistant to decay, four were resistant *(H. utilis, T. ivorensis, M. excelsa and S. glaucescens),* 10 *(A. adianthifolia, L. trichiloides, E. cylindricum, K. anthotheca, D. benthamianus, A. pterocarpoides, C. albidum, P. africanum, E. angolense* and *N. papaverifera)* were moderately resistant and 11 were non resistant *(T. superba, P. angolensis, A. altissima, C. schweinfurthii, D. ogea, T. africanum, B. brevicuspe, C. mildbraedii, C. pentandra, P. macrocarpa and A. africana).* The mean per cent weight loss and subsequent decay resistance rating are shown in Table 6. The detailed results for each experimental set-up and treatment combinations are shown in Appendix I, II and III.

Table 6. Decay resistance of 30 Ghanaian timber species.

Wood species	Duration (weeks)	Mean percentage weight loss				Decay resistance rating
		C. polyzona	*O. placentus*	*P. sanguineus*	*T. versicolor*	
P. elata	12 10	1.22 4.31	0.00 0.92	1.88	0.73	**Highly resistant (≤10%)**
T. heckelii	12 10	8.80 5.65	1.01 0.01	3.09	1.60	**Highly resistant**
L. alata	12 10	3.04 5.19	0.34 1.13	3.97	0.46	**Highly resistant**
E. utile	12	4.7	9.53	7.32	0.66	**Highly resistant**
Afzelia africana	12 10	2.69 7.63	4.10 0.54	5.26	2.58	**Highly resistant**
H. utilis	12 10	10.66 14.20	13.43 9.34	6.66	0.71	**Resistant (10<x<25%)**
T. ivorensis	12 10	10.68 9.40	0.82 0.00	3.83	0.59	**Resistant**
M. excelsa	12	11.10	0.86	3.96	1.59	**Resistant**
S. glaucescens	12 10	14.57 12.34	14.72 9.86	6.45	0.53	**Resistant**
A. adianthifolia	12 10	25.85 18.37	23.32 12.79	10.81	0.67	**Moderately Resistant (24<x<45)**
**P. africanum*	12	27.60	11.73	11.32	1.54	**Resistant**
***E. cylindricum*	12	27.23	9.57	9.96	0.98	**Resistant**
L. trichiloides	12	26.11	25.03	13.27	0.00	**Moderately Resistant**
K. anthotheca	12	29.13	18.24	10.91	0.33	**Moderately Resistant**
D. benthamianus	12	29.15	25.05	11.11	0.22	**Moderately Resistant**
A. pterocarpoides	12 10	29.51 30.87	10.83 11.09	9.48	2.27	**Moderately Resistant**
C. albidum	12	30.00	23.76	22.71	0.20	**Moderately Resistant**

E. angolense	12	25.86	3.37	7.11	0.58	**Moderately Resistant**
N. papaverifera	12	37.31	23.21	13.64	0.20	**Moderately Resistant**
T. superba	12 10	42.50 45.92	12.56 21.63	16.73	3.00	**Non-Resistant (>45)**
P. angolensis	12 10	47.52 48.04	10.05 42.39	20.73	2.46	**Non-Resistant**
A. altissima	12 10	47.98 44.65	11.77 23.33	19.77	1.79	**Non-Resistant**
C. schweinfurthii	12 10	49.62 47.74	36.12 38.11	18.45	1.29	**Non-Resistant**
D. ogea	12 10	57.30 46.14	52.44 25.03	15.55	1.65	**Non-Resistant**
T. africanum	12 10	57.64 48.21	30.78 28.14	21.59	0.75	**Non-Resistant**
B. brevicuspe	12 10	63.44 49.54	37.26 27.22	21.58 26.51	18.89 14.76	**Non-Resistant**
C. mildbraedii	12 10	65.07 49.86	18.20 36.56	19.33	2.88	**Non-Resistant**
C. pentandra	12 10	66.66 54.25	15.57 29.82	18.39 27.10	23.90 17.89	**Non-Resistant**
P. macrocarpa	12 10	72.24 49.34	50.42 41.62	11.15	4.81	**Non-Resistant**
A. africana	12 10	72.72 47.34	45.11 35.96	18.12	2.37	**Non-Resistant**
@Betula sp.	12 10	85.10 46.63	14.20 31.82	25.2	4.5	**Non-Resistant**

@Reference block *based on weight loss of four most decayed blocks ** Based on two blocks.

4.2 WOOD DECAY POTENTIAL IN GHANA

Wood decay hazard potential for various locations in Ghana as determined from 1986-1995 temperature and rainfall data for selected towns are shown in Table 7. Appendix IV shows the annual decay indices for the various towns over a 10-year period.

Decay hazard ratings were earlier established: 0-35 (low), 36-70 (moderate), 71-100 (high) and >100 as (very high) (Scheffer, 1971). The highest three ratings are represented in Ghana (Table 7). The areas with moderate rating were classified as "A" and "B" with "A" representing areas to the north of the country and "B" for areas along the coast. Table 7 shows that the lowest decay index values occur in the moderate "B" location. Lower latitudes had higher decay index values than those of higher latitudes, although the latter are closer to the equator. This gives an indication that the prevailing winds from the ocean and topography rather than the proximity to the equator seems to play an important role in determining the rainfall and temperature regimes for a given area when all the areas lie in the coastal tropics.

A very high decay hazard rating is represented by nine of the selected towns, a high rating by six towns and eight of the towns had a moderate rating.

Table 7. Decay indices of various towns in Ghana.

Town	Latitude	Longitude	Decay index	Decay hazard rating
Axim	04° 52' N	02° 14'W	159	Very high
Akim-Oda	05° 56'N	00° 59'W	144	Very high
Sefwi-Bekwai	06° 12'N	02° 20'W	139	Very high
Koforidua	06° 05'N	00° 15'W	132	Very high
Ho	06° 36'N	00° 28'E	115	Very high
Kumasi	06° 43'N	01° 36'W	114	Very high
Abetifi	06° 40'N	00° 45'W	112	Very high
Takoradi	04° 53'N	01° 46'W	105	Very high
Sunyani	07° 20'N	02° 20'W	105	Very high
Wenchi	07° 45'N	02° 06'W	96	High
Kete-Krachi	07° 49'N	00° 02'W	89	High
Yendi	09° 27'N	00° 01'W	83	High
Akuse	06° 06'N	00° 07'E	78	High
Bole	09° 02'N	02° 29'W	74	High
Saltpond	05 ° 12'N	01° 04'W	71	High
Wa	10° 03'N	02° 30'W	70	Moderate "A"
Tamale	09° 30'N	00° 51'W	66	Moderate "A"
Navrongo	10° 54'N	01° 06'W	60	Moderate "A"
Bawku	11° 04'N	00° 15'W	60	Moderate "A"
Akatsi	06° 07'N	00° 48'E	60	Moderate "B"
Accra	05° 36'N	00° 01'W	48	Moderate "B"
Ada	05° 47'N	00° 38'E	46	Moderate "B"
Tema	05° 37'N	00° 00'	41	Moderate "B"

The climate index for the five vegetational zones is shown in Table 8. Table 8 indicates that the forest zones in Ghana have very high decay hazard rating (Rain and Semi-deciduous forests), the Savanna woodland has high hazard rating, while the Coastal grassland and Mangrove zones have moderate hazard ratings. Locations in the Savanna woodland vegetational zone shows two sub-groups: high and moderate decay hazard areas. Three towns , Kete-Krachi, Yendi and Bole which are southern locations in the Savanna zone show high rating, while Wa, Tamale, Bawku and Navrongo which are northern locations represent areas to the north of the country and have moderate hazard rating. This indicates a transition from north to south of moderate to high hazard rating. The decay hazard potential increases from Strand and Mangrove zone through Coastal scrub and grassland, Savanna woodland, Semi-deciduous forest to the Rain forest. This shows that wood decay hazard potential and vegetation in Ghana and probably other tropical areas are influenced by the same factors.

Table 8. Decay indices for the various vegetational zones in Ghana.

Vegetational Zone	Town	Decay Index	Zone Decay Index (mean)	Decay Hazard Rating
Rain forest	Axim	159	134	Very high
	Sefwi-Bekwai	139		
	Takoradi	105		
Semi-deciduous	Akim-Oda	144	117	Very high
	Koforidua	132		
	Ho	115		
	Kumasi	114		
	Abetifi	112		
	Sunyani	105		
	Wenchi	96		
Savanna-Woodland	Kete-Krachi	89	72	High
	Yendi	83		
	Bole	74		
	Wa	70		
	Tamale	66		
	Bawku	60		
	Navrongo	60		
Coastal scrub & Grassland	Akuse	78	66	Moderate
	Saltpond	71		
	Accra	48		
Strand & Mangrove	Akatsi	60	49	Moderate
	Ada	46		
	Tema	41		

Figure 2 shows the general trend of annual variation in decay index values for the various hazard zones over a 10-year period (1986-1995). Although there is annual variation in the decay index for each hazard zone, the index value still fall mostly within the rating ranges for each of the zones. The general trend for the various zones follows a descending order of magnitude in decay index from very high, high, moderate "A" to moderate "B". The decay index establishes that areas along the eastern coast of the country (moderate "B") are the driest part of the country.

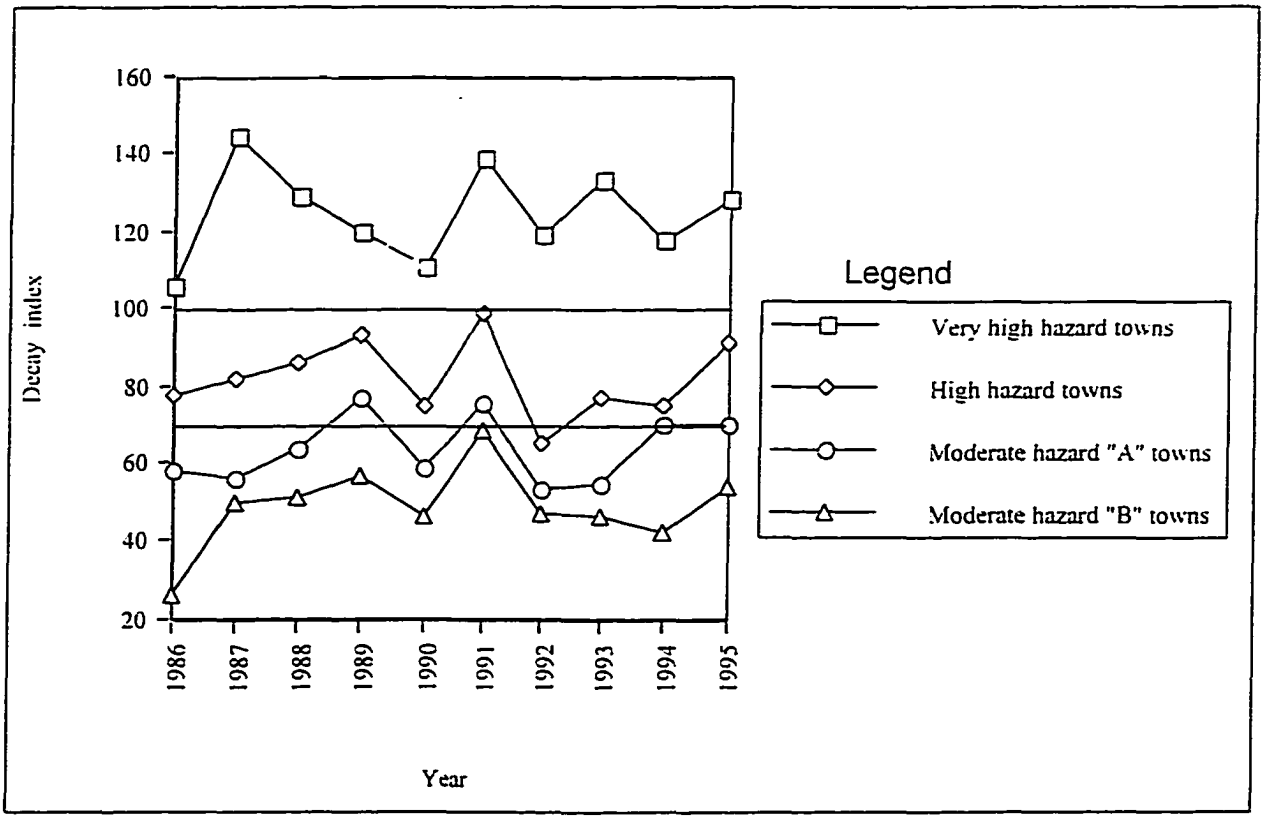

Figure 2. Annual decay index variation for the four decay hazard zones.

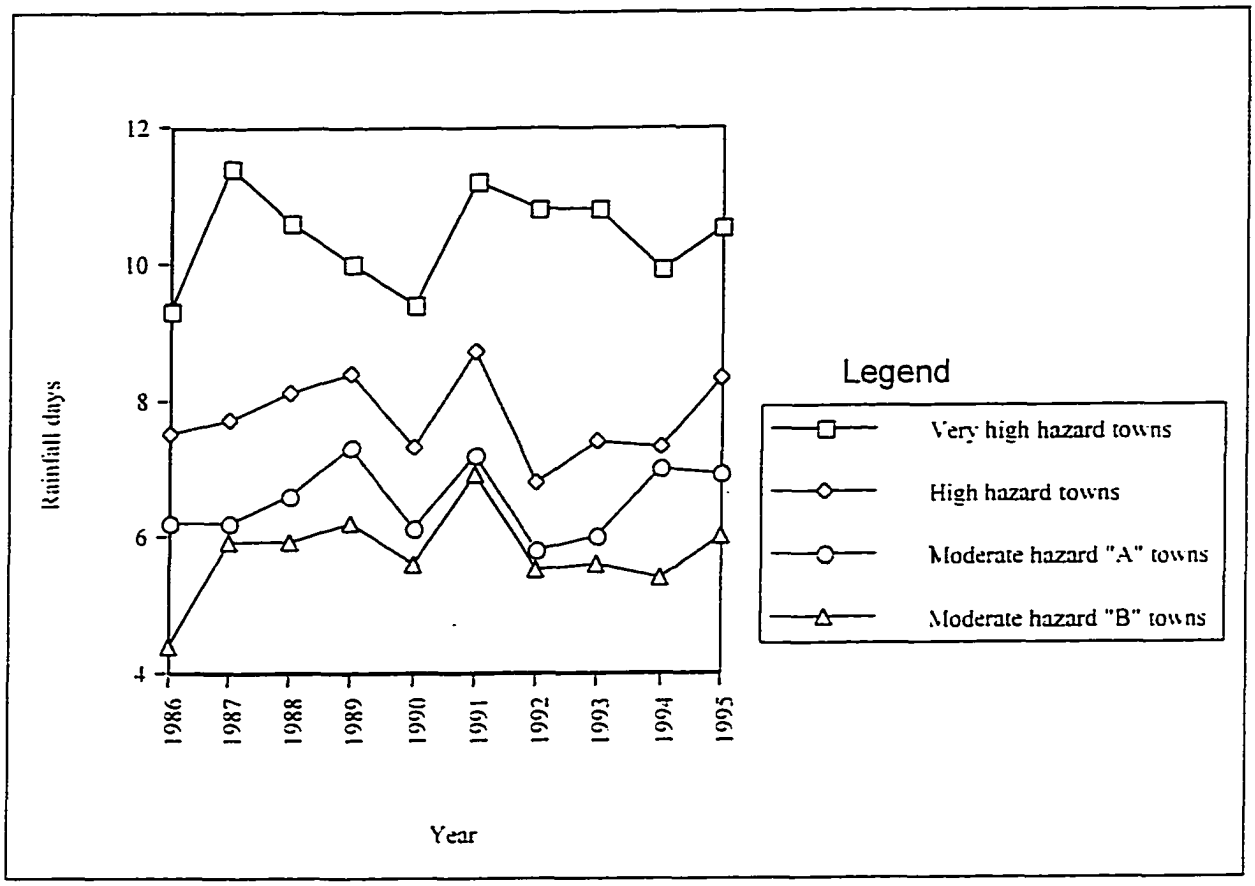

Figure 3. Mean annual rainfall days >0.25 mm over a 10-year period for the four hazard zones.

The mean rainfall amounts for the four zones over the 10-year period (Figure 3) relate well with their decay index variation over the same period (Figure 2) indicating that rainfall amounts greatly influence the decay index and hence the decay hazard potential.

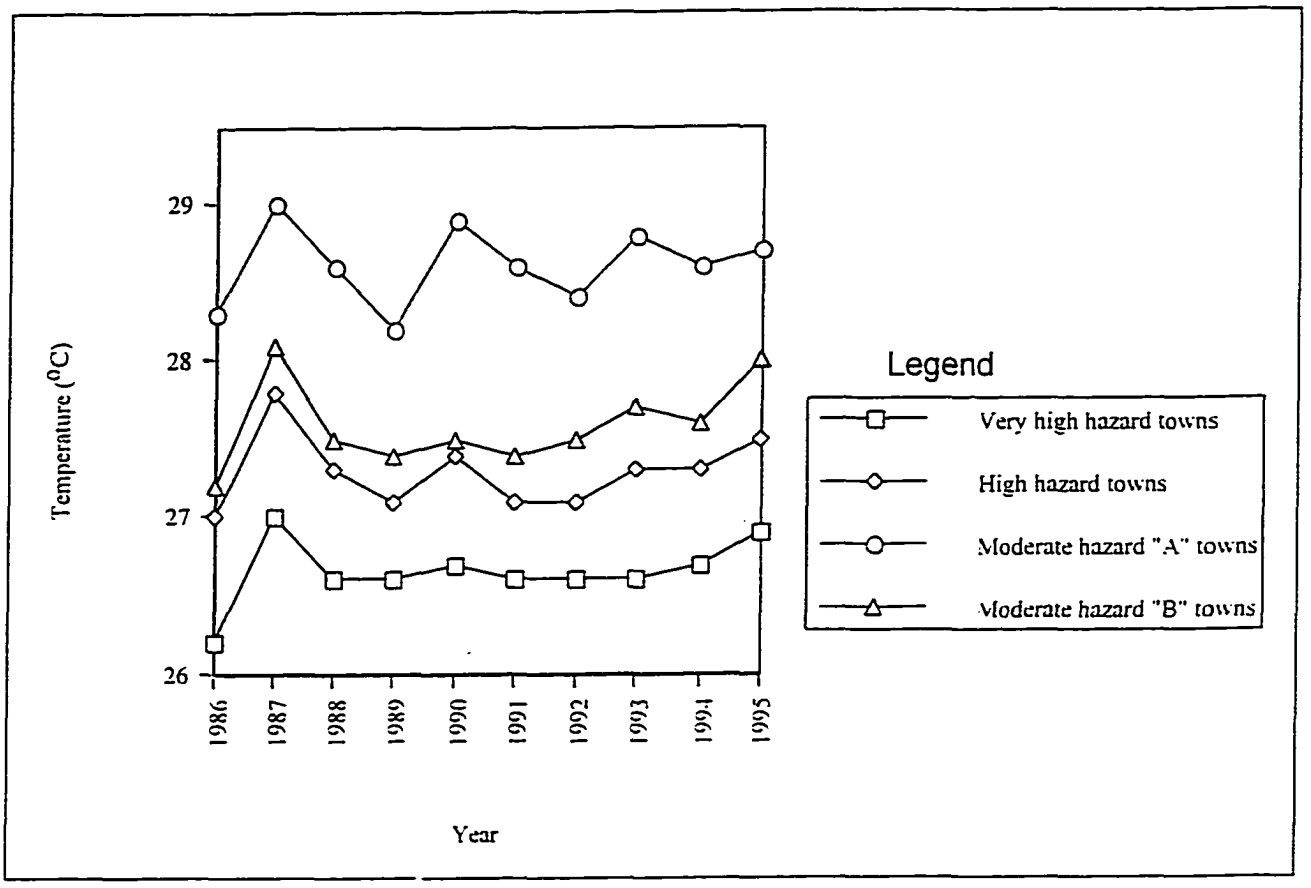

Figure 4. Mean annual temperature for the four hazard zones over a 10-year period.

Although temperature is a contributing factor in determining the decay index and inversely related, the trends in temperature variation over the 10-year period (Figure 4) do not directly relate to the decay index variation (Figure 2) especially when the very high, high and moderate "B" zones are considered.

According to Baker (1989) the rainfall pattern in Ghana varies with the vegetational zone, however the trends for the various zones are fairly constant. The annual rainfall pattern for the various decay hazard zones is shown in Figure 5. The very high, high and moderate "B" hazard zones show two peak rainfall pattern with rainy days in all the months. However, the areas with moderate "A" hazard rating show a single peak rainfall trend with the rainy days occurring between March and December (Figure 3). There is a general decrease in number of days with rainfall in excess of 0.25 mm from the very high, high, moderate "A" to moderate "B" hazard zones. The peak rainy period of the moderate "A" zone show a pattern comparable to the peak periods of the very high hazard zone and greater than that of the other zones.

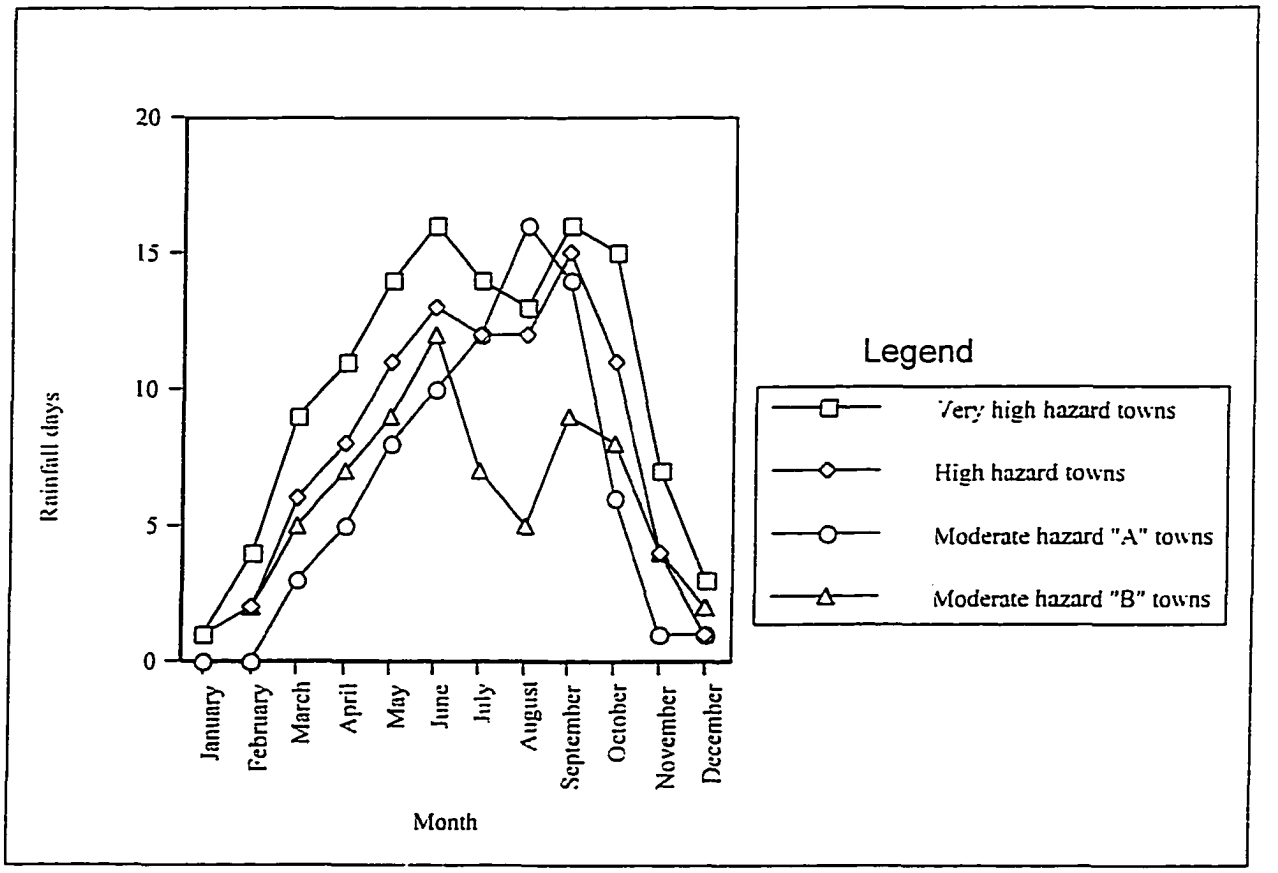

Figure 5. Annual rainfall pattern for the four decay hazard zones.

The very high, high and moderate "B" hazard zones show comparable monthly temperature values, while moderate "A" zones show a rather high monthly temperature relative to the other zones (Figure 6). In general however, all the zones show a similar pattern of increasing temperature from January to a peak around March, decreasing temperatures from March to August and then a slight increase to a peak around October-November. They then decrease once again from November to January.

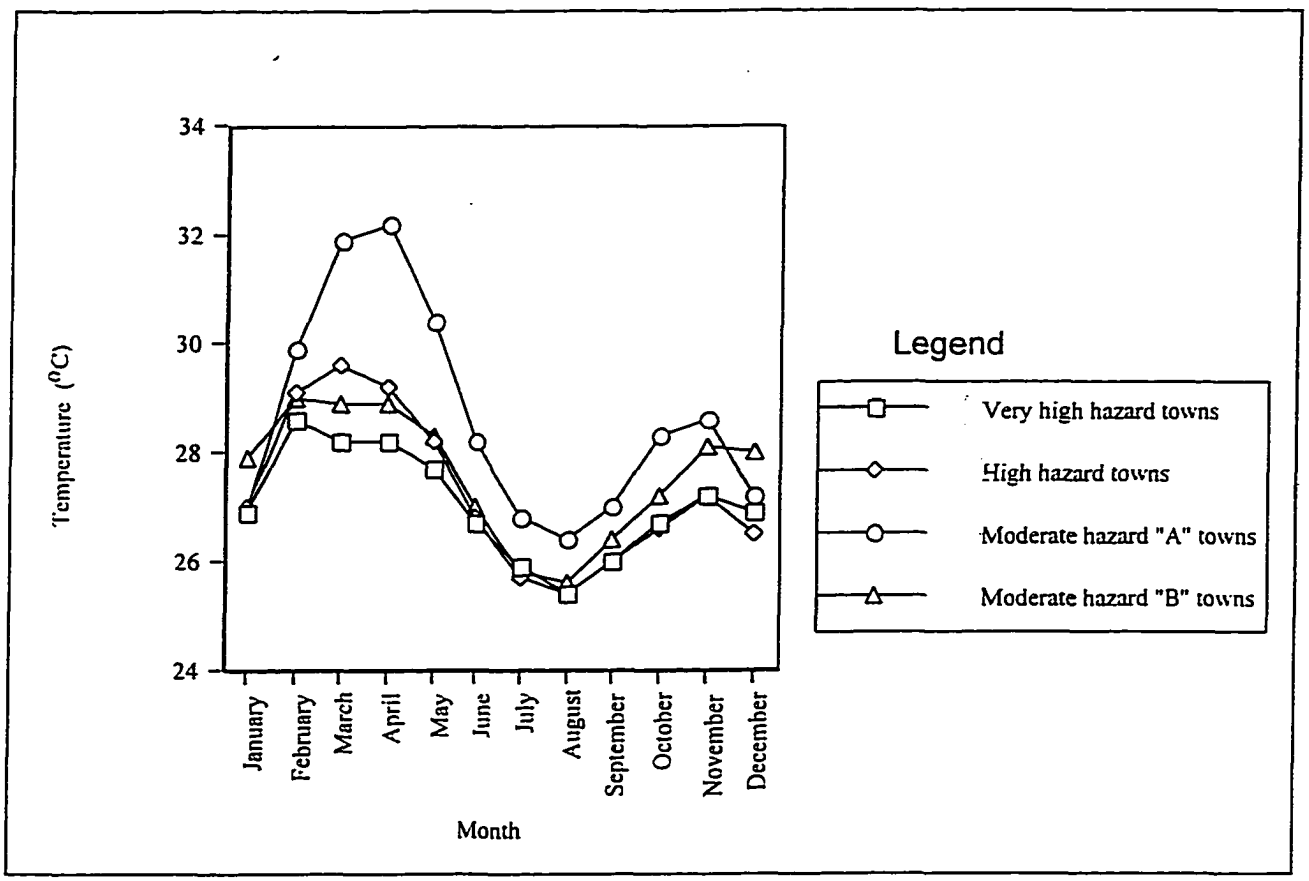

Figure 6. Annual temperature trend for the four decay hazard zones.

The general trend in wood decay potential in Ghana is shown in Figure 7 based on the determined hazard rating for various towns. This indicates that three hazard zones are represented in Ghana with the moderate decay hazard zone covering two main areas in the country. The three decay hazard zones seems to cover equal areas of the country.

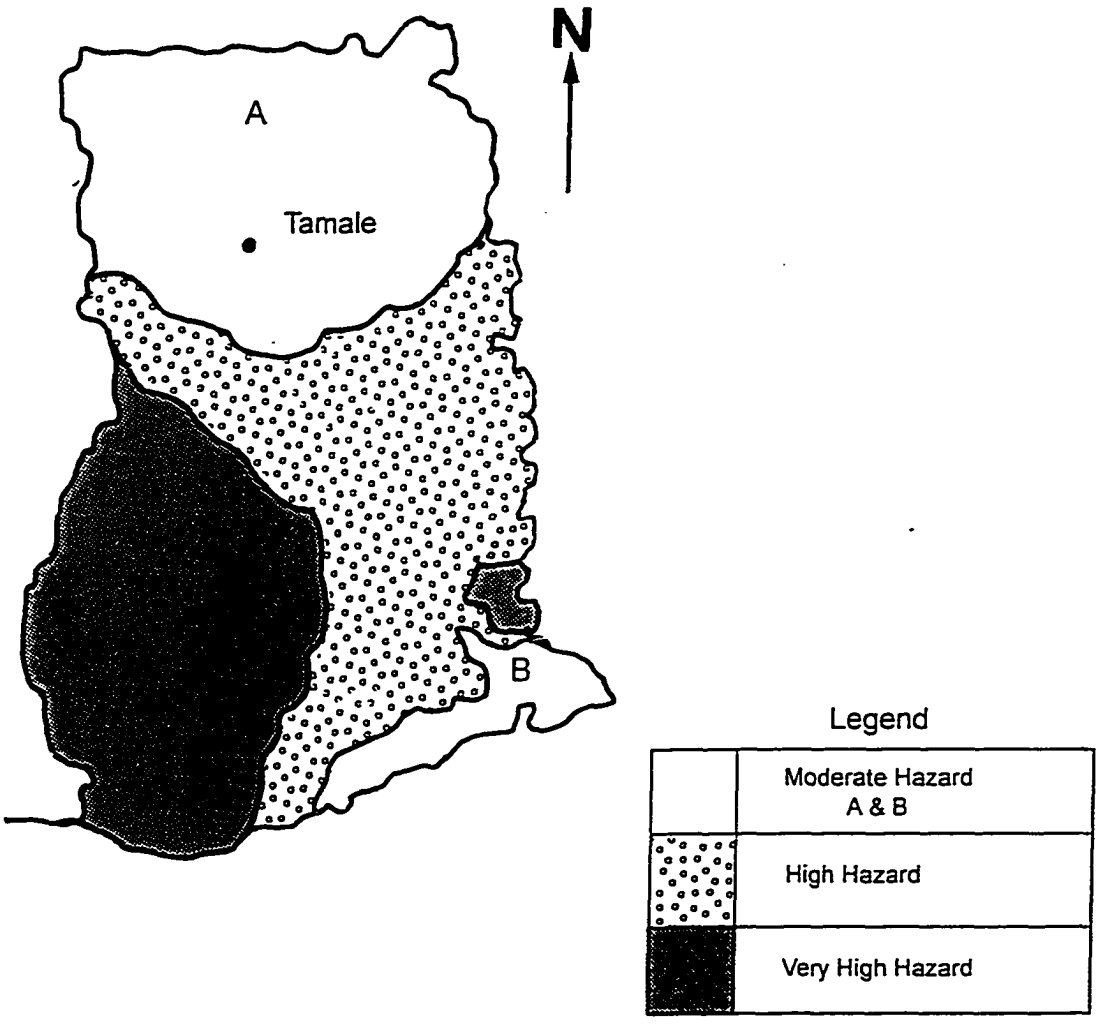

Figure 7. Wood decay hazard potential for Ghana.

CHAPTER 5

5.0 DISCUSSION

This chapter deals with the decay resistance test and the wood decay potential in Ghana as the two main categories for discussion. Discussions on the decay resistance tests are, however, sub-headed as decay resistance of the 30 Ghanaian timbers, performance of decay fungi and assessment of test methods.

5.1 DECAY RESISTANCE TEST

5.1.1 DECAY RESISTANCE OF THE SELECTED GHANAIAN TIMBERS

Of the four fungi used in the experiment, only *Coriolopsis polyzona* could be used in ranking the decay resistance of the various wood species due to the relatively low decay ability of the others in the soil-block method (ASTM, 1991). Table 5 shows the high disparity in the performance of the four strains of fungi used, with only *C. polyzona* able to induce weight loss > 60 per cent in the non-resistant wood species. Laks *et al.* (1992) noted that any test fungus which induce weight loss below 50 per cent in reference blocks should be considered invalid. On that basis *C. polyzona* could be used to assess the decay resistance of the various wood species in both methods and *O. placentus* in

agar-block test only, while neither of the other two fungi could give valid results after 12 weeks of exposure (Table 5). However, even in the agar-block test, *O. placentus* showed relatively low decay ability in the other two non resistant species (Table 5) and hence may not give comparable results using the agar-block method. Since the soil-block method was used in the determination of decay resistance of the wood species, only the performance of *C. polyzona* could be considered valid in decay resistance rating and hence was the only strain used in the rating. Ratings based on resistance to an effective strain of fungus has been done and results deemed valid as reported by Puri (1960) and Wilcox (1992). However, since *C. polyzona* induced weight loss of 46.6 in the reference wood after 10 weeks of exposure it gave an indication of the decay resistance of the various species where the lower limit of each resistance class is very important in resistance rating.

Based on their resistance to *C. polyzona,* five wood species were classified as highly resistant, six as resistant, eight as moderately resistant and 11 as non-resistant (Table 6). This ranking confirms earlier reports by Ayensu and Bentum (1974), Amponsah (1980) and Bultman *et al.* (1979) on the decay resistance of some of the species. The differences in the absolute values of the results may be due to the unrepeatability of the test results (ASTM, 1991).

Pericopsis elata, Afzelia africana, Lophira alata, Entandrophragma utile and *Tieghemella heckelii* were highly resistant. This corresponds with reports on the durability of these species by Ayensu and Bentum (1974), although their rating was based mainly on resistance to termite attack in the case of *L. alata* and T. *heckelii.* These

species were reported among the most durable species in West Africa with the former being used as marine timber in parts of Europe (Ayensu and Bentum, 1974). *E. utile* has, on the other hand, been reported as resistant to termites (Ayensu and Bentum, 1974; Bultman *et al.*, 1979) and was found in this study to be highly decay resistant. This implies the *E. utile* may be suited for use as off ground structural timber while the other two species may be better suited for more hazardous situations.

Heretiera utilis, Terminalia ivorensis, Milicia excels and *Strombosia glaucescens* were found to be resistant to decay. Reports on T. *ivorensis* indicate that it is also resistant to termites and are generally ranked as durable (Bultman *et al.*, 1979; Ayensu and Bentum, 1974). *Entandrophragma cylindricum* and *P. africanum* were classified as moderately resistant based on weight loss in two and four most highly decayed wood blocks respectively due to high variation in the weight loss of the six blocks (Appendix III). Hence further tests need to be done to verify their resistance. Amponsah (1980) also reported that *Milicia excelsa* is resistant to decay which is partly due to the presence of silica and other inorganic compounds present in the wood. This seems to confirm the report by Taniguchi *et al.* (1986), that such chemicals make the wood resistant to microorganisms due to its alteration of the water holding capacity of the wood and also resistant to marine borers as a result of its hardness. The comparable nature of the results of this study with that of some reports on the resistance of the wood species tested indicates the reliability of the results. This is shown by the comparability of the ratings of six of the species with accepted field durability performance of the species (Farmer, 1972) and ratings determined from Kolle flask method (Anonymous, 1972) in Table 9.

The results from the study seems to relate well with the accepted field performance and less so with that from the Kolle flask method which may be due the differences in fungi and methods used.

Table 9. Comparison of timber durability indications.

Wood species	Study rating (soil block for 12 months)	Kolle flask exposure at 22° C for 4 months	Field performance
Afzelia sp.	Highly resistant	Durable	Very durable
Distemonanthus sp.	Moderately resistant	Durable	Moderately durable
Khaya sp.	Moderately resistant	Non durable	Moderately durable
Lovoa sp.	Moderately resistant	Non durable	Moderately durable
Nesorgodonia sp.	Moderately resistant	Moderately durable	Durable
Terminalia ivorensis	Resistant	Non durable	Durable

Most of the moderately decay resistant and non resistant species are reported to show similar resistance to termite attack. However, *T. superba* which was ranked as moderately resistant to decay in the 12-week experiment with weight loss of 42.5% has been reported to be non durable and was found to be non resistant with weight loss of 45.9% in the 10-week test. The highly resistant *E. utile* has been reported to be durable (resistant to termites) indicating a likelihood for it to deteriorate faster when used in ground contact .

Analysis of weight loss vary both among the different resistance classes, among wood species in each class and among blocks of the same species (Appendix IV and V).

Variation among blocks of the same wood species exposed to the same strain of fungus over the same period of time may stem from differences in the microclimate in the various set-ups which affects the performance of the fungi and variation in wood quality of each block which stem from variation among trees of the same species and within tree (Clark and Scheffer, 1983; Zabel and Morrell, 1992). The observed variation among wood species confirm the general knowledge of the variation of wood quality and consequently wood decay resistance among species (Panshin and de Zeeuw, 1980).

Appendix IV shows high variation in per cent weight loss induced in blocks of the same wood species exposed to the same decay fungus. This is observed in the case of *T. ivorensis, E. cylindricum, L. trichiloides, K. anthotheca, E. angolense and N. papaverifera* exposed to C. *polyzona* over a 12 week period and in the other wood species exposed to the other three fungi. The difference seems to arise from the various jars used and may stem from differences in microclimatic conditions in the jars with regard to gas exchange over the exposure period (Appendix II, III and IV). This seems to suggest that in some of the jars oxygen became limiting with decreasing oxygen availability as decay progressed and led to retardation of the decay process after 12 weeks of exposure (Zabel and Morrell, 1992). However, the observed difference seems to have had less effect on the decay resistance rating based on the mean per cent weight loss. Table 10 shows that decay resistance rating based on the mean of all six replicates and four of the highly decayed blocks of the seven species were the same except for two of the species which had lower resistance using the four samples rather than all six. The 10 week experiment also confirms the trend except in the case of *T. superba* where the

species was found to be non resistant although initially determined to be moderately resistant.

Table 10. Decay resistance rating based on the mean of four most highly decayed and all six blocks.

Wood species	Rating based on four blocks Resistance rating (mean)	Rating based on six blocks Resistance rating (mean)
T. ivorensis	Resistant (14.3)	Resistant (10.7)
E. cylindricum	Resistant (15.7)	Resistant (11.1)
P. africanum	Moderately resistant (27.6)	Resistant (19.0)
L. trichiloides	Moderately resistant (38.6)	Moderately resistant (26.1)
K. anthotheca	Moderately resistant (41.8)	Moderately resistant (29.1)
E. angolense	Moderately resistant (32.1)	Moderately resistant (30.2)
N. papaverifera	Non-resistant (49.4)	Moderately resistant (37.1)

Sapwood of all tree species is not durable (Highley, 1978) and this holds true with the non resistance of the sapwood of *Strombosia glaucescens* (Table 5), whereas the heartwood was resistant (Table 6).

A comparison of Tables 1 and 5 shows that most of the unclassified species under the Forestry Department (FD) system used for the study are non resistant with only one being moderately resistant. The class 1 species range from highly resistant to moderately resistant species which indicates that the durability of a given species influenced the demand and consequent classification of wood species in Ghana. However, the classes 2 and 3 species represent all decay resistance classes and could be used as substitutes for woods in the various classes with due consideration for other wood quality requirements

for a given end-use. Most of the non resistant species hold promise and have been used in the manufacture of wood panel products (Pleydell, 1972) and may hold promise for pulp and paper production.

5.1.2 PERFORMANCE OF THE DECAY FUNGI

Although wood decay is known to be caused by some bacteria and fungi (Nilsson and Holt, 1983; Nilsson and Singh, 1984; Zabel and Morrell, 1992), especially basidiomycetes are known to be the principal agents. Therefore in decay resistance tests, several basidiomycetes have been used as the decay agents, three of which are recommended by ASTM (1991) for use in such tests. The number of species used in various tests have varied from one as used by Puri (1960) to several (Findlay, 1957; 1942; Osborne, 1970). The performance of the various fungal species have varied with the strains used, with some being unable to decay wood appreciably for use in decay resistance tests (Cartwright and Findlay, 1958). According to ASTM (1991) fungi to be used in a decay resistance test should be able to induce weight loss of 60 per cent in the reference wood over the exposure period (12 weeks usually). The study did show a variation in the performance of the four fungi used, with three of them not inducing adequate weight loss to be considered for use in decay resistance test.

Laks *et al.* (1992) noted that weight loss of less than 50 per cent in reference blocks when using various fungal strains is commonly reported in the literature. The current study confirms that in both agar- and soil-block methods especially with the strains of *T. versicolor* and *P. sanguineus* used, the decay ability of the strains of the

four fungal species used increases from *T. versicolor, P. sanguineus, O. placentus* to *C. polyzona.* However, *P. sanguineus and O. placentus* show comparable decay abilities in soil-block test, but the latter has higher decay ability in agar-block test (Table 5).

The decay ability of the various fungi seems to relate to the culture medium, time of exposure, wood species and the inherent decay ability of a given strain of fungi (Appendix I and II).

From Table 5 and with reference to *Betula* sp. (birch), it could be deduced that the extent of decay depends on the duration of exposure of wood samples to decay fungi. Extent of decay, expressed as percentage weight loss, increases with duration of exposure in both culture media (agar-block and soil-block). This corresponds with the general knowledge of the time dependence of decay (Zabel and Morrell, 1992). Not all the strains of fungi species used induce appreciable decay, weight loss of up to 60 per cent, in the reference wood after 6 weeks of exposure in either test methods. The percentage weight loss caused by *C. polyzona* in soil-block test which was the best performance had a mean of 56.7% (Table 5) and a range of 45.6-63.0% (Appendix II). *O. placentus* which gave the best performance in agar-block test caused a mean per cent weight loss of 49.4 (Table 5) and a range of 45.2-53.3% in experiment 1 and 43.2% with a range of 31.2-48.9% in experiment 2 (Appendix II).

However, after 12 weeks of exposure C. *polyzona* caused a mean per cent weight loss of 65.8 in agar-block and 85.1 in soil-block methods with a range of 56.0-70.0% and 69.0-92.0%, respectively. After 10 weeks it induced an average weight loss of 46.6% and a range of 39.5-52.7% (experiment 2) in soil-block test. *O. placentus* on the other hand

caused a mean weight loss of 58.8% in agar-block test after 12 weeks and 31.8% after 10 weeks of exposure.

It was observed that most of the decay fungi did not cause appreciable decay after six weeks of exposure. Per cent weight loss was less than 60 in all cases. Soil-block cultures for *C. polyzona* which had the highest decay capacity had a mean of 56.7% with a range of 45.6-63.0% (experiment 1). Agar-block cultures of O. *placentus* which had the higher decay rate for the two culture media, and second highest value for the various fungi had a mean value of 49.4% and a range of 45.2-53.3%. This implies six weeks was an inadequate duration for analysis of decay resistance of various wood species, since the reference block *(Betula* sp.) could not be decayed up to 60%.

It is known that the decay abilities of fungi vary (Cartwright and Findlay, 1958) and this was shown in this study. After exposing the reference block to the various fungi for 12 weeks, *C. polyzona* showed appreciable decay ability in both soil-block and agar-block tests having the highest decay capacity in soil-block test (85.1 %) and 65.8% in agar-block set-up. *Oligoporus placentus* showed appreciable decay capacity only in agar-block test with a mean of 58.8%. The other fungi, *Pycnoporus sanguineus and Trametes versicolor,* did show low decay capacity. *Pycnoporus sanguineus* however, had greater decay ability relative to *Trametes versicolor.*

Performance of *Coriolopsis polyzona*

The strain of C. *polyzona* (004) showed the highest performance (Table 5 and 6) comparable to that required of fungi to be used for decay resistance tests (ASTM, 1991)

in both agar- and soil-block methods after 12 weeks of exposure. The comparable decay ability of this strain of C. *polyzona* to some strains of *T. versicolor* in the literature (ASTM, 1991) may be due to the close relationship of their genera. Gilbertson and Ryvarden (1986) noted that the basic character separating the two genera is the coloured hyphae of *Coriolopsis* which give the fruit bodies of the latter genus a generally brown colour, but all other characters are similar. They also believed that being white rot fungi they apparently have the same enzyme system for wood decay. Peterson (1995) reported that the geographical location has effect on the characteristics and enzyme systems of some fungi. The aggressive behaviour of this strain may possibly relate to the source, and since the strain was collected in Ghana, it may have evolved an effective enzyme system for decomposing tropical hardwoods. Ofosu-Asiedu (1976) also reported the fungus to be one of the main wood decay fungi in Ghana and mainly associated with hardwoods.

Performance of *Oligoporus placentus*

The strain of *O. placentus* (ATCC 11538), the only brown rot fungus used, showed good performance only in agar-block test whereby it induced weight losses of 49.4 and 43.2% in experiment 1 and 2, respectively after six weeks and 58.8% after 12 weeks in the reference block. However, the relatively low performance of 12.7% and 14.2% after 6- and 12-weeks, respectively, in the soil-block test did not give adequate performance for use in decay resistance testing.

O. placentus can be used in the agar-block test since it induced weight loss of 58.8%

and a range of 52.9 to 61.8% (Appendix II) in the reference wood.

O. placentus is naturally found in association with dead wood of conifers generally and is known to be a major cause of decay in Douglas fir, but it is found rarely on hardwoods (Zabel *et al.*, 1980; Gilbertson and Ryvarden, 1986) which indicates the general substrate preference of the species. From Tables 5, the decay ability of the strain used seem to relate not only to the wood species, but also the nutrient medium (culture medium). Scheffer (1983) noted that the fungus prefers wood in ground contact. This may imply the fungus relies on moisture and supplementary nutrient to facilitate wood decay. Highley (1987) reported that the fungus removed the polysaccharides but only slightly depleted lignin. Mannan was removed much faster than glucan or xylan and xylan was usually depleted faster than glucan. Panshin and de Zeeuw(1980) reported that hardwoods have higher amounts of xylan than softwoods , while softwoods have galactoglucomannans as hemicellulose. Also the type of lignin residues varies between hardwoods and softwoods. While hardwoods have guaiacyl and syringyl residues, softwoods have only guaiacyl lignin. The variation in the chemistry of the substrate may play a role in the extent to which the fungus deteriorates it. It may be deriving some supplementary nutrient from the malt agar (MEA) in the agar-block method to facilitate the decay of birch. This is because, as Table 5 indicates, a remarkable performance of the fungus in the agar-block method when exposed to birch wood and less so with the other wood species. Highley (1977) reported that *O. placentus* requires other carbohydrates *e.g.* holocellulose, as essential components for utilisation of cellulose. Consequently, high lignin content as occurs in hardwoods may hinder effective access to the

carbohydrates, but with supplement from the malt extract, the decay process is facilitated, especially in the short term (6 weeks) from Table 5.

Although strains of *O. placentus* were found to show high decay ability in pines and Douglas fir (conifers) (Eslyn, 1986), Eslyn reported that extractives from tropical hardwoods are effective against the fungus and may contribute to the low decay ability observed especially in soil-block test. The white rot fungi are able to utilise both holocellulose and lignin (Zabel and Morrell, 1992) and so were able to perform better in the soil-block method (Tables 5).

Nevertheless, the performance of this strain was lower than some strains of the same fungi reported in literature (Scheffer, 1983). Highley *et al.* (1989), and Highley and Micales (1989) reported that there are variations in extracellular glucan production and decay ability between strains of the brown rot fungus *O. placentus.* They determined that one monokaryotic isolate was unable to degrade wood and also failed to produce extracellular polysaccharide; however hybrids of the strain with other monokaryotes had decay ability. This indicates that decay ability of a given fungal strain depends on its genetic potential as much as on the interaction between its genetic potential and environmental factors which influence its physiological processes and production of extracellular enzymes. The strain used showed relatively higher decay ability in experiment 2 than experiment 1 (Table 7) indicating that oxygen and moisture availability might have limited its decay rate.

Performance of *Pycnoporus sanguineus*

Pycnoporus sanguineus, a white rot fungus, with similar characteristics to *Trametes and Coriolopsis,* except for its bright reddish-orange colour was expected to show high decay ability. It is found in sub-tropical and tropical regions with hardwoods as substrates under natural conditions (Gilbertson and Ryvarden, 1986). Yakoleva *et al.* (1993) reported the strains of the species as occurring on both hardwoods and conifers. The strain used in this study is part of a Ghanaian collection and found on hardwood species.

The strain did show low decay ability relative to the strain of *C. polyzona* used, although both were collected from the same location and on hardwood substrates. This confirms the report by Eslyn (1986) that decay ability does not relate directly to substrate. The difference in performance of the all three white rot fungi may stem from different enzyme patterns employed by different white rot fungi leading to different modes of lignin metabolism as reported by Nerud *et al.* (1991). However, like all the white rot fungi used, *P. sanguineus's* decay ability seems to be higher in soil-block test than in agar. As a white rot fungus, it has a capacity to utilise both lignin and cellulose and hence does not seem to require nutrient supplement to be able to induce weight loss. Availability of nutrient supplement (malt extract) in the agar-block might have led to the fungus utilising that and decreasing its decay of the wood samples irrespective of both period of exposure and wood species (Tables 5 and 6). The better performance of the fungus in soil-block test seem to confirm a report by Pinzon-Picaseno and Hemandez-Jimenez (1986) of its relative effectiveness with the method. However, the performance

of the strain was lower than that of most strains used in the test under the same procedure and which have extensively been used in Asia and Mexico (Suhirman and Khusniati, 1987; Vongkaluang and Vongkaluang, 1985; Arora and Garg, 1992; Balasundaran and Gnanaharan, 1985) and has been recommended for effluent treatment (Castro *et al.*, 1993). Yakovleva *et al.* (1993) found that different strains of the species show different growth rates and extracellular peroxidase and laccase activities. Also test on the aggressiveness of two strains of the fungus from different geographical locations (Mexico and India) did show strong differences in performance in both soil- and agar-block techniques (Pinzon-Picaseno and Martinez-Marcial, 1983; Pinzon-Picaseno *et al.*, 1983). Peterson (1995) reported distinct variability in overall, and in individual alleles, phenotypic expression in enzyme production in strains of the same fungus *(Pleurotus pulmonarius)* from different regions. This indicates that geographical barriers may lead to differences in decay and other performances and hence strains from different locations are likely to be different.

The extractive content of the wood sample also affects the decay ability of the fungus. A strain of *P. sanguineus* has been reported to be inhibited by methanol extractives of tropical hardwoods (Hong and Abdul-Razak, 1983). This is likely to have accounted for the variation in the decay ability of the fungus as regards the various wood species, but the generally low decay ability might be due to its inherent low decay potential and to a lesser extent the experimental conditions.

Performance of *Trametes versicolor*

The low decay ability of the strain of *T. versicolor* used (ATCC 12679) is quite remarkable in that most strains of the fungus are reported to have high decay ability and have been used extensively in decay resistance and wood preservative toxicity tests (Balasandaran and Gnanaharan, 1985; Laks *et al.*, 1992; De Groot *et al.*, 1992; Morrell and Freitag, 1995) and recommended for such test by ASTM (1991).

T. versicolor is a circumglobal white rot fungus which grows on deadwood of numerous hardwoods and occasionally on conifers (Gilbertson and Ryvarden, 1986). Eslyn and Lombard (1983) reported its presence as decay fungus on mine timbers. A strain of the fungus (FPIO 1664-SP) was reported to induce highly variable weight loss in coniferous wood (Morrell and Freitag, 1995), and substantial weight losses in hardwoods. The standard therefore recommends its use with hardwoods (ASTM, 199 1). The low decay ability expressed was therefore unexpected.

The decay ability of a given fungus depends on the right identification of the species, its genetic potential and environmental requirements of temperature, moisture, nutrient, oxygen, favourable pH range, light and chemical growth factors like nitrogen, vitamins and essential elements (Zabel and Morrell, 1992). Laboratory procedure and measurements, and the fungal mass also influence the measured response as well (Blanchette *et al.*, 1978).

Gilbertson and Ryvarden (1986) noted that since so many species in *Trametes* have similar spores or mostly are found sterile, some specimens are difficult to determine and a considerable field experience will be necessary to establish good species concepts in this

genus. Eslyn and Lombard (1983) noted that the wrong identification of a specimen leads to wrong conclusions on the characteristics and decay ability of a specimen. This could raise the possibility of the strain used being a different species, hence its low decay ability. However, this strain has been found to have good decay ability and used for decay studies by Laks *et al.* (1 992). Hence the low decay ability could relate some other factor(s) aside from correct identification.

The temperature requirements of mesophyllic fungi of which *T. versicolor* is believed to be part lies in the range of 15-40^0 C with an optimum of 28^0 C (Zabel and Morrell, 1992). Laks *et al.* (1992) found the strain to have an optimum growth rate at 26^0 C in MEA + 0.5% yeast and to vary with nutrient medium. Its performance was found to be higher than *O. placentus (ATCC* 11538) under the same conditions. However, the decay ability of the strain has been higher at 26^0 C in soil-block tests causing 85.4% weight loss in sweetgum reference wood and has been favourably used (Laks *et al.*, 1992). This implies that temperature and nutrient may be less significant factors in the low decay ability of the strain used although it might have contributed to the slow growth rate observed.

Moisture content requirements were adequate for the growth and development of the fungus since the same levels have been used in earlier works with satisfactory performance, especially in experiment 2 where higher levels of moisture was made available. Water is required as a reactant in hydrolysis, as a diffusion medium for enzymes and to solubilize substrate molecules, as a medium for life systems, and as wood capillary swelling agent by fungi (Zabel and Morrell, 1992). However, fungi may release

metabolic water during the decay process which makes water less of a limiting factor especially under conditions as provided in this study.

Although fungi require oxygen for growth, the level is relatively low for most (Zabel and Morrell, 1992). Nevertheless, the lid closure method used allows for free gas exchange between test chamber (culture bottle) and external environment and might not have made oxygen supply limiting (Smith, 1978). Smith (1978), reported variation in performance among fungal species with regards to size of lid hole which results from oxygen and carbon dioxide balance in the growth chamber during the decay process. Consequently, gas exchange may have contributed to the low decay ability of the fungus, but this effect may be less since slow growth was observed in petri dish cultures as well. The fungal mass in wood blocks also contributed to the measured response (weight loss). Blanchette *et al.* (1978) reported a variation in amount of fungal mass present in wood after decay by various fungi (determined by chemical analysis) and indicated that the portion of *T. versicolor* is greater than *O. placentus.* This will consequently contribute to the observed difference between the fungi.

The pH requirements for the best growth of fungi is reported to be in the range of 3-6, hence a pH of 5.6 of the soil medium used might not have limited the performance of the fungus. Light is also assumed to be harmful to vegetative growth of wood decay fungi and to cause growth reduction owing to the lethal effects of the ultraviolet portion of light at high intensities (Zabel and Morrell, 1992). Duncan (1967) however, reported that periodic exposure to light may increase decay rates which may be due to temperature increase as a result of a subtle greenhouse effect. The incandescent light used in the

controlled environment chamber may not therefore have a significant effect on the performance of the fungus as reported by De Groot *et al.* (1992).

The other possible reason for the low decay ability of this strain may be due to the low decay potential of the isolate which could arise from hybridisation as observed by Highley *et al.* (1989). The strain did show a low decay potential relative to the other fungi used in both agar- and soil-block methods irrespective of which wood species exposed (Table 5). This suggests that the strain has inherent low decay ability which is less affected by the culture medium used and hence may be a diseased isolate (Setliff pers. comm.) since the strain has been used successfully in decay resistance studies by Laks *et al.* (1992). The strain was observed to show slow growth rates in both methods and in petri-dish cultures using MEA at 26^0 C. The slow growth rate, 17 days to fill a 100 mm petri dish, may influence both the rate of penetration and utilisation of the wood substrate since white rot fungi unlike brown rot fungi show progressive erosion of all cell wall components from lumen surface with low rate of enzyme diffusion, while rapid chemical attack of all cell wall carbohydrates is associated with the latter group of fungi, on wood substrates. The highest decay induced at the end of 12 weeks of exposure was 6.88 and 4.5 per cent in agar- and soil-block methods respectively in the reference wood which was lower than expected.

From the forgone discussion, the low decay ability of the strain used (ATCC 12679) seems to relate to a low O_2:CO_2 ratio in the culture bottle and its inherent slow growth and low decay potential as a result of its probable diseased condition. The fungal mass in the wood blocks contribute to the low measured weight loss relative to the other fungi,

however, the magnitude of the difference is marginal relative to the observed differences in performance.

5.1.3 ASSESSMENT OF TEST METHODS

Reports on the effects of test methods on resultant decay induced by fungi has been variable. Amburgey (1976) and Verner and Krause (1951) compared agar- and soil-block tests and concluded that the two tests are equally usable provided that proper moisture and nutrient levels are maintained. Archer *et al.* (1995) reported that both tests are very similar, except that agar is substituted for soil in agar-block test. Monteiro *et al.* (1992) alternatively reported that the two methods give significantly different results, while Duncan (1953) reported different results but a similar order of effectiveness.

Table 5 indicates that after six weeks of exposure there is a significant difference between the two test methods on the effectiveness of the four fungal species and seems to agree with the report by Monteiro *et al.* (1992). All the three white rot fungi, *T. versicolor, P. sanguineus and C. polyzona,* induced weight losses of 4.3, 11.7 and 56.7% respectively in soil-block test as opposed to 3.8, 7.0 and 29.4 in agar-block. This seems to confirm a report by Setliff and Eudy (1980) that several white rot fungi seem to show better decay ability in the soil-block method than the agar-block after five weeks of exposure. The brown rot fungus, *O. placentus,* on the other hand induced a higher weight loss of 49.4 per cent in agar-block, but less so in soil-block (12.7 per cent). The high relative performance of the brown rot fungi in agar-block after this period may be due to its utilisation of supplementary nutrient from the agar to facilitate effective decay of the

wood block. This is made more evident by the fact that it did not show such a remarkable difference between the two methods with the other two wood species *(Celtis* sp. and *Strombosia* sp.*)* compared to birch wood (Table 5). This could be that birch wood lacked some essential nutrient which is needed for the growth and development of the fungus, but which was available in the malt extract agar (MEA) medium.

The white rot fungi on the other hand are effective decay fungi of hardwoods and also able to utilise all sources of lignin and polysaccharides. Hence in the agar-block method, in the short term (6 weeks) utilize the readily available nutrients of the MEA and decay the wood to a less extent, but utilise the wood blocks more in the soil-block (Table 5) due to the absence of other alternative nutrients.

However, after 12 weeks of exposure (Table 5), with the exception of the high decay ability of *O. placentus* strain with birch wood in agar-block, the performance of all the fungi, using three wood species, did not show obvious variation with the test method. The resultant weight loss of the various wood species induced by each fungus were comparable for the two methods. This confirms reports by Duncan (1953), Ejechi and Obuekwe (I994) and Archer *et al.* (1995) that the methods are similar in terms of effectiveness, except that agar replaces soil in agar-block test, making the latter method relatively expensive. The slight variations in performance of each fungus exposed to any wood species may be due to slight variations moisture and nutrient levels (Amburgey, 1976; Verner and Krause, 1951), and wood quality variations among blocks and differences in moisture absorption by wood blocks during weighing due to the hygroscopicity of wood (Panshin and de Zeeuw, 1980).

5.2 WOOD DECAY POTENTIAL IN GHANA

5.2.1 DECAY HAZARD ZONES

The decay index for specific locations in a given region vary somewhat as might be expected. Nevertheless there are general decay hazard patterns that cover broad areas. This gives a general indication that wood decay hazard may vary substantially from place to place as reported in earlier studies (Scheffer, 1971; Setliff, 1986).

The decay hazard areas assigned as very high are those with index values >100. The very high hazard areas in Ghana have higher decay potential than the most hazardous location in the United States since the formula was computed to yield a maximum decay index of 100 for the most hazardous areas in the United States (Scheffer, 1971; De Groot, 1982), but the very high decay potential areas in Ghana have decay indices far in excess of 100, up to 159. This indicates that the very high hazard zones may have much higher decay potential than anywhere in the United States. The field assessment of the decay rate from fungi in these areas as a large factor in CO_2 evolution is of great importance.

All the hazard zones had consistent ratings based on their index values over the 10-year period. However, the annual variations indicate the inadequacy of using one year's results to rank decay hazard for a given location, especially considering the variation in index values for individual towns while 10 years seem quite representative (Figure 2).

Rainfall amount seems to be the main determinant of the decay hazard potential in the country, and this may be true for some tropical countries (Figure 5). The very high and hazard areas lie in a region where rain tends to fall throughout the year with two peak

annual rainfalls, with areas of relatively high rainfall intensity limited to the very high decay index zones (Baker, 1989). This shows a direct relationship between rainfall and decay hazard with high rainfall amounts causing high decay hazard. Although temperature has a contributing effect with decay hazard increasing with decreasing temperature (Figure 6), its effect is minimal in that with the exception of moderate "A" which has relatively very high mean monthly temperature, the other hazard zones have comparable temperatures in both value and annual trend. The significance of rainfall amounts on decay hazard is made more clear by the fact that, although moderate area "A" has relatively high mean monthly temperature (Figure 6), and may be expected to have a lower decay index relative to moderate "B" and the other zones, its high number of rainfall days during its peak period (June-August) (Figure 5) offsets the impact of the long dry period especially between January and April (Figure 6). Moderate "B" on the other hand has low decay index values because of its relatively low rainfall days and amounts while the others have high rainfall amounts, although all three zones have two peak rainfall regimes. However, it has temperature regimes comparable to the high and very high zones, This is also made clear by similar trends observed in rainfall pattern and the decay index of the four zones (Figures 2 and 3), which is not observed with the temperatures trend over the same period (Figures 2 and 4).

5.2.2 RELATIONSHIP BETWEEN DECAY HAZARD POTENTIAL AND VEGETATION

The decay index relates closely to changes in vegetation. The forested regions have very high ratings *e.g.* an average index of 134 for the rain forest and 117 for the semi-deciduous forest. Only one location , Wenchi, which is in the transition zone between the semi-deciduous forest and the savanna woodland has a high hazard rating (index 96) in the forested region. This is followed by the savanna woodlands with high rating (index 72) and both the coastal scrub and grassland (index 66), and strand and mangrove (index 49) with moderate hazard rating (Table 8). This indicates that the southeastern corner of the country which is covered by coastal scrub and grassland, and strand and mangrove vegetation is the driest part of the country, followed by the savanna areas in the north of the country (Figure 5). This area is reported to be the driest part of the country even though it lies along the coast. The explanation of this is topography and the divergence of the moisture laden SW Monsoon winds from the area by Cape Three Points (Baker, 1989; Dickson and Benneh, 1988).

The Savanna-Woodland vegetational zone represents two hazard zones *viz.* areas of high decay hazard to the south of the zone (Kete-Krachi, Yendi and Bole) and areas of moderate decay hazard to the north of both the vegetational zone and the country (Wa, Tamale, Bawku and Navrongo) (Table 8). By comparing Figures 1 and 5, there is an indication that areas to the north of the country are "true" savanna with a moderate decay hazard situation. The southern Savanna-Woodland locations seem to be "derived" savanna since they have high decay hazard which is similar to the transition zone between

savanna and forest vegetation. This trend indicates that the observed savanna situation is probably due to human activities (grazing of livestock and farming) which are extending the savanna grassland vegetation southwards as a progression of deforestation. This is because this area has two peak rainfall regimes like the forest zone and only slightly lower amounts of rain and has comparable temperature regimes (Figures 3 and 4). The northern part has one peak rainfall and high temperatures which predisposes the area to pyric factors and experiences annual fires, and has moderate decay hazard rating. This area is characterised by one peak rainfall with a prolonged dry season due to the dry NE trade winds which affect the area between November and April. Rainfall here is very intensive (Baker, 1989) during the rainy season and causes floods.

It should be noted that the area around Ho in the southeastern corner of the country has a very high decay index, much greater than the surrounding areas. The relief map of Ghana (Dickson and Benneh, 1988) shows that portion of the country to be mountainous. This suggest that the mountain ranges in that part of the country influence the climate, especially rainfall and consequently the decay index. This confirms the report by Scheffer (1971) that mountainous areas have significantly different decay indices from other areas.

The strong relationship between decay hazard potential and vegetational zones will facilitate a quantitative assessment of change in either of these parameters in the future. Data over the last 10 years serve as baseline data for future assessment of climatic trend and foster environmental change detection which may relate to global weather changes.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

From the forgone discussions on the decay resistance tests and the wood decay in Ghana, the following conclusions can be drawn:

1. The decay ability of fungi vary with species and may depend on the particular strain of fungus species used and the durability of the wood species to which it is exposed,
2. *Coriolopsis polyzona* had the highest decay ability and adequate performance for use in assessment of decay resistance of hardwoods both in agar- and soil-block tests. *Pycnoporus sanguineus* on the other hand showed low decay ability and could not be used in decay resistance rating.
3. *Trametes versicolor* (ATCC 12679) showed very low decay ability and could not be used to assess the decay resistance of the various hardwoods. The low decay ability of this strain seems to be related to the low decay potential of the strain rather than growth conditions and may be a diseased isolate,
4. Preliminary assessment of the decay ability of fungi to be used in decay resistance tests is very important to the applicability of the decay resistance test procedure,
5. After 6 weeks of exposure of wood blocks to fungi, culture media significantly

influence the decay ability of fungi but less so after 12 weeks. White rot fungi used showed greater decay ability in soil medium than in agar and the converse is true for the brown rot fungus after 6 weeks of exposure. After 12 weeks of exposure however, no such relationship was found,

6. Both agar- and soil-block methods seem to give comparable results for each fungus with different wood species. However, the soil-block method may be preferred for economic reasons,
7. The study confirmed some knowledge about wood decay processes which include the fact that sapwood of most species is not durable and that extent of decay is directly related to exposure time,
8. Based on resistance to decay by *C. polyzona,* five of the Ghanaian timbers were ranked as highly resistant, four as resistant, 10 as moderately resistant and 11 as non-resistant. One of the lesser utilised wood species was rated as resistant, four as moderately resistant and nine as non-resistant,
9. As a consequence of (8) above, it can be concluded that under end-use situations where resistance is the desired quality, and with due consideration for other desired wood quality concerns, some species can be used as substitutes for others.
10. The decay hazard potential in Ghana is generally high and covers three main ratings moderate, high and very high. The wood decay potential, like the vegetation of Ghana, relate more to rainfall than temperature, moderate decay hazard potential was found in the driest parts of the country and very high hazard in the wet parts of the country. The decay hazard trend seems to indicate that in tropical climates, rainfall

rather than temperature is the main determinant of decay hazard, since temperature trends are suitable for fungal growth all year round while rainfall varies from small to large amounts with the seasons limiting moisture availability. Also the prevailing winds rather than proximity to the equator are the main determinants of rainfall and temperature regimes.

The determined decay potential for the Savanna woodland vegetational zone of the country indicates a progression of deforestation from the north to the south and also shows a direct relationship between decay hazard and vegetation.

The occurrence of mountain ranges influences the decay potential in the area with obvious differences between adjacent areas. This was shown by the very high decay potential of areas around Ho while adjacent areas had high decay potential.

6.1 FUTURE RESEARCH

The current study poses some questions and may serve as a prelude for future research into several aspects of wood decay study. Some areas that need consideration include the following:

1. identify the most important wood inhabiting fungal species deteriorating wood in service; establish the mechanisms of variation in wood decay capacity within the same fungal species, particularly strains with low decay capacity;
2. establish field verification studies on wood durability of the species tested in this study and others under the different hazard zones to facilitate a better assessment of

durability of the various woods in and above ground contact, and also to determine the applicability of Scheffer's decay index formula to the upper limits of decay in tropical rain forests;

3. test of wood preservative quality (leachability, toxicity, and long term potency) under the four decay hazard zones to help determine appropriate threshold levels of various preservatives and help predict service-life of treated poles at various locations;
4. establish preservative treatability of different wood species; and
5. examine the prospects of using *C. polyzona,* especially the strain used in the study for biopulping, bioremediation and other biotechnologies.

LITERATURE CITED

Abankwah, J. M. 1970. A field test for natural relative durability of timbers against fungal decay. Res. Note, Build. and Road Res. Inst., Ghana. No. 33. 10 pp.

Amburgey, T. L. 1976. Observation on the soil-block and agar-block methods of evaluating wood decay. Mat. und Org. 11: 273-277.

American Society for Testing and Materials (ASTM). 1991. Standard method of accelerated laboratory test of natural durability of woods. ASTM D 2017-81, reapproved 1986. Annual book of ASTM standards, vol. 4.09: 346-350.

Ampong, F. F. K. 1977. Preliminary investigations into the wood-boring activities of the nymphal stages of *Povilla adusta* Navas at Nzulezo, western Ghana. Tech. Bull. For. Prod. Res. Inst., Ghana. 24: 1-12.

Ampong, F. F. K. 1979. Natural resistance of timbers to marine borer attack. COIPNFIRG cooperation, final rep. Concerning panels exposed in the sea at Sekondi, Ghana. Doc.- Int. Res. Group IV, Marine Wood Preservation, No. IRG/WP/414. 2 pp.

Amponsah, S. 1980. Report on natural durability of *Chlorophora excelsa* Benth. and Hook. (Odum) and *Triplochiton scleroxylon* K. Schum (Wawa) using a soil-block test. Forintek tech. report. Vancouver B.C. 5 pp.

Anderson, A. B., T. C. Scheffer, and C. G. Duncan, 1963. The chemistry of decay resistance and its decrease with heartwood aging in incense cedar *(Libocedrus decurrens)* Holzforschung 17: 1-5.

Anonymous. 1972. Laboratory test of natural decay resistance of timber. Timberlab papers No. 50 Princes Risborough Laboratory. London.

Archer, K., D. D. Nicholas, and T. P. Schultz, 1995. Screening of wood preservatives: comparison of the soil-block, agar-block, and agar-plate tests. For. Prod. Jour. 45: 86-89.

Arora, D. S. and K. K Garg, 1992. Comparative degradation of lignocellulosic residues by different fungi. Bioresource Tech. 41: 279-280.

Ashiabor, W. K. 1967. The strength properties of Ghanaian timbers. Tech. Newslett. For. Prod. Res. Inst. Ghana. 1: 14-23.

Atuahene, S. K. N. 1972. Preliminary studies on woodwool resistance to termite attack in Ghana. Tech. Bull. For. Prod. Res. Inst., Ghana. 6: 11-15.

Ayensu, E. S. and A. L. K. Bentum, 1974. Commercial timbers of West Africa. Smithsonian Contributions to Botany, No. 14. 69 pp.

Baidoo, J. F. 1987. The timber export development board and the Ghana timber trade and industry. TEDB report. Ghana.

Baker, H. J. 1989. "The ecological study of vegetation of Ghana", in Agriculture and Land use in Ghana (J. B. Wills, ed.). Longmans Pub. London. pp. 151-159.

Balasundaran, M. and R. Gnanaharan, 1985. Natural decay resistance of *Vitex altissima* Linn, F. Jour. of Indian Academy of Wood Science. 16: 75-77.

Barnacle, J. E. and K. Ampong, 1975. Selective attack of limnoriid marine wood borers at Sekondi (Ghana) in sawn heartwood piles of *Chlorophora excelsa.* Mat. und Org. 10: 289-310.

Bentum, A. L. K. 1969. Properties of Ghana timbers: Kaku *(Lophira alata* var. Procera). Tech. Newslett. For. Prod. Res. Inst. Ghana. 1: 27-29.

Bentum, A. L. K. 1970. Properties of Ghanaian timbers: Dahoma *(Piptadeniastrum africanum* Hook. F.). Tech Newslett. For. Prod. Res. Inst. Ghana. 4: 19-2 1.

Bentum, A. L. K. and F. W. Addo-Ashong, 1977. Weathering performance of some Ghanaian timbers. Tech. Bull. For. Prod. Res. Inst., Ghana. 26: 13 pp.

Behr, E. 1974. Decay resistance of Northern White Cedar from wet site in lower Michigan. Michigan State Univ. Agric. Exp. Stat., Michigan, Res. Rep. 229.

Blanchette, R. A., S. Gurusiddaiah, and C. G. Shaw, 1978. A modified technique for the determination of fungal mass in decayed wood. Can. Jour. For. Res. 8: 486-490.

Boateng, E. A. 1966. A geography of Ghana, 2nd ed. Cambridge Univ. Press. U.K. 212 pp.

Bolza, E. and W. G. Keating, 1972. African timbers: the properties, uses and characteristics of 700 species. CSIR, Div. of Build. Res., Australia. 699 pp.

Boyce, J. S. 1961. Forest Pathology, 3rd ed. McGraw-Hill, N. Y. 572 pp.

Bultman, J. D., R. H. Beal, and F. F. K. Ampong, 1979. Natural resistance of some tropical African woods to *Coptotermes formosanus* Shiraki. For. Prod. Jour. 29: 46-51.

Cartwright, K. St. G. and W. P. K. Finlay, 1958. Decay of timber and its preservation. Second ed. Her Majesty's Stationary Office, London. 294 pp.

Castro-e-Silva, A., E. Esposito, A. Ferraz, and N. Duran, 1993. Decay of *Parkia oppositifolia* in Amazonia by *Pycnoporus sanguineus* and potential use for effluent decoloration. Holzforschung 47: 361-368.

Clark, J. W. and Scheffer, T. C. 1983. Natural decay resistance of the heartwood of coast redwood *Sequoia sempervirens* (D. Don.) Endl. For. Prod. Jour. 33: 15-20.

Coaton, W. G. H. and J. L. Sheasby, 1972. Preliminary report on a survey of the termites *(Isoptera)* of South West Africa. Cimbebasia Memoire, Windhoek No. 2. 129 pp.

De Groot, R. C. 1982. An assessment of climate index in predicting wood decay in houses. Durability of Building Materials. 1: 169-174.

Deon, G. 1984. The correlation between the natural durability of some tropical species and their content of extractives. Min. de la Rech. et de la Tech. Paris, France. 351-366 pp.

Deon, G., M. Chadenson, and M. Hauteville, 1980. The effect of natural wood extractives on resistance to decay. Bois-et-For.-des-Trop. 191: 75-90.

Dickson, K. B. and G. Benneh, 1988. A new geography of Ghana. Longmans Pub. London. 212 pp.

Duncan, C. G. 1953. Soil-block and agar-block techniques for evaluation of oil-type wood preservatives: Creosote, copper naphthenate and pentachlorophenol. USDA For. Serv. Pathology Special Release No. 37. Forest Prod. Lab., Madison,USA.

Duncan, C. G. 1967. Effect of light on the rate of decay of three wood-destroying fungi. Phytopathology 57: 1121-1125.

Ejechi, B. 0. and C. 0. Obuekwe, 1993. Preliminary studies on the effects of crude opepe *(Nauclea diderrichii)* timber extractives on timber biodeterioration. Int. Biodet. and

Biodegrad. 31: 71-75.

Ejechi, B. 0. and C. 0. Obuekwe, 1994. A comparative study of two laboratory methods of wood decay tests. Wood Sci. 13: 474-477.

Eslyn, W. E. 1986. Utility pole decay Part 4: Growth-temperature relations and decay capability of eleven major utility pole decay fungi. Holzforschung 40: 69-77.

Eslyn, W. E. and F. F. Lombard, 1983. Decay in Timbers Part I: Basidiomycetes associated with coal mine timbers. For. Prod. Jour 33: 19-23.

Falconer, J. 1992. Non-timber forest products of southern Ghana. A summary report. ODA Forestry Series No. 2. U.K.

Farmer, R. H. (Rev.). 1972. Handbook of Hardwoods. Second ed. Her Majesty's Stationary Office, London. 243 pp.

Findlay, W. P. K. 1942. Resistance to decay. Emp. For. Jour. 21: 134.

Findlay, W. P. K. 1957. Durability of African mahogany *Khaya ivorensis.* Emp. For. Rev. 36: 991-993.

Forest Products Research Institute (FPRI), 1967. Properties of Ghanaian timbers. 11 Danta *(Nesogordonia papaverifera* A. Chev.). Tech. Newslett. For. Prod. Res. Inst. Ghana. 1: 2, 26-27.

Freas, A. D., M. Chudnoff, R. C. Koeppen, and S. B. Huchinson, 1973. Factors influencing the utilisation of tropical wood species. Agency for International Dev. Report, Washington, DC. No. TA/OST 73 -22, 31 pp.

Frimpong-Mensah, K. 1989. Requirement of the timber industry. Ghana forest inventory project seminar proceedings (J. L. G. Wong, ed), 29-30 March 1989, Accra. Overseas Dev. Agency, London, U.K. pp. 70-78.

Gambetta, A. and Orlandi, E. 1978. Natural durability of some tropical woods to marine borers in the Tyrrhenian Sea. Inst. del Legno, Florence, Italy. Tech. Bull. 22: 9-17.

Gardner, J. A. F. 1960. The distribution of dehydroquercitin in Douglas fir and western larch. For. Prod. Jour. 10: 171-173.

Gardner, J. A. F. and G. M. Barton, 1958. The extraneous components of western red cedar. For. Prod. Jour. 8: 189-192.

Ghartey, K. K. F. 1989. Results of the inventory. Ghana forest inventory project seminar proceedings (J. L. G. Wong, ed), 29-30 March 1989, Accra. Overseas Dev. Agency, London, U.K. pp. 32-46.

Gilbertson, R. L. and L. Ryvarden, 1986. North American Polypores. Vols. I and II. Fungiflora, Oslo, Norway. 885 pp.

Graham, R. D. 1973. History of wood preservation. In "Wood Deterioration and its prevention by preservative treatments" (D. D. Nicholas, ed.). Syracuse Univ. Press, Syracuse, N. Y. pp. 1-30.

Hall, J. B. and M. D. Swaine, 1981. Distrbution and ecology of vascular plants in a tropical rain forest: forest vegetation in Ghana. Geobotany (W. Junk ed.) , The Hague. 383 pp.

Hart, J. H. 1981. Role of phytostilbenes in decay and disease resistance. Ann. Rev. Phytopath. 19: 437-458.

Hart, J. H. and W. E. Hillis, 1974. Inhibition of wood-rotting fungi by stilbenes and other polyphenols in *Eucalyptus sideroxylon.* Phytopathology 64: 939-948.

Hawley, L. F., L. C. Fleck, and C. A. Richards, 1924. The relation between durability and chemical composition in wood. Indust. and Eng. Chem. 16: 699-700.

Hawthorne, W. 1990. Field guide to the forest trees of Ghana. Ghana Forestry Series 1. London, U.K., Overseas Dev. Agency 276 pp.

Highley, T. L. 1977. Requirements for cellulose degradation by brown-rot fungus. Mat. und Org. 12: 25-36

Highley, T. L. 1978. How moisture and pit aspiration affect decay of wood by white rot and brown rot fungi. Mat. und Org. 13: 3, 197-206.

Highley, T. L. 1987. Changes in chemical components of hardwood and softwood by a brown-rot fungus. Mat. und Org. 22: 39-45.

Highley, T. L. and J. A. Micales 1989. Physiological characteristics of a non-degradative isolate of *Postia (Poria) placenta.* Mycology 81: 205-215.

Hillis, W. E. 1985. Biosynthesis of tannins. *In* Biosynthesis and Biodegradation of wood components (T. Higuchi, ed.), Acad. Press, N Y. pp. 325-347.

Hillis, W. E. 1987. Heartwood and Tree exudates. Springer-Verlag, N Y. 268 pp

Hong, L. T. and M. A. Abdul-Razak, 1983. Anti-fungal properties of methanol extractives from some tropical hardwoods. Malayian Forester. 46: 138-139.

Irvine, F. R. 1961. Woody plants of Ghana with special reference to their uses. Oxford Univ. Press, London, UK. 868 pp.

Jin, L., B. J. van der Kamp, and J. Wilson,1988. Biodegradation of thujaplicins in living western red cedar. Can. Jour. For. Res. 18: 782-786.

Johnson, B. 1991. Responding to tropical deforestation: an eruption of crisis - an array of solutions. Osbom Centre Research Paper. WWF Pub., UK. 63 pp.

Johnson, E. L. and A. J. Cserjesi, 1980. Weathering effect on thujaplicin concentration in western red cedar shakes. For. Prod. Jour. 30: 52-53.

Laks, P. E., M. S. Pruner,, J. B. Pickens,and T. L. Woods, 1992. Efficacy of chlorothalonil against 15 wood decay fungi. For. Prod. Jour. 42: 33-38.

Merrill, W. B. and Cowling, E. B. 1965. Effect of variation in nitrogen content of wood on rate of decay. Phytopathology 55: 1067-1068.

McDaniel, C. A. 1989. Major termiticidal components of Port Oxford cedar, *Chamaecyparis lawsoniana* (A. Murr.) Parl. Mat. und Org. 24: 1-15.

Ministry of Lands and Forestry (MLF). 1993. Republic of Ghana: forest and wildlife policy. Draft policy Document 5.0.93.

Monteiro, M. B. B., S. Brazolin, and G. Catanozi, 1992. Comparison between agar-block and soil-block methods for wood destroying basidiomycetes. Inter. Res. Group Pap. IRG/WP2401-92. IRG Secretariat, Stockholm, Sweden.

Moor, H. W. 1940. Gold Coast timber industry. Nigeria For. 1: 3-8.

Morrell, J. J. and C. M. Freitag 1995. Durability of Dahurian larch. For. Prod. Jour. 45: 77-78.

Nault, J. 1988. Radial distribution of thujaplicins in old and second growth of western red cedar *(Thuja plicata* Donn). Wood Sci. and Tech. 22: 73-80.

Nerud, F., Z. Zonchora, and Z. Misurocora, 1991. Ligninolytic properties of different white-rot fungi. Biotechnology lett. 13: 657-660.

Nilsson, T. and D. M. Holt, 1983. Bacterial attack occuring in the S2 layer of wood

fibers. Holzforschung 37: 107-108.

Nilsson, T. and A. Singh, 1984. "Cavitational bacteria". International Research Group on Wood preservation, Document No. IRG/WP/1235. Stockholm, Sweden.

Nolan, T. M. 1989. Increment, annual cut and the growth of the forest. Forest inventory project seminar proceedings (J. L. G. Wong, ed). ODA (UK) and Forestry Dept., Ghana. pp. 53-58.

Ocloo, J. K. 1975. The natural resistance of the wood of Ghanaian timbers against attack by subterranean termites. Report on the seminar on utilization of the wood resources of Ghana, U.S.T., Kumasi, 19-21 Aug., 1975. For. Dep. pp. 171-179.

Ocloo, J. K. 1978. The natural resistance of the wood of *Terminalia ivorensis* A. Chev. (Idigbo, Emire) to both fungi and termites. Jour. Inst. of Wood Sci. 8: 1, 20- 23.

Ocloo, J. H. and E. Laing, 1991. Anatomical properties of the wood of some *Celtis sp.* indigenous to Ghana. Disc. and Innov. 3: 89-98.

Ofori, J. 1985a. A comparative study in minimizing the splitting of plantation grown Emire, *Terminalia ivorensis* A. Chev. fencing posts during drying. Tech. Bull. For. Prod. Res. Inst., Ghana. 5: 1-8.

Ofori, J. 1985b. The equilibrium moisture content of wood under sheltered outdoor conditions in Ghana. Tech. Bull. For. Prod. Res. Inst., Ghana. 5: 33-42.

Ofori, S. 1987. Corrosion of metal fasteners in contact with Kusia (*Nauclea diderrichii*) stakes. Tech. Bull. For. Prod. Res. Inst., Ghana. 3: 46-52.

Ofosu-Asiedu, A. 1976. The occurrence and importance of some wood decay fungi in Ghana. Mat. und Org. 3: 35-42.

Okoh, I. K. A. 1977a. Compilation of data on the properties of some tropical hardwoods indigenous to West Africa. Tech. Bull. For. Prod. Res. Inst., Ghana. 22: 14 pp.

Okoh, 1. K. A. 1977b. Moisture dependence of DC electrical resistivity of some Ghanaian woods. Tech. Bull. For. Prod. Res. Inst., Ghana. 1: 33-41.

Osborne, L. D. 1970. Decay resistance of south-west Pacific rain-forest timbers. CSIR, Australia. Div. For. Prod. Tech. Paper No. 56. 30 pp.

Panshin, A. J. and C. De Zeeuw, 1980. Textbook of Wood Technology. 4th ed. McGraw-Hill, N. Y. 722 pp.

Peterson, R. H. 1995. There is more to a mushroom than meets the eye: mating studies in the *Agaricales*. Mycologia 87: 1-17.

Pinzon-Picaseno, L. M. and J. D. Martinez-Marcial, 1983. The aggressiveness of 2 strains of *Pycnoporus sanguineus* (L. ex Fr.) Murr. towards Mexican tropical timbers. Anales del Inst. de Biol. Univ. Nac. Auto. de Mexico, Botanica 54: 233-240.

Pinzon-Picaseno, L. M. and J. Hernandez-Jimenez, 1986. Type of rot and aggressiveness of Mexican wood decaying fungi on pine and sweetgum woods. Anal-del-Inst. de Biol. Univ. Nac. Aut. de Mexico, Botanica 57: 1-9.

Pinzon-Picaseno, L. M., F. A. Veliz-Avila, and M. T. Lopez-Guerrero, 1983. Evaluation of the aggressiveness of wood decaying fungi: laboratory tests with *Pycnoporus sanguineus* (fungi, Basidiomycetes). Anal.- del- Inst. de Biol. Univ. Nac. Aut. de Mexico, Botanica 54: 227-232.

Pleydell, G. J. 1972. Increasing the utilization of secondary species through the manufacture of wood-based panels. Proceedings of the Seventh World Forestry Congress, Buenos Aires, Argentina, 4-18 Oct., 1972, Vol. V.: World Forestry Congress: Seventh technical.

Puri, Y. N. 1960. A note on the decay resistance test of Ghana timbers. Indian For. 86: 621-622.

Rancurel, P. 1967. Compared tests on the resistance of various tropical types of wood to worm attack on the coast of West Africa. Transl. Commonw. Sci. Indust. Res. Organ. No. 8544. 5 pp.

Rayner, A. D. M. and L. Boddy, 1988. Fungal decomposition of wood. Wiley and Sons Ltd. London. pp. 215-473.

Roff, J. W., E. I. Whittaker, and H. W. Eades, 1963. Decay resistance of western red cedar relative to kiln seasoning, colour and origin of the wood. Forestry Dept., Can., For. Prod. Res. Branch, Tech. Note No. 32. 19 pp.

Safo-Sampah, S. 1977. Annotated bibliography on marine wood destroying organisms. Tech. Bull. For. Prod. Res. Inst., Ghana. 23: 26 pp.

Sargent, C., T. Husain, N. A. Kotey, J. Mayers, E. Prah, M. Richards, and T. Treue, 1994. Incentives for the sustainable management of the tropical high forest of Ghana. Commonwealth For. Rev. 73: 155-163.

Saussier, J. D. 1982. Guide to the marine wood-boring organisms of Ghana with illustrated key. Tech. Bull. For. Prod. Res. Inst., Ghana. 2: 1-24.

Scheffer, T. C. 1936. Progressive effects of *Polyporus versicolor* on the physical and chemical properties of red gum sapwood. USDA Tech. Bull. No. 527. Washington, D. C.

Scheffer, T. C. 1957. Decay resistance of western red cedar. Jour. For. 55: 434-442.

Scheffer, T. C. 1963. Effect of gamma radiation on decay resistance of wood. For. Prod. Jour. 13: 268.

Scheffer, T. C. 1971. A climate index for estimating potential for decay in wood structures above ground. For. Prod. Jour. 21: 25-3 1.

Scheffer, T. C. 1983. Decay resistance of Alaska-cedar. For. Prod. Jour. 33: 25-26.

Scheffer, T. C., G. H. Englerth, and G. G. Duncan, 1949. Decay resistance of seven native oaks. Jour. Agric. Res. 78: 129-152.

Scheffer, T. C. and Hopp, H. 1949. Decay resistance of black locust heartwood. USDA Tech. Bull. No. 984. Washington, D. C.

Scheffer, T. C. and E. B. Cowling, 1966. Natural resistance of wood to microbial deterioration. Ann. Rev. Phytopath. 4: 147-170.

Scheffer, T. C. and W. E. Eslyn, 1961. Effect of heat on decay resistance of wood. For. Prod. Jour. 11: 485-490.

Seeham, G. 1976. On the fungal resistance of Khaya. Holz.-als-Roh.-und-Werkstoff 34: 465-468.

Setliff, E. C. 1986. Wood decay hazard in Canada based on Scheffer's climate index formula. For. Chron. 62: 456-459.

Setliff, E. C. and Eudy, W. W. 1980. Screening white-rot fungi for their capacity to delignify wood. In "Lignin biodegradation: microbiology, chemistry, and potential applications, vol. 1. (T. K. Kirk, T. Higuchi and H. M. Chang eds.). C R C Press, Boca Raton, Florida. pp. 135-149.

Shigo, A. L. 1965. The pattern of decays and discolorations in northern hardwoods. Phytopathology 55: 648-652.

Smith, R. S. 1978. A new lid closure for fungal culture vessels giving complete protection against mite infestation and microbiological comtamination. Mycologia 70: 499-508.

Smith, J. B. and S. F. Primakov, 1977. Ghana woods as raw material for pulp production. Visn.-Kiiv.-Politekh.-Inst. 14:31-33.

Southwell, C. R. and J. D. Bultman, 1971. Marine-borer resistance to untreated woods over long periods of immersion in tropical waters. Biotropica 3: 81-107.

Suhirman, T. and T. Khusniati, 1987. Laboratory study of the effect of mud-submersion treatment on the durability of two bamboo and one wood species against fungi. Mat. und Org. 22: 289-296.

Taniguchi, T., H. Harada, and K. Nakato, 1986. Characterization of inorganic deposites in tropical woods by a new method of isolation. Jour. Japan Wood Res. Soc. 32: 227-233.

Twimasi, K. A. 1991. Strength characteristics of packaging papers made from tropical wood species. Trop. Sci. 31: 1, 95-100.

Usher, M. B. and J. K. Ocloo, 1979. The natural resistance of 85 West African hardwood timbers to attack by termites and microorganisms. Trop. Pest Bull. 6: 47 pp.

van der Drift, J. W. P. T. and P. B. Laming, 1979. Basis for assessment of the natural durability of tropical timber in connetion with end-uses in external joinery in the Netherlands. Economic Commission for Europe, Timber Committee: Seminar on the utilization of tropical hardwoods, Amsterdam, the Netherlands, 15-18 May. No. TINVSEM. 8/R. 14: 4 pp.

Verner, R. W. and R. L. Krause, 1951. Agar-block and soil-block methods for testing wood preservative. Ind. and Eng. Chem. 43: 1102-1107.

Vongkaluang, C. and I. Vongkaluang, 1985. Destruction of rattan by wood-destroying fungi. Malayian Forester. 48: 3-4, 240-243.

Voorhoeve, A. G. 1979. Liberian high forest trees. Centre for Agric. Pub. and Doc., Wageningen, the Netherlands. 416 pp.

Wilcox, W. W. 1992. Effectiveness of Lentrek and Polyphase preservation treatment in Douglas-fir determined by a soil-block analysis. For. Prod. Jour. 42: 31-32.

Yakovleva, N. S., V. P. Gavrilova, V. A. Solovev, S. V. Nikolaev, and O. N. Malysheva, 1993. Growth and oxydoreductase activity of *Pycnoporus sanguineus* (L.: Fr.) Murr. during surface culture. Mikologiya-i-Fitopat. 27: 48-51.

Zabel R. A. 1948. Variation in the decay resistance of white oak. New York State College of Forestry Tech. Pub. 68. Syracuse, NY.

Zabel, R. A., F. F. Lombard, and A. M. Kenderes, 1980. Fungi associated with decay in treated Douglas fir transmission poles in northeastern United States. For. Prod. Jour. 30: 51-56.

Zabel, R. A. and J. J. Morrell, 1992. Wood microbiology: Decay and its prevention. Acad. Press, Inc. NY. 476 pp.

Zainal, A. S. 1976. The effect of a change in cell-wall constituents on decay of Scots pine by a soft-rot fungus. Mat. und Org. 11: 295-301.

APPENDICES

APPENDIX I

Percentage weight loss of *Betula alleghaniensis* and *Celtis mildbraedii* wood exposed to four fungal species over six weeks.

Culture medium	Wood species	*C. polyzona*		*O. placentus*		*P. sanguineus*		*T. versicolor*	
		Exp.1	Exp. 2	Exp.1	Exp. 2	Exp.1	Exp. 2	Exp.1	Exp. 2
Agar	Betula sp.	35.6	18.1	46.7	45.1	9.1	1.6	2.2	1.8
		31.0	16.1	51.2	48.9	7.4	2.7	1.7	4.1
		21.1	14.0	50.3	50.0	7.1	10.6	4.2	2.1
		37.9	18.1	53.3	45.0	6.8	5.3	3.7	3.6
		26.0	13.6	49.7	38.8	6.0	4.9	6.6	10.0
		24.9	16.6	45.2	31.2	5.4	5.6	4.2	4.2
	Mean	29.4	15.9	49.4	43.2	7.0	5.1	3.8	4.3
	(SD)	6.5	1.9	3.0	7.1	1.3	3.1	1.7	3.0
Soil	Betula sp.	56.9	12.5	7.2	14.2	13.9	13.8	2.3	1.7
		58.6	10.0	4.1	17.0	23.8	14.2	2.3	2.1
		58.8	14.1	19.1	15.1	5.3	6.4	10.5	2.1
		57.1	13.2	22.7	18.8	13.1	4.8	7.7	1.1
		45.6	9.8	10.8	16.3	5.8	4.0	1.7	1.1
		63.0	9.7	12.2	8.7	8.2	4.6	1.1	1.6
	Mean	56.7	11.6	12.7	15.0	11.7	8.0	4.3	1.6
	(SD)	5.8	1.6	7.1	3.5	7.0	4.7	3.9	0.5
Agar	Celtis sp.		10.2		7.2		1.8		3.4
			21.3		1.9		1.9		3.7
			21.4		-1.8		3.9		3.2
			22.9		-1.4		3.6		3.3
			13.4		0.9		2.3		2.8
			17.8		-1.51		2.8		2.6
	Mean		17.8		0.9		2.7		3.2
	(SD)		5.1		3.4		0.9		0.4
Soil	Celtis sp.		22.6		15.1		18.6		4.1
			21.8		17.9		22.4		3.7
			23.2		16.1		24.8		3.3
			22.1		18.4		45.1		2.7
			19.8		22.1		31.6		4.8
			19.3		23.4		27.6		4.7
	Mean		21.5		18.8		28.3		3.9
	(SD)		1.6		3.3		9.3		0.8

APPENDIX II

Per cent weight loss of three wood species exposed to four fungal species over a 12-week period.

Culture Medium	Wood Species	*Coriolopsis polyzona*	*Oligoporus placentus*	*Pycnoporus sanguineus*	*Trametes versicolor*
Agar	*Betula* sp.	69.8	58.8	14.7	11.2
	(Sapwood)	66.0	52.9	12.3	11.2
		70.0	59.0	21.3	7.7
		56.0	61.6	15.9	3.3
		65.5	59.2	13.6	3.4
		67.6	61.8	10.6	4.4
	Mean (SD)	65.8 (5.2)	58.8 (3.2)	14.7 (3.7)	6.9 (3.7)
Agar	*Celtis* sp.	43.1	0.8	14.8	3.3
	(Heartwood)	64.7	1.2	5.1	3.5
		60.6	4.7	13.7	4.4
		58.5	13.7	15.0	3.6
		57.8	18.4	10.2	4.6
		65.9	9.9	13.2	3.4
	Mean (SD)	58.4 (8.2)	8.1 (7.1)	12.0 (3.8)	3.8 (0.6)
Agar	*Strombosia* sp.	48.1	6.5	13.0	3.0
	(Sapwood)	42.9	1.8	12.8	3.2
		51.6	5.0	9.3	3.7
		55.9	3.3	6.5	3.4
		49.8	1.7	13.5	0.5
		60.2	4.3	13.5	2.7
	Mean (SD)	51.6 (5.9)	3.8 (1.9)	11.4 (2.9)	2.6 (1.1)
Soil	*Betula* sp.	92.0	21.1	28.2	2.2
	(Sapwood)	90.8	10.8	35.4	2.7
		69.0	13.3	27.3	1.7
		83.4	7.5	19.5	15.5
		86.8	12.9	23.8	3.8
		88.8	19.7	17.1	1.2
	Mean (SD)	85.1 (8.5)	14.2 (5.3)	25.2 (6.6)	4.5 (5.5)
Soil	*Celtis* sp.	75.9	*	24.7	4.2
	(Heartwood)	54.5	*	17.8	4.6
		74.7	19.7	18.0	1.4
		72.1	15.2	16.6	2.9
		55.9	20.9	16.3	2.7
		57.4	17.0	22.6	1.5
	Mean (SD)	65.1 (10.2)	18.2 (2.6)	19.3 (3.5)	2.9 (1.3)

Soil	*Strombosia* sp.	54.9	6.5	13.0	3.0
	(Sapwood)	60.5	1.8	12.8	3.2
		71.5	5.0	9.3	3.1
		54.0	3.3	6.5	3.4
		34.8	1.7	13.5	0.5
		31.8	4.3	13.5	2.7
	Mean (SD)	51.2 (15.3)	3.8 (1.9)	11.4 (2.9)	2.6 (1.1)

APPENDIX III

Per cent weight loss of 31 wood species exposed to various fungal species for 10- and 12-week period (experiment 2 and 1 respectively).

Wood species	*Coriolopsis polyzona*		*Oligoporus placentus*		*Pycnoporus sanguineus*		*Trametes versicolor*	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
Pericopsis elata	1.60	1.79	0.00	0.01	1.32		0.50	
	0.46	6.06	0.00	0.01	0.86		1.01	
	1.55	5.37	0.00	1.12	2.67		0.49	
	1.08	4.79	0.00	2.17	1.36		1.02	
	1.78	4.76	0.00	2.17	1.49		0.89	
	0.87	3.11	0.00	0.01	3.55		0.48	
Mean	1.22	4.31	0.00	0.92	1.88		0.73	
(SD)	(0.5)	(1.9)	(0.0)	(1.1)	(1.0)		(0.3)	
Afzelia africana	3.76	8.02	2.14	0.00	4.44		2.16	
	3.09	8.40	2.11	2.14	5.70		3.85	
	2.22	6.62	1.12	1.09	3.72		3.16	
	3.85	6.86	2.19	0.01	5.26		1.66	
	1.09	7.75	9.50	0.01	4.30		2.89	
	2.13	8.11	7.53	0.01	8.15		1.78	
Mean	2.69	7.63	4.10	0.54	5.26		2.58	
(SD)	(1.1)	(0.7)	(3.5)	(0.9)	(1.6)		(0.9)	
Lophira alata	1.69	6.27	0.65	1.79	4.59		0.34	
	1.05	4.91	0.00	0.01	2.45		0.33	
	4.03	5.35	0.00	1.72	3.56		0.36	
	3.38	5.35	0.61	1.94	4.73		0.68	
	4.42	4.59	0.75	0.00	4.20		0.35	
	3.66	4.67	0.00	1.30	4.26		0.70	
Mean	3.04	5.19	0.34	1.13	3.97		0.46	
(SD)	(1.4)	(0.7)	(0.4)	(0.9)	(0.9)		(0.2)	
Entandrophragma utile	0.87		13.56		4.39		0.00	
	1.75		13.60		11.02		0.00	
	1.71		9.32		1.79		1.69	
	0.89		2.63		7.69		1.02	
	9.09		8.96		10.13		0.64	
	13.89		9.13		8.91		0.62	
Mean	4.70		9.53		7.32		0.66	
(SD)	(5.5)		(4.0)		(3.6)		(0.6)	

Tieghemella	7.73	**5.41**	1.23	**0.01**	4.29	1.88
heckelii	9.18	**6.54**	0.87	**0.01**	3.15	1.30
	12.96	**6.83**	1.30	**0.00**	2.37	0.71
	9.31	**5.02**	1.33	**0.01**	2.74	2.01
	7.07	**4.83**	1.34	**0.00**	3.20	1.79
	6.54	**5.26**	0.00	**0.00**	2.77	1.89
Mean	8.80	**5.65**	1.01	**0.01**	3.09	1.60
(SD)	(2.32)	**(0.8)**	(0.5)	**(0.0)**	(0.7)	(0.5)
Heretiera utilis	9.43	**16.34**	16.15	**12.43**	6.88	0.56
	9.94	**14.29**	7.26	**6.59**	7.01	0.68
	8.93	**13.55**	21.43	**12.03**	5.71	1.04
	9.36	**15.19**	22.94	**10.90**	7.53	0.63
	13.89	**15.63**	1.71	**6.82**	5.17	0.81
	12.43	**10.18**	11.08	**7.26**	7.64	0.52
Mean	10.66	**14.20**	13.43	**9.34**	6.66	0.71
(SD)	(2.0)	**(2.2)**	(8.2)	**(2.7)**	(1.0)	(0.2)
Terminalia	6.58	**9.17**	1.67	**0.00**	1.80	0.65
ivorensis	9.70	**11.57**	1.82	**0.00**	6.43	0.73
	3.25	**10.11**	0.70	**0.00**	2.14	0.79
	3.55	**9.14**	0.70	**0.01**	3.28	0.65
	23.81	**7.63**	0.00	**0.00**	6.25	0.00
	17.19	**8.76**	0.00	**0.01**	3.09	0.69
Mean	10.68	**9.40**	0.82	**0.00**	3.83	0.59
(SD)	(8.2)	**(1.3)**	(0.8)	**(0.0)**	(2.0)	(0.3)
Milicia excelsa	8.57		1.14		2.31	1.72
	8.89		1.12		1.12	1.70
	11.30		1.11		3.89	2.14
	13.12		0.63		6.67	1.98
	13.22		0.57		5.09	0.98
	11.48		0.57		4.68	1.01
Mean	11.10		0.86		3.96	1.59
(SD)	(2.0)		(0.3)		(2.0)	(0.5)
Entandrophragma	2.96		1.05		10.47	1.02
cylindricum	1.03		1.03		10.40	0.98
	3.09		10.02		8.63	0.87
	5.10		9.44		5.88	1.00
	27.23		18.79		12.62	0.91
	27.32		16.93		11.74	1.10
Mean	11.12		9.57		9.96	0.98
(SD)	(12.6)		(7.6)		(2.4)	(0.1)
Strombosia	10.00	**12.75**	12.91	**8.99**	5.15	0.67
glaucescens	14.12	**11.60**	28.34	**9.04**	4.56	0.01
	13.24	**12.63**	13.24	**9.97**	4.23	0.81
	19.88	**12.78**	13.80	**10.18**	4.89	0.27
	15.04	**11.08**	9.88	**10.88**	9.71	0.65
	15.16	**13.21**	10.14	**8.10**	10.16	0.78
Mean	14.57	**12.34**	14.72	**9.36**	6.45	0.53
(SD)	(3.2)	**(0.8)**	(6.9)	**(1.0)**	(2.7)	(0.3)

Piptadeniastrum	2.01		4.12		12.50	1.60
africanum	1.59		8.84		8.42	2.01
	33.51		10.06		9.53	1.52
	27.05		12.44		13.49	1.57
	26.49		16.32		14.49	0.99
	23.17		18.59		9.46	1.55
Mean	18.97		11.73		11.32	1.54
(SD)	(13.7)		(5.3)		(2.5)	(0.3)
Albizia	29.86	17.74	27.40	10.01	13.34	0.00
adianthifolia	33.84	15.20	21.68	10.10	13.88	0.66
	28.97	21.06	24.16	11.36	11.87	0.87
	30.21	16.54	19.89	12.48	10.98	0.73
	15.94	21.28	21.67	12.79	8.69	1.02
	16.28	18.42	25.11	18.82	6.11	0.76
Mean	25.85	18.37	23.32	12.76	10.81	0.67
(SD)	(7.7)	(2.4)	(2.8)	(3.3)	(3.0)	(0.4)
Lovoa trichiloides	1.71		13.10		7.23	0.00
	0.67		16.55		13.01	0.00
	33.84		32.54		9.76	0.00
	61.29		27.42		10.77	0.00
	28.96		31.47		20.19	0.00
	30.17		29.07		18.67	0.00
Mean	26.11		25.03		13.27	0.00
(SD)	(22.7)		(8.2)		(5.1)	(0.0)
Khaya anthotheca	39.74		13.75		9.20	0.00
	43.95		17.18		5.85	0.00
	44.81		24.36		9.26	0.00
	38.85		19.62		7.60	0.65
	1.29		21.68		12.21	0.68
	6.13		12.84		21.33	0.66
Mean	29.13		18.24		10.91	0.33
(SD)	(19.9)		(4.5)		(5.5)	(0.4)
Distemonanthus	36.27		36.72		2.45	0.00
benthamianus	38.92		32.81		3.69	0.00
	40.15		24.90		17.07	0.92
	20.61		17.76		11.41	0.42
	18.90		18.49		15.79	0.00
	20.04		19.61		16.22	0.00
Mean	29.15		25.05		11.11	0.22
(SD)	(10.3)		(8.0)		(6.5)	(0.4)
Amphimas	25.73	30.98	0.93	12.56	7.58	3.88
pterocarpoides	25.98	30.39	0.97	9.77	9.52	1.44
	32.24	32.86	7.50	11.17	9.66	2.96
	32.26	32.17	7.25	8.96	11.94	3.11
	31.68	31.00	24.29	12.44	9.85	1.05
	29.15	27.84	24.02	11.62	8.33	1.20
Mean	29.51	30.87	10.83	11.09	9.48	2.27
(SD)	(3.1)	(1.7)	(10.7)	(1.5)	(1.5)	(1.2)

Chrysophyllum	27.86		7.25		22.07	0.00
albidum	29.50		13.48		24.82	0.00
	30.07		35.29		17.22	0.61
	32.37		36.67		23.91	0.58
	31.47		25.78		25.14	0.00
	28.70		24.11		23.11	0.00
Mean	30.00		23.76		22.71	0.20
(SD)	(1.7)		(11.7)		(2.9)	(0.3)
Entandrophragma	28.49		2.75		4.73	0.58
angolense	22.53		7.78		2.30	0.55
	34.10		2.27		10.29	0.60
	38.29		0.58		7.78	0.00
	27.55		3.37		6.67	1.17
	4.20		3.49		10.91	0.57
Mean	25.86		3.37		7.11	0.58
(SD)	(6.1)		(2.4)		(3.3)	(0.4)
Nesorgodonia	48.05		25.14		15.10	0.00
papaverifera	44.26		24.28		6.90	0.00
	65.57		20.96		11.73	0.00
	39.55		23.33		18.82	0.00
	11.96		23.14		17.16	0.59
	14.44		22.41		12.14	0.63
Mean	37.31		23.21		13.64	0.20
(SD)	(20.7)		(1.5)		(4.3)	(0.3)
Terminalia superba	38.64	**47.86**	12.78	**30.55**	17.48	4.72
	37.12	**45.82**	11.44	**30.61**	7.32	1.47
	44.62	**53.55**	12.91	**16.81**	18.37	3.41
	34.35	**47.02**	12.75	**18.10**	13.79	1.32
	62.64	**35.79**	13.37	**16.52**	23.21	4.11
	37.61	**45.48**	12.11	**17.17**	20.19	2.97
Mean	42.50	**45.92**	12.56	**21.63**	16.73	3.00
(SD)	(10.4)	**(5.8)**	(0.7)	**(7.0)**	(5.6)	(1.4)
Pycnanthus	51.77	**50.00**	17.46	**40.89**	21.95	3.15
angolensis	52.67	**47.30**	34.15	**43.33**	28.57	2.36
	39.44	**51.27**	1.52	**41.97**	16.00	1.96
	49.66	**49.66**	2.46	**39.46**	19.84	3.12
	47.22	**46.98**	2.33	**46.51**	12.61	2.14
	44.37	**43.04**	2.36	**42.15**	25.39	2.01
Mean	47.52	**48.04**	10.05	**42.39**	20.73	2.46
(SD)	(5.0)	**(3.0)**	(13.3)	**(2.4)**	(5.9)	(0.5)
Aningeria altissima	64.52	**52.31**	15.08	**24.87**	23.44	1.50
	60.80	**51.45**	7.20	**25.13**	22.22	1.82
	36.30	**48.13**	18.18	**15.17**	12.31	1.73
	40.63	**44.19**	23.53	**17.32**	18.85	2.11
	40.47	**35.87**	3.23	**27.50**	20.15	1.93
	45.13	**35.97**	2.40	**30.00**	21.63	1.67
Mean	47.98	**44.65**	11.60	**23.33**	19.77	1.79
(SD)	(11.8)	**(7.3)**	(8.6)	**(5.8)**	(4.0)	(0.2)

Canarium	39.31	47.27	18.18	34.24	7.96		1.82	
schweinfurthii	54.02	50.12	17.37	36.09	6.08		1.20	
	60.37	48.65	50.00	39.48	27.65		1.36	
	63.98	53.14	45.83	36.79	22.29		1.21	
	38.41	41.51	46.13	43.12	21.63		0.97	
	41.61	45.73	39.18	38.92	25.11		1.19	
Mean	49.62	47.74	36.12	38.11	18.45		1.29	
(SD)	(11.3)	(4.0)	(14.6)	(3.1)	(9.1)		(0.3)	
Daniella ogea	82.82	41.09	71.70	22.46	21.15		4.64	
	32.31	43.04	36.56	33.53	14.29		0.00	
	71.08	46.06	58.00	22.50	14.47		1.36	
	33.88	44.33	55.48	28.05	10.33		1.45	
	78.57	51.41	55.71	21.16	22.08		1.89	
	45.16	48.91	37.16	22.46	10.97		0.55	
Mean	57.30	46.14	52.44	25.03	15.55		1.65	
(SD)	(22.9)	(3.8)	(13.5)	(4.8)	(5.0)		(1.6)	
Turraeanthus	58.4	39.95	30.08	24.39	12.69		0.00	
afticanus	51.8	42.72	34.75	23.28	13.13		0.00	
	61.94	48.68	31.21	34.39	21.43		0.96	
	55.63	53.99	25.00	35.93	21.09		1.91	
	57.98	54.82	30.95	24.07	30.16		0.67	
	60.07	49.12	32.68	26.90	31.04		0.94	
Mean	57.64	48.21	30.78	28.14	21.59		0.75	
(SD)	(3.6)	(5.9)	(3.3)	(6.2)	(7.9)		(0.7)	
Bombax brevicuspe	66.39	46.88	28.67	25.72	26.45	24.74	22.22	13.01
	59.84	43.48	22.30	26.43	14.48	25.89	16.56	12.23
	60.17	53.31	72.84	28.35	25.97	23.25	23.16	13.67
	55.91	55.41	10.83	28.12	20.13	25.19	24.11	15.00
	69.75	48.96	46.79	28.59	21.92	33.08	14.37	17.65
	68.75	49.18	42.11	26.08	20.51	26.88	12.89	17.01
Mean	63.44	49.54	37.26	27.22	21.58	26.51	18.89	14.76
(SD)	(5.6)	(4.3)	(21.8)	(1.3)	(4.4)	(3.4)	(4.9)	(2.2)
Celtis mildbraedii	75.93	48.96	*	39.86	24.66		4.17	
	54.46	49.18	*	41.97	17.82		4.61	
	74.66	49.12	19.67	43.12	18.01		1.40	
	72.07	53.14	15.24	38.92	16.59		2.91	
	55.87	43.14	20.89	28.59	16.30		2.70	
	57.42	55.62	17.01	26.88	22.62		1.47	
Mean	65.07	49.86	18.20	36.56	19.33		2.88	
(SD)	(10.2)	(4.3)	(2.6)	(5.78)	(3.46)		(1.3)	
Ceiba pentandra	68.75	56.18	16.67	28.75	32.14	26.20	9.62	15.09
	59.26	49.55	11.32	35.49	31.04	27.00	1.88	17.86
	67.27	55.00	14.29	26.36	11.32	29.10	47.92	16.19
	71.70	53.62	11.77	24.58	8.70	28.08	48.00	18.90
	69.01	52.74	20.46	32.92	10.97	26.20	15.98	17.69
	63.98	58.40	18.92	30.83	16.19	26.02	20.01	21.61
Mean	66.66	54.25	15.57	29.82	18.39	27.10	23.90	17.89
(SD)	(4.4)	(3.0)	(3.76)	(4.1)	(10.5)	(1.3)	(19.6)	(2.3)

Pterygota	68.92	**51.36**	32.28	**43.24**	6.54	4.52
macrocarpa	69.86	**46.08**	36.18	**49.01**	6.16	3.95
	76.67	**55.13**	64.15	**35.66**	4.67	3.23
	72.33	**38.61**	63.64	**39.86**	4.97	3.43
	76.47	**52.61**	57.24	**41.97**	36.49	5.48
	69.18	**52.24**	49.03	**40.00**	8.08	8.23
Mean	72.24	**49.34**	50.42	**41.62**	11.15	4.81
(SD)	(3.6)	**(6.0)**	(13.7)	**(6.5)**	(12.5)	(1.9)
Antiaris africana	79.44	**55.79**	50.48	**33.66**	8.46	2.11
	76.27	**54.44**	52.21	**21.84**	22.32	2.25
	22.73	**49.45**	65.42	**62.18**	18.02	0.89
	87.38	**30.00**	52.17	**30.48**	23.93	2.75
	84.27	**49.82**	19.84	**36.00**	18.01	2.91
Mean	86.21	**44.52**	30.51	**31.58**	17.98	3.33
(SD)	72.72	**47.34**	45.11	**35.96**	18.12	2.37
	(24.9)	**(9.4)**	(16.7)	**(13.7)**	(5.4)	(0.9)
@*Betula* sp.	92.0	**49.18**	21.1	**39.86**	28.2	2.2
	90.8	**43.12**	10.8	**38.61**	35.4	2.7
	69.0	**52.74**	13.3	**30.83**	27.3	1.7
	83.4	**49.18**	7.5	**25.11**	19.5	15.5
	86.8	**39.46**	12.9	**27.39**	23.8	3.8
	88.8	**46.09**	19.7	**29.14**	17.1	1.2
Mean	85.1	**46.63**	14.2	**31.82**	25.2	4.5
(SD)	(8.5)	**(4.8)**	(5.3)	**(6.1)**	(6.6)	(5.5)

* contaminated samples @ reference block

APPENDIX IV

Decay index values for 23 towns in Ghana between 1986-1995.

Town	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Mean index	Hazard rating
Axim	129	205	152	138	141	162	178	163	195	126	159	Very high
Akim Oda	121	164	170	143	111	148	145	163	135	137	144	Very high
S. Bekwai	113	143	139	139	135	150	131	162	121	158	139	Very high
Koforidua	104	141	130	132	126	156	129	148	121	128	132	Very high
Ho	124	127	133	112	89	143	87	101	104	128	115	Very high
Kumasi	87	128	130	108	119	125	111	119	84	130	114	Very high
Abetifi	101	135	121	98	102	132	91	121	87	128	112	Very high
Takoradi	75	131	83	85	94	120	122	111	111	116	105	Very high
Sunyani	103	125	105	125	85	112	79	108	102	102	105	Very high
Wenchi	101	106	86	118	88	108	76	80	79	120	96	High
KeteKrachi	97	91	93	85	99	115	67	87	63	90	89	High
Yendi	77	69	92	95	82	106	66	75	82	87	83	High
Akuse	65	81	92	83	50	74	63	103	66	101	78	High
Bole	70	71	87	89	70	97	55	60	70	72	74	High
Saltpond	56	72	64	85	63	94	61	56	89	73	71	High
Wa	47	70	67	94	68	73	46	59	76	95	70	Moderate
Tamale	62	51	62	86	77	79	40	62	67	70	66	Moderate
Navrongo	65	51	65	62	39	72	66	49	78	53	60	Moderate
Bawku	59	52	62	65	51	81	60	48	60	62	60	Moderate
Akatsi	39	60	71	66	48	67	58	71	58	60	60	Moderate
Accra	38	67	50	41	41	70	51	27	40	50	48	Moderate
Ada	07	42	42	61	51	68	38	58	36	58	46	Moderate
Tema	19	31	40	59	44	70	40	27	33	46	41	Moderate

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6″

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