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Decomposition of Wood by Polypore Fungi in Tropics - Biological, Ecological and Environmental Factors- A Case Study

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Abstract

The tropical region, it is clearly understood that decomposition of wood by polypore fungi is influenced by the distribution of host species; forest types; ecological, environmental and seasonal interactions; decomposition and nutrient cycling; mode of attack and anthropogenic activities. It has been found that the white rot polypore prefer angiosperm wood than gymnosperm wood because the angiosperm lignin is relatively easier to oxidize than gymnosperm lignin and therefore angiosperm trees might be preferred by more white rot polypores. Among the common species in tropics, like, Coriolopsis retropicta, Microporus xanthopus, Fomitopsis palustris, Hexagonia sulcata, Rigidoporus lineatus, etc. exhibited restricted distribution and very narrow host range. Among the Fomitopsis dochmius and F. rhodophaeus were the most widespread in occurrence as well as they exhibited a wide host range. Some species such as Cyclomyces tabacinus, Earliella scabrosa, Ganoderma australe, Microporus affinis, and Rigidoporus microporus were found mainly found on newly fallen trees while other species such as Antrodiella species, Nigroporus vinosus, Postia species, and Tyromyces species were found on well-decomposed trees. Species richness of wood-decaying basidiomycetes was higher in a primary forest plot than in a regenerating forest plot and suggested that a low frequency of tree fall in the regenerating forest reduced the species richness of wood-decaying basidiomycetes. Studies shown that Ganoderma australe has been collected from species in the Leguminosae, Dipterocarpaceae, and Euphorbiaceae, and Phellinus lamaensis has been collected from species in the Dipterocarpaceae and Meliaceae. Amongst all the families, genera of Fabaceae are found to be most susceptible, followed by Rosaceae, Myrtaceae, Cupressaceae, Caesalpiniaceae, Ericaceae, Euphorbiaceae and Lauraceae. The families like Meliaceae, Pinaceae, Rubiaceae Arecaceae, Fagaceae and Olecaceae were also reported as the most frequently infected families. Quercus was the most frequent host of Phellinus species. To ensure the well- being of the forests, management of coarse wood debris need to be strengthened. The domestication of useful species and crafting market regimes for the products derived from polypores should be promoted.

Keywords: Decomposition, wood, polypore fungi, biological, ecological and environmental factors.

Introduction

The exercise of classifying biodiversity is of great importance because we need to know what's out there and how they are related to each other. This information in turn can be used to our benefit and moreover it is central for the management and conservation of our biological heritage. Autotrophic producer and woody plants in particular, support very high diversity of consumers and decomposers representing several trophic levels and specializations. Decaying wood is a unique, spatially and temporally discrete terrestrial habitat where Animalia, Plantae, Fungi, Protista, and Prokaryota co-occur and interact[1]. Wood-decay fungi are important natural components of indigenous forests, causing decay of fallen wood and of heartwood and sapwood of living trees. Fungi are the main organisms responsible for wood decay equipped with enzymes efficient in cellulose and lignin degradation. A wide range of fungi occur on wood using various constituents for their metabolism. Wood as a food source is limited to those fungi which are able to utilize the components and in the process break down the wood[2]. Consequently, organic substances of plants turn into fungal mycelia and fruit bodies, which make for an attractive food source for many organisms. Dead wood is a central element of complex and species-rich food webs, which include organisms dependent on wood, such as fungi and wood-boring insects, as well as their parasitoids, predators and fungivores[3]. The presence of fungal mycelia affects the species composition of saproxylic beetles attracted by dead wood[4-5]. Deadwoodology, the ecology of deadwood is a thriving research field, with wood-decaying fungi has a major role in it. Wood-decaying fungi are excellent ecosystem engineers, because they directly modulate resource availability other than themselves for several other functional groups. One group of deadwood-dependent species that has gained special attention is the polypores (Basidiomycota: Polyporales)[6].

Fungi have been known and used by humans for centuries, but mycology (the scientific study of fungi) traces its beginnings to the 18th century, with the development of the microscope[7]. By now, fungi are the concern of taxonomists, morphologists, geneticists, ecologists, phytopathologists, physicians, biochemists, molecular biologists, human doctors and commercial microbiologists. Fungi along with algae, lichens and bryophytes are coming under *Cryptogamae* of plant kingdom and characterized by lacking the specialized fluid conducting tissues typical of higher or vascular plants. Their propagation is by the production of minute reproductive propagules, usually spores. Among these, fungi have a worldwide distribution, and grow in a wide range of habitats, including extreme environments such as deserts or areas with high salt concentrations or ionizing radiation, as well as in deep sea sediments but they are not autotrophs and absorb nutrients from the surrounding environment[8]. Only about 6.7 per cent of 1.5 million species of fungi estimated in the world have been described and most of these are in temperate regions[9]. The tropical region which is undoubtedly hosting the highest mycodiversity has been inadequately sampled and the mycoflora scarcely documented[10].

Brief Details About Polypores

Historical development of international explorations and taxonomy of polypores: The earliest record of both poroid and non-poroid fungi goes back to “Nova Plantarum Genera” published by Micheli[11] an Italian botanist. Persoon[12] published the first systematic arrangement of the fungi as “Synopsis Methodica Fungorum”. Seventy one genera of fungi were recognized and classified by him. He divided fungi into two classes “Angiocarpii and Gymnocarpii”. Class Gymnocarpii was further subdivided into three orders Lytothecii, Hymenothecii and Naematothecii. The resupinate members belonging to order Polyporales were placed under order Hymenothecii.

Fries[13] classified and gave a complete account of fungi known at that time as “Systema Mycologicum” under three volumes. He divided fungi into four classes, *viz.* Coniomycetes, Hyphomycetes, Gasteromycetes and Hymenomycetes. The Hymenomycetes was further divided into 6 orders *i.e.* Pileati, Clavati, Mitrati, Cupulati, Tremellinae and Sclerotiaceae on the basis of a single character, “Hymenium nudum” (exposed hymenium). He recognized eight genera of polypores based on the hymenial configuration and macro morphological characters of basidiocarps[14]. Persoon[12] placed the poroid fungi with basidia lining the interior surface of the tubes into group "Porodermei". Leveille[15] divided the Hymenomycetes into 2 subclasses: Basidiosporii and Thecosporii (Ascomycetes) based on the internal structure of the basidiocarp. Fries[14] divided Hymenomycetes into 6 orders on the basis of hymenial configuration in “Hymenomycetes Europaei”. Hymenium and internal structure of the basidiocarp were taken as the basis for the classification of Basidiomycetes by Berkeley[16], Tulasne[17-18] and Massee[19]. Fries[20] subdivided genus Polyporus into three subgenera - *Eupolyporus, Fomes and Poria* in his “Novae Symbolae Mycologici”. Later the *Polyporus* was divided into *Merisma* (for branched stipitate species), *Physisporus* (for resupinate species) and *Fomes* (for woody perennial species) by Gillet[21]. Cooke[22] raised *Poria* to generic rank for resupinate poroid species. Saccardo and Sydow[23] placed resupinate poroid and non-poroid fungi under families Polyporaceae and Thelephoraceae of group Gymnocarpi.

Karsten[24-26] divided the Friesian genera into many smaller genera based on the consistency, pigmentation of basidiocarp, context, color of basidiospores, characters of the upper surface and presence or absence of stipe *etc.* Murrill[27] largely followed the Karsten’s system and divided Polyporaceae into 4 tribes: Porieae (for resupinate species), Polyporeae, Fomiteae and Daedaleae in his “North American Flora” (Polyporaceae). Smith[28] divided Basidiomycetes into Hymenomycetes and Gasteromycetes in his book “British Basidiomycetes”. He further divided Hymenomycetes into six families- Agaricaceae, Polyporaceae, Hydnaceae, Thelephoraceae, Clavariaceae and Tremellinaceae. The resupinate members of order Polyporales were placed under families Agaricaceae, Polyporaceae and Thelephoraceae. Patouillard[29] in his outstanding contribution “Essai Taxonomique surles families et les generes des Hymenomycetes” revised the system to classify Hymenomycetes based on microscopic characters and divided Basidiomycetes into “Basidiomycetes Heterobasidies” and “Basidiomycetes Homobasidies”. The “Basidiomycetes Homobasidies” was further divided into four families i.e. Exobasidiaces, Aphyllophoraces, Agaricaces, and Gasteromycetes. Majority of the resupinate members were placed under Aphyllophoraces.

Burt[30] followed the Friesian system and described 600 resupinate, non-poroid species belonging to 30 genera of Agaricomycetous fungi in a series of papers “The Thelephoraceae of North America”. Rea[31] divided Basidiomycetae into Homobasidiae and Heterobasidiae. The Homobasidiae was divided into 2 subdivisions (Exobasidiinae and Eu-homobasidiinae) in his monograph “British Basidiomycetae”. He listed 3 orders *i.e.* Gasteromycetales, Agaricales and Aphyllophorales under Euhomobasidiinae. Order Aphyllophorales was divided into two *i.e.* Porohydnineae with pileate, stipitate, sessile or resupinate members and Clavarniineae with erect, dendroid, coralloid, simple or branched never pileate members. Seven families were placed under Porohydnineae. Following Patouillard’s classification in general, the monumental work “Hymenomycetes de France” by Bourdot and Galzin[32] gave stress on the importance of microscopic features such as arrangement of hyphae in the context, presence or absence of clamp connections, shape of basidia and presence of modified structures in basidiocarp and amyloid reaction of spore wall. Corner[33-35] explained the occurrence of different types of hyphae in the basidiocarps of poroid fungi and introduced the concept of hyphal systems.

Bondartsev and Singer[36] arranged 60 poroid genera in 6 suborders and 8 families. Five subfamilies were placed under family Polyporaceae, one of which was Porioideae which included most of the resupinate species under 8 genera. Based upon the type of thickening of hyphae as they mature and presence or absence of clamp connections, Pinto-Lopes[37] proposed a new system. Eriksson[38] studied resupinate fungi from Sweden and introduced 7 new genera. Bondartsev[39] divided the artificial group "Polyporineae" into 5 suborders and 6 families in his monograph "The Polyporaceae of the European U.S.S.R. and Caucasia". He included 54 genera in family Polyporaceae, which was further divided into five subfamilies and 10 tribes. Christiansen[40] in his monograph "Danish Resupinate Fungi Part II, Homobasidiomycetes" described seven families of resupinate Aphyllophoraceous fungi. Cunningham[41] studied and gave a consolidated account of the resupinate fungi of Australia and New Zealand. Later he divided the family Polyporaceae into two subfamilies *i.e.* Polyporoideae and Fomitoideae in his monograph 'Polyporaceae of New Zealand'[42]. Donk[43] gave a detailed annotated nomenclatorial enumeration of polyporoid genera in "The generic names proposed for Polyporaceae". He published his most outstanding work "A conspectus of the families of Aphyllophorales" and recognized 21 families in 1964[44]. Later he added 2 more families i.e. Lachnocladiaceae and Tulasnellaceae to the existing list in 1971[45].

Locquin[46] introduced a new system of classification for fungi in his "De Taxie Fungiorum I- syllabus". He divided the fungi into 11 subdivisions on the basis of thallus organization, septation and nature of septa. The subdivision Acromycotina was divided into two classes: Endomycetes and Basidiomycetes. The class Basidiomycetes was further divided into three subclasses on the basis of spore character. The subclass Basidiomycetidae was subdivided into 9 orders and 95 families. Further, Ryvarden[47] described 78 poroid species under 31 genera in his manual "The Polyporaceae of North Europe" Vol. I. The study of polypores contributed from Arizona, Gulf-coast region, Hawaii and North America in a series of papers[48-54]. The various studied agaricomycetous fungi from Sweden, Romania, Austria, U.S.S.R, America, Africa, Europe, Spain, New York, U.S.A, Germany, Argentina and Canada[55-60]. In "Dictionary of the Fungi" Hawksworth et al.[61] listed 1200 species under the order Aphyllophorales. Following Donk's classification in general, Ryvarden and Gillbertson[62-63] published their monograph "European Polypores" under two volumes.

Hawksworth et al.[64] divided Basidiomycetes into Phragmo-basidiomycetideae and Holobasidiomycetideae. Phragmobasidiomycetideae and Holobasidiomycetideae were further divided into five and twenty-seven orders respectively. Resupinate members of Polyporales were mainly included under orders Stereales and Poriales of Holobasidimycetidae. Kirk et al.[65] divided the class Basidiomycetes into two sub classes Tremellomycetidae and Agaricomycetidae. The Agaricomycetidae was further divided into 8 orders and 94 families. Recently Kirk et al.[66] divided Basidiomycota into 3 subphyla: Pucciniomycotina, Ustilaginomycotina and Agaricomycotina. Agaricomycotina was divided into 3 classes: Tremellomycetes, Dacrymycetes and Agaricomycetes. Agaricomycetes was divided into 17 orders: Agaricales, Atheliales, Boletales, Geastrales, Gomphales, Hysterangiales, Phallales, Auriculariales, Cantharellales, Corticiales, Gloeophyllales, Hymenochaetales, Polyporales, Russulales, Sebacinales, Thelephorales and Trechisporales.

History of Polypores of India: The species richness of macrofungi, including wood-decaying polypores, is expected to be high in tropical regions. The proportion of fine woody debris is also expected to be higher in the tropical zone than in the temperate and boreal zones. The species richness of wood-decaying polypores in tropical regions may be largely underestimated without conducting surveys on at least three occasions[67]. The taxonomic study of Indian polypores was initiated by European scientists towards the middle of the Nineteen century. The earliest reported recorded by Kotzch[68-69]. A large number of polypores were reported by Berkeley[70-75] based on his studies of Dr. Hooker's extensive collection of macro fungi from Sikkim-Himalayas. Other reported of Indian polypores include Montagne[76], Leveille[77-78], Cook[79], Massee[80], Theissen[81], Blatter[82], Lioyd[83-84] and Murrill[85]. In their compilation of fungi of India, Butler and Bisby[86] lists 293 polyporoid species in 16 genera.

Bose[87] was the first Indian mycologist to provide a comprehensive account of the Indian polypores which he collected from Bengal and its surroundings. He described 143 species including nine new species in a series of papers "Polyporaceae of Bengal" I-XI. He made a valuable contribution on the geographical distribution and history of polypores in Bengal[88]. He studied the Polyporaceae from Lokra Hills (Assam) in 1937. Bose[89] stressed the importance of anatomy in systematics of Polyporacea and suggested the use of certain characteristic anatomical features in addition to the characters of basidia and spores for the specific identification of these fungi. The worked on polypores of Bengal was continued by other researchers[90-95]. Some of their other contributions are on polypores of Sikkim-Himalayas[96] and devising a simple method for producing typical sporophores of *Polystictus sanguineus*[97].

By the middle of the Twenty century observed of polypores causing disease and decays in forest trees gained momentum at the Forest Research Institutes, Dehra Dun. The similar studies have reported in different forest species by several researchers such as polypores causing diseases of oaks and other economically important forest trees species[98], diseases and decay of conifers[99] diseases of *Acacia catechu* and its prevention[100], root rot of *Shorea robusta* caused by *Polyporus shorea* and *P. ruidus*[101], heart rot due to *P. palustris*[102], disease complex in teak[103] and heart rot in trees[104] exposed the menace of wood decay fungi of which polypores play the major role. Other important contributors include the studies on *Trameles, Poria* and *Fomes*[105-109], on the polypore flora of South Andamans[110] and Nicobar Islands[111] and on the temperature relations of Indian polyporaceae on the trees and timber by Bakshi[112] described 355 species belonging to 15 genera.

The Panjab University has reported several polypores including some new species from the Western Himalayan and Mussoorie Hills[113-120]. Polypores in culture have been undertaken by Bakshi *et al.*[121-122], while Roy and co-workers have done interfertility and culture studies of several polypores[123-124]. The list of Southern Indian fungi complied by Rangaswami et al.[125] includes 44 polyporoid species belonging to 13 genera of which only 5 reported from Kerala. Natarjan and Kolandavelu[126] described some resupinate Aphyllophorales from Tamil Nadu region and this includes the pooroid members Inonotus polymorphus (Rostk.) Pilat, *Phellinus allardii* (Bres.) Ryv., *P. umbrinellus* (Bres.) Ryv. and *P. purpureo-gilvus* (Petch) Ryv. The polypore of Kerala has reported only six species[127]. The tabulated list has given of 251 species of order *Aphyllophorales* from Western Ghats[128]. It reported that 778 species of macrofungi belonging to 43 families, 101 genera in semi-evergreen and moist deciduous forest of Shimoga district, Karnataka[129]. The studied of taxonomy and diversity of *Ganoderma* spp. and reported 15 species and 3 varieties of *G. lucidum*, from Western Parts of Maharashtra[130]. The data indicated that 256 species of Aphyllophoraceous fungi from Western Ghats in his checklist, including 170 poroid and 86 non-poroid species[131]. More recently, it described that 89 species of polypores belonging to 32 genera from Kerala state[132]. Even though, much of the forests in Kerala are unexplored and many of the polypores probably have not even been recognized, described or named.

Systematic account of polypores

Polypores are coming under order Polyporales under class Agaricomycetes and division Basidiomycota in phylum Fungi. The members were distributed in three families namely Ganodermataceae, Hymenochaetaceae and Polyporaceae. The family Ganodermataceae is characterized by species with spores which are invariably double walled with an inner verrucose to ornamented, thickened and usually coloured wall over which there is a thin hyaline outer wall. It was the unique structure of the spore wall, which prompted Donk[133] to establish this family. This family includes genera *Amauroderma, Elfvingia, Ganoderma*, *Haddowia, Humphreya,* and *Magoderna.* The members of this family characterized by annual or perennial fruit body; one sided, tabulate or often stratified hymenophore; small to minute pores; dissepiments with sterile edges; pallid to dark brown or purplish context; trimitic hyphal system; branching of skeletal hyphae at extremities; rare presence of binding hyphae; absence of cystidia and setae; short, swollen and 4-spored basidia; an outer very thin, hyaline, membrane-like exosporium covering an ornamented thick-walled and often brownish endosperm.

The Hymenochaetaceae Donk is a well-marked family of Polyporales characterized by species having setae and or dark coloured context becoming irreversibly black in KOH solution and generative hyphae without clamps. This family emphasized on the absence of clamps[133] and by the Corner[134], who opinioned that “the absence of clamps so distinguishes the xanthochroic series and their presence is the proof that a species does not belong.” The presence of setae is a unique character of Hymenomysetes[44]. The study has reported on the basis of cultural characters of about forty polyporoid species and supported the naturalness and homogeneity of this group[135]. The family Hymenochataceae as conceived by Donk[44] consisted of three sub-families *viz.,* Asterostromatoideae Donk, Hymenochaetoideae Donk and Vararioideae Donk with a total of 18 genera. It also recognized eighteen genera in Hymenochaetaceae, distributed in three sub families *viz.,* Asterostromatoideae, Hymenochaetoideae and Vararioideae[136]. However, all the genera in this Hymenochaetaceae are not the similar of Donk[44]. In his key to world genera of polypores, have accepted only 12 genera in Hymenochaetaceae[137].

The term Polyporaceae has been used with different connotations varying from a diverse assemblage of poroid species to the family Polyporaceae sensu stricto, which includes only poroid genera not included in other families of Aphyllophorales. The poroid genera in the order Aphyllophorales are distributed in about ten families and Polyporaceae is only one among ten families[44]. Several efforts have been made since early times to divide Polyporaceae into smaller families and one result of these efforts was that some members of this family were assigned to the Agaricales[138]. Fries[139-140] gave much importance to hymenial configuration. Polyporaceous genera with more or less typically lamellate hymenophore such as Lenzities and some of the tabulate genera such as Favolus (*P. Beauv*) Fr. were shifted to agarics. The relation of Polyporus sensu stricto to agaricales was also supported based on the observations on the similarity in hyphal system of *Pleurotus* (Fr.) P. Kumm. and *Polyporus squamosus* (Huds.) Fr.[134]. Few researchers have transferred Polyporus sensu stricto to Agaricales[141-142]. Donk[44] has criticized of these transfers on the ground that they were not based on redefinition of the generic and family characters and preferred to maintain the artificial family Polyporaceae in a broader sense among Aphyllophorales until better solutions was found. Taxonomic studies carried out by several researchers[136-137] has used the term Polyporaceae in the sense used by Donk[44], and by interpreting the same definition the term Polyporaceae has been used in the present study also.

A good number of these fungi produce large and conspicuous fruitbodies and therefore called as macrofungi. These macrofungi mainly belong to two orders, Polyporales and Agaricales, of class Basidiomycetes while a few are Ascomycetes. The polypores are Basidiomycetes producing holobasidia and ballistosporic basidiospores typically on the inside of the tubes lining the underside of the fructification[138]. Most of the polypores are wood inhabiting and rests are terrestrial. Wood rotting polypores are the important elements of forest ecosystem since it decompose wood and coarse woody debris, and play a primary and central role nutrient cycling in the forest ecosystem. Seventy five per cent of the species of fungi, that plays a significant role in timber decay belong to the polyporaceae, and are probably responsible for producing ninety per cent decay of the economically important timbers[143].

In Europe and North America, detailed studies on wood decaying fungi have been performed for a long time and many taxonomic monographs based on morphology have been published[137,144-146]. Polypore taxonomy is in a state of constant flux. New orders like the Amylocorticiales are still being generated based on DNA phylogenies[149]. Within the established orders, our understanding of classification, ecological aspects and evolutionary relationships is still fragmentary and much work remains to be done. After the introduction of molecular techniques in species identification, the phylogeny and taxonomy of wood decaying fungi were modified to a great extent and many higher-level taxonomic ranks were put forward or established[147-147].

Mode of attack of polypores

The establishment of polypores on coarse wood debris is facilitated by the exposure of massive amount of unprotected tissues. The entry into living trees is usually affected via wounds. Other probable routes of entry include lenticels, leaf scars and tissue weakened by drought or microbial damage. The colonization of polypores is by germinating spores and migratory mycelia. The mycelium of polypores at first grows well and the hyphae can grow unhindered by cell wall barriers in vessels. The axial alignment of tracheids, vessels and fibres and the radial arrangement of the xylem ray parenchyma facilitate access into the wood and allow widespread distribution of hyphae within the xylem[150]. Access to adjacent cells occurs via pit apertures, or direct penetration may take place directly through the cell wall. Radial spread takes place more slowly through disrupted pit membranes in lignified cell walls and through the cell walls of non-lignified wood parenchyma. Formation of boreholes by specialized cell wall degrading hyphae has been described in the literature[151]. These were initiated by fine penetration hyphae, less than 0.5 mm diameter, which penetrated the cell wall by means of lignolytic enzymes, which were released at the hyphal tip[152]. Subsequently, bore holes progressively enlarged by the secretion of enzymes from the general surface of the hypha. At a more advanced stage of decay, cracks often developed between adjacent boreholes in the radial cell walls, and the boreholes eventually coalesce. The mycelia ramify the wood tissues and absorb nutrients after breaking the cell wall constituents by enzymatic activity resulting in decay. Most dangerous is the “heart rot” which establishes itself in the heartwood and progress with time.

Decomposition of wood and Nutrient Cycling

Wood rotting fungi are the important elements of forest ecosystem. Fungi decompose wood and coarse woody debris, and play a primary and central role of degrading organic materials in the forest ecosystem. Wood inhabiting fungi release the carbon stored in the form of cellulose, hemicellulose and lignin from the woody debris back to the soil[153]. Within this group of fungi, the polypores are the main wood decayers. Polypores are very diverse group of organisms both morphologically and functionally. Based on the type of attachment and shape of the pileus the polypores can be divided into resupinate, effused reflexed, stiputate, dimidiate, flabelliform, spathulate, conchate, substipitate, ungulate and imbricate[138]. 75% of the species of fungi, that plays a significant role in timber decay belong to the polyporaceae, and are probably responsible for producing 90% decay of the economically important timbers[145]. Different polypore species have distinct functional characteristics defined by their differential decay capacity in different wood substrate conditions (e.g. living stem, standing or fallen dead stem, dead log, and branches of different diameters) with different physical and chemical properties[154]. The polypore species that decay the wood of living trees are usually called parasites, and those species that decay the wood of dead trees or dead parts of living trees are called saprobes. During the decay processes, the physical and chemical structure of the wood changes and therefore new species of polypores are likely to appear[154]. At the level of the forest stand, changes in the diameter class and decay stage of the wood (substrate conditions) also occur, not only during forest succession, but also under widespread forest exploitation or management[155-156]. Therefore, changes in the community structure of wood-decay fungi are expected[157-158]. Because different species have distinct decay capabilities, these shifts in community composition can be associated with changes of certain functional traits (e.g. decay capabilities) that in turn can affect certain ecosystem processes[159]. Although polypore species have usually been considered as a unique functional entity (i.e. wood decayers), within them they found many functionally different species and/or different stages of the wood decaying[161-162], rot type[163-164] and different trophic levels[138].

Decay Process by Polypores

The establishment of polypores on coarse wood debries is facilitated by the exposure of massive amount of unprotected tissues. The entry into living trees is usually effected via wounds. Other probable routes of entry include lenticels, leaf scars and via tissue weakened by drought or microbial damage. The colonization of polypores is by germinating spores and migratory mycelia. The mycelium of polypores at first grows well and the hyphae can grow unhindered by cell wall barriers in vessels. The axial alignment of tracheids, vessels and fibres and the radial arrangement of the xylem ray parenchyma facilitate access into the wood and allow widespread distribution of hyphae within the xylem. Access to adjacent cells occurs via pit apertures, or direct penetration may take place directly through the cell wall. Radial spread takes place more slowly through disrupted pit membranes in lignified cell walls and through the cell walls of non-lignified wood parenchyma. Formation of boreholes by specialized cell wall degrading hyphae has been described in the literature[151]. These were initiated by fine penetration hyphae, less than 0.5 mm diameter, which penetrated the cell wall by means of lignolytic enzymes, which were released at the hyphal tip. Subsequently, bore holes progressively enlarged by the secretion of enzymes from the general surface of the hyphae. At a more advanced stage of decay, cracks often developed between adjacent boreholes in the radial cell walls, and the boreholes eventually coalesce. The mycelia ramify the wood tissues and absorb nutrients after breaking the cell wall constituents by enzymatic activity resulting in decay. The decay polypores play an important role in nutrient cycling processes that replenish carbon dioxide and other substances essential for the plant growth. Most dangerous is the “heart rot” which establishes itself in the heartwood and progress with time.

Decay Types of Polypores

The polypores are classified into white rot polypores and brown rot polypores based mode of degradation of the woody cell walls and substances removed. White rot polypores can degrade lignin as well as cellulose and hemicelluloses of the wood. The wood becomes soft spongy in texture and retains its fibrous structure into the advanced stages and will absorb and retain a considerable amount of water. However, the relative rates of decomposition of lignin and cellulose vary greatly according to the species of fungi and the conditions within the wood. The brown rot polypores remove cellulose and hemicelluloses in the wood substrate, but decomposition of lignin is limited[165]. The studied on the polypore ecological patterns between gymnosperm and angiosperm trees based on data collected from more than 10 year field investigations in Fenglin and Changbaishan Nature Reserve, northeast China (boreal and temperate zone)[166]. It has been found that the white rot polypore prefer angiosperm wood than gymnosperm wood because the angiosperm lignin is relatively easier to oxidize than gymnosperm lignin[167] and therefore angiosperm trees might be preferred by more white rot polypores. In Kerala approx 90 % of the reported polypores are white rot causing polypres[138]. The estimated diversity of insects is about 30 to 80 million species worldwide, but the number of species associated with fungal habitats is difficult to even roughly estimate. Mycophagy, the consumption of fungi for food, has evolved multiple times among insects occurring in such diverse lineages as Coleoptera, Diptera, Lepidoptera, Hemiptera, Collembola, Isoptera, and Hymenoptera[168].

Ecological triangle made up by dead wood, beetles and polypore includes a wide range of interactions. For example, sporocarps and mycelia can serve as feeding and breeding grounds for beetles that may also act as vectors for the dispersal of both spores and mycelia, thus enhancing colonization of the cambium by the fungal partner[169-173]. Beetles act as either passive or active vectors for the dispersal of spores[169,174]. An understanding of these interactions is important as dead wood constitutes one of the most important structural components for maintaining biodiversity in forest ecosystems[157].

The beetle community on sporocarps of various polypore species has been studied intensively in the Nordic countries[175-179]. In most cases, closely related polypores support similar beetle faunas[175], but the closely related species *Fomitopsis pinicola* and *Fomitopsis rosea* host different species assemblages[179-180]. Other features of the sporocarp that affect the species assemblage include its physical structure[181], developmental stage[182] and persistence after death[176]. Further, the type of rot caused by fungi determines which beetles colonize the wood[183].

A number of studies have shown that saproxylic beetles may be attracted by volatiles emitted either by the wood[184-186], or by the host in response to fungal infection[187]. Furthermore, wood infected with active decay fungi emit more volatiles (ethanol and monoterpenes) than wood without active decay fungi[188]. Additionally, wood infected by different fungi[189] or rot may host different species[183]. Studies on wood-decaying polypores have previously tested the attraction of beetles to the odour of sporocarps[175,189-190]. A large number of cambium feeding beetles also feed on mycelia, and some beetle species are attracted to smell from the mycelium.

The conducted an experiment to test the attraction of beetles to volatiles from the sporocarps and mycelia of wood-decaying fungi. In a randomized block design, six substrate types: *Fomitopsis pinicola* sporocarp, *F. pinicola* mycelium-infected wood, *Fomitopsis rosea* sporocarp, *F. rosea* mycelium-infected wood, *Phellinus chrysoloma* sporocarp and *Phlebia centrifuga* mycelium-infected wood were attached separately to specially designed window traps in four old-growth spruce forests in northern Sweden. Empty traps and traps with sterilized wood were used as controls[191]. This demonstrates that both sporocarps and mycelium of wood-decaying fungi emit volatiles that attract some specific beetle species. The sterilized wood and the empty trap did not attract any beetles. Most recently study has carried out to evaluate the possibility of coleopteran species being vectors of spore dispersal of *Cryptoporus volvatus*, a wood decay fungus widely distributed in North America and East Asia by quantifying the number of spores attached to their bodies[192]. All species had spores attached to their bodies, with *Mycetophagus attennatus* having the lowest number (1.0×10^4), and *Trogossita japonica* having the highest number (5.2×10^5). In general, insects with a larger surface area had higher spore counts.

Forest Type of Polypore

Forest vegetation type is one of the factors that are related with

the occurrence of macrofungal communities in the forests[193-194]. Distribution patterns of polypores are the reflection of distributions of forest vegetation types[195-196]. The experiment examined that species composition and diversity of wood-inhabiting polypores in beech, Castanopsis, secondary oak, secondary pine, Japanese cedar, and Hinoki cypress forests situated in a temperate area of Japan[197]. Cluster analysis of the polypore communities revealed a correlation between forest vegetation types and the species composition of polypores occurring in the forests. He divided the polypores as vegetation type specific species, hardwood specific species and conifer specific species. Vegetation type specific species are defined as those recorded only in one forest vegetation type, which will include real specialists restricted to the forest type and infrequent species possibly occurring in other forest types. *Cystidiophorus castaneus*, *Cryptoporus volvatus*, *Diplomitoporus lenis* and *Trichaptum abietinum* were vegetation type specific species in pine forest. *Phellinus sanfordii*, *Antrodiella gypsea* and *Oxyporus cuneatus* were vegetation type specific in Japanese cedar plantations.
In mangrove forests the abundant polypores were distinct from those in freshwater swamp forests suggesting that a unique mycobiota exists in mangrove forests[198]. Hymenochaetaceae species, especially *Phellinus rimosus* and its allies, are important mangrove-inhabiting fungi in Central and South America and in Micronesia[199-201]. In freshwater swamp forest in lowland Malaysia, *Earliella scabrosa*, *Microporus affinis* and *Rigidoprus microporus* showed preferences for freshwater swamps[198]. Similarly, out of 100 species of polypores were recorded from montane forests of Malaysia, 26 species were montane species known only from the montane forest of Malaysia and 57 species were classified as lowland rainforest species that are more frequently collected in lowland areas of Malaysia. Most of the others are temperate species distributed mainly in temperate areas in East Asia[197].

The investigated was carryout of diversity and preferences for hosts and substrates for polypores from a boreal forest, a temperate and warm temperate forest zone, and a tropical and subtropical forest zone in China and found that the their ecological patterns are generally related to the type of forest ecosystem[202]. The tropical and subtropical forest zone harbored the highest polypore diversity. The temperate and warm temperate forest zone showed a greater similarity of polypore diversity to the boreal forest zone than to the tropical or subtropical forest zone, although the representative areas of temperate and warm temperate forest and tropical and subtropical forest zones are geographically closer. The species number and proportion of brown rot polypores decreased from the boreal forest to tropical and subtropical forest zone by 22 per cent and 21.8 per cent respectively. Fallen trunks were the most attractive substrate for polypores in all three zones, but the proportion of polypores on fallen trunks decreased from the boreal forest to tropical and subtropical forest zone by 20%. They have been explained that the distinctions could be due to the varied proportion of gymnosperm and angiosperm trees, as well as different substrate diversity in the three forest zones with different climatic conditions.

Host Preference and Specificity of polypores

A combination of the distributions of suitable hosts and environmental conditions determine the natural distribution of plant-associated fungi across broad geographic ranges[203-205]. Many fungi that depend on plants for nutrition are associated with a broad diversity of plant hosts and habitats[198]. Determination of selectivity is usually based on the presence of fruit bodies, but absence of fruit bodies does not necessarily indicate absence of mycelia. The causes of host selectivity of wood-decay species are complex and include wood chemistry, wood microclimate, gaseous regime and the way of fungal establishment[206]. The study on decay of standing trees in the semi evergreen, evergreen and wet evergreen forests of Kerala showed a wide host range of polypores. While a few species like *Fomitopsis palustris*, *Hexagonia sulcata*, *Rigidoporus lineatus*, etc. exhibited restricted distribution and very narrow host range. Among the *Fomitopsis dochmius* and *F. rhodophaeus* were the most widespread in occurrence as well as they exhibited a wide host range[207]. The study of the decay characteristics of polypores on some selected tree species of local significance in Kerala showed signs of host preference[208]. *Hexagonia tenuis* was found infecting the wood of all the five selected tree species. The *Phellinus gilvus* was found attacking only *Peltophorum ferrugineum* timber. The studies on the macrofungal flora of Peechi-Vazhani wildlife sanctuary have shown that most of the polypore has a wide host range and *Terminalia paniculata*, *Tectona grandis*, *Xylia xylocarpa* were the most infected host trees[209].

Studies on the community structure of wood-decaying Basidiomycetes in Pasoh Forest Reserve, a lowland rainforest of Malaysia recorded that saprobic species of polypores and other *aphyllophoraceous* fungi on fallen logs of 33 tree families[210]. Many of the frequently occurring polypores did not show a preference for any particular tree family: *Ganoderma australe*, one of the most common species in Pasoh, was recorded on 15 tree families, Nigroporus vinosus on 13 families and *Rigidoporus microporus* on 10 families. However, in Pasoh the some common polypores and *aphyllophoraceous* wood-inhabiting fungi occurred exclusively on Dipterocarpaceae.

The host specificity of polypores and other wood-inhabiting basidiomycetes is widely considered to be low in tropical areas because the probability of successful colonization decreases, as host trees become rarer in these areas with high species richness[211]. Nevertheless, the study conducted in low diversity neotropical Caribbean mangrove forest revealed that just three polypore species comprised 88 per cent of all collections, and each of the five species encountered multiple times showed very strong host preferences[222]. In Micronesian tropical flooded forests also polypores shows strong host preferences[212]. Globally generalist wood inhabiting polypores may be host specialists within given ecological contexts[198,213]. More than half of the polypore fungi described as pine or spruce specialists in Scandinavia show broad host ranges in China[214]. Understanding local host selectivity is important since it affects patterns of spread, density-dependent population dynamics, and in turn the maintenance of biological diversity and aspects of ecosystem function[198].

Studies on the *aphyllophoraceous* fungi in a tropical rainforest on Borneo Island, Malaysia have shown that some fungal species are generalists that can survive on a range of plant species. For example, *Ganoderma australe* has been collected from species in the Leguminosae, Dipterocarpaceae, and Euphorbiaceae, and *Phellinus lamaensis* has been collected from species in the Dipterocarpaceae and Meliaceae in this study site[215]. However, the study conducted in broadleaf forest in cool temperate area of Japan detected host specificity of fungal species at species and population level[216]. The five of the dominant wood-inhabiting fungal species were recorded only on oak and chest nut trees. Among them *Hymenochaete rubiginosa*, *Piploporous soloniensis*, *Xylobolus frustulatus* has completely restricted to Quercus and Castanea. In Europe, nearly one-third of the polypores have preferences for certain tree genera and only a limited number of species occur on both coniferous and hardwood trees[217-218]. A study based on thorough world literature survey for the host range of Phellinus species has shown its infection on about 91 plant families. Amongst all the families, genera of Fabaceae are found to be most susceptible, followed by Rosaceae, Myrtaceae, Cupressaceae, Caesalpiniaceae, Ericaceae, Euphorbiaceae and Lauraceae. The families like Meliaceae, Pinaceae, Rubiaceae Arecaceae, Fagaceae and Olecaceae were also reported as the most frequently infected families. Quercus was the most frequent host of Phellinus species[229].

The studied of the diversity and host specificity of wood rotting fungi in Western Ghats region of Maharashtra. Out of total rotting specimens collected, 94.45 per cent (102 specimens) were grown exclusively on dicotyledonous host whereas; only 5.55 per cent (6 specimens) were grown on monocotyledon family. They have been reported severe infection of *Polyporus xanthopus* on live trunk of *Terminalia bellerica*; *Fomes albomarginatus* and *F. Fomentarius* with extensive colonization on *Terminalia arjuna* and *Delonix regia* respectively. The most frequently seen species of wood rotting fungi infecting to different host found in Western Ghats of Maharashtra were Daedalia (12 hosts), Hexgonia (14 hosts), Lenzites (7 hosts), Polyporus (19 hosts), Schizophyllum (7 hosts), Trametes (16 Hosts) and Sparassis (1 host) [220].

Reviewing the literature, it was noted that studies regarding the polypore phenology, host specificity, role of substrate features and decay class and forest type on the diversity of polypores in tropical forests was negligible compare to the temperate forests. The literature cites only few studies with respect to the polypore phenology, seasonal variation and diameter class preference of polypores in tropical forests. Under all these background the present study is aimed to explore the above mentioned aspects and thus would be helpful in determining the ecological and functional role of polypores in tropical ecosystems.

Substrate Characteristics of Polypore

Different polypore species have distinct functional characteristics defined by their differential decay capacity in different wood substrate conditions (e.g. living stem, standing or fallen dead stem, dead log, and branches of different diameters) with different physical and chemical properties[221]. The substrate type, size of the substrate and decay stage of substrate will influence the polypore diversity[222].

Substrate habitat of polypore: Studies on the community structure of polypores in Andean alder wood in Argentina have shown a preferential occurrence of polypores on different wood conditions[223]. Species richness was lowest on living trunks and highest on dead branches. Out of 16 species of polypores were encountered, 14 were found on dead branches followed by dead trunk (8), cut stump (6) and living trunk (4). They have observed that the *Trametes cubensis*, *Ganoderma aff. adspersum* and *Phellinus gilvus* were characterized by the capability to decay standing living trunks. *Bjerkandera adusta* and *Lenzites betulina* showed the highest frequency on dead logs mainly on cut stumps and dead branches.

Substrate specificity of macrofungi community at the University of Dar es Salaam main campus, Tanzania has shown that the distribution of macrofungi differed markedly based on substrate[224]. The tree log substrate supported more macrofungi (28%) followed by soil (26%), wood substrate (22%) and decaying leaf litter (22%). The live tree substrate supported the least macrofungi (6%) followed by 7 per cent on wood debris. The reason for the higher number of macrofungi utilizing the tree log substrate was explained that this is due to the ready availability of the type of vegetation of the studied site having many host trees both natural and artificial.

In Finland only 36 polypore species (16%) are known to utilize living trees, whereas 207 species (93%) grow on dead wood and 20 species can live on both living and dead trees[225]. The 32 species has documented from logged areas and old-growth boreal forests in Northern Finland, among them 84 per cent occurred on logs followed by 25 per cent on snags, 9 per cent on both cut and natural stumps and 41 per cent on logging waste[236]. In general, on downed trees (logs), the total number of species and occurrences and the number of red-listed species were reported to be high than on standing dead trees[226-231]. Moreover, the number of unique species is higher on logs than on standing dead trees, i.e. most of those species that can grow on standing trees can also live on logs but not the other way around[226,222-233].

The studies on the wood-rotting fungi in East Khasi Hills of Meghalaya, northeast India have shown that the logs harboured the maximum number of wood-rotting fungi (59.7 %) followed by tree stumps and twigs (32.5 %). The living trees harboured the least with 7.8 per cent of macrofungi[234]. This substrate preference is due to the different species adaptations to the defence mechanisms present in the living trees, and not in logs, tree stumps and twigs, as well as differences in the microclimate within each substrate[206]. Further the larger logs contain more core-wood which supports a specialized flora of polypores with conk-shaped fruit-bodies[231].

Substrate diameter class effected of polypore: Studies on the community structure of polypores in Andean alder wood in Argentina have shown a preference of large diameter logs (25-50 cm) by *Trametes cubensis*, Ganoderma aff. adspersum and *Phellinus gilvus*. While *Bjerkandera adusta* and *Lenzites betulina* were characterized by having the highest frequency on dead logs of intermediate diameter (10-15 cm). Finally, *Schizopora radula*, *Datronia mollis*, *Hexagonia papyracea*, *Junghuhnia carneola*, *Polyporus tricholoma*, *Perenniporia* species formed a group that was always found on decayed wood, mainly on dead branches with small diameter (less than 10 cm)[223]. The threshold diameter critical for polypores species richness appears to be at 20-30 cm, at least on spruce logs[161,236-237]. At this diameter, species demanding large-diameter dead wood starts to appear, while species that are able to utilize small-diameter debris can usually grow on large logs as well.

Furthermore, many common polypore species are more frequent on large logs than on small ones, which increase the average species number per log[249]. The importance of log diameter in promoting fungal species richness, however, is not straight forward. It has been shown that if equal volumes are compared, small-diameter dead wood can host more species than large-diameter wood[250-251]. This has been explained by a larger surface area per volume of small-diameter dead wood, and a larger number of wood pieces per volume which, in turn, results in a larger variation in micro-environmental conditions[250].

Among the common species in Pasoh Forest Reserve, Malaysia, *Coriolopsis retropicta*, *Microporus xanthopus* were restricted to small substrata such as fallen branches and twigs while *Erythromyces crocicreas*, *Ganoderma australe* were found mostly on large substrata. *Earliella scabrosa*, *Stereum ostrea* occurred on both large and small substrata[197]. Spatial distribution of the basidiocarps of aphyllophoraceous fungi in a tropical rainforest on Borneo Island, Malaysia has shown that the *Phellinus lamaensis* and *Ganodema australe* appeared to colonize woody debris across the full diameter range. While *Coriolopsis retropicta*, *Microporus xanthopus*, *M. affinis* and *Trametes cf. mimetes* appeared primarily from woody debris smaller than 20.0 cm in diameter[215].

Substrate diameter is an important factor that determines the occurrences of wood-inhabiting polypores. Studies have shown that these fungi have different preferences for substrate diameter. Generally the number of species per dead wood item increases with increasing diameter of the substrate[233]. The study on diversity of polyporous fungi in northern boreal forest has shown that the number of polypore species more than doubled from the diameter classes less than 20 cm to the diameter classes >20 cm (all tree species included)[236]. The studies on the community structure and dynamics of wood-rotting fungi on decomposing conifer trunks in northern Finland have also shown the similar trend[161]. However it found that the number of occurrences of polypores on logs less than or equal to 30 cm in diameter was 2–48 times the number of occurrences on logs 10–19 cm in diameter, depending on the species[235]. The studied on effect of tree diameter on establishment, diversity and richness of Bracket fungi in Golestan province forest, North of Iran. They have found that the fungi establishment increased by increasing the trees diameters, and the stand trees with more than 80 cm diameter and fallen trees with more than 40 cm diameter has more bracket fungi than other trees[240].

Substrate decay class effected of polypore: During wood decay, moisture, temperature and gaseous conditions vary, and thereby also the prerequisites for fungal growth[150]. These changes are to a major extent an effect of fungal decomposition itself and thus the activity of early species may facilitate the establishment of others[150]. Among the variables related to the quality of dead wood, decay gradient has been identified as the strongest factor[247,254-255]. Compared to the diameter of trees, the decay stage is a more subjective measure and decay stages measured in different studies are more difficult to compare. Nevertheless, the general hump-shaped trend is clear: more species at the mid-decay stages than at the early or late stages[246,254-260].

Studies on the polypores on fallen logs of Norway spruce have shown that newly fallen and weakly decayed logs in a natural forest had higher species richness, more red-listed species, as well as more indicator species compared to similar logs in a managed forest[241]. Presence of logs in later stages of decomposition increased the total species number in a natural forest stand with 42 (63 %), compared to a survey of only newly fallen and weakly decayed logs. Presence of logs in later stages of decomposition also increased the diversity of the species pool colonizing newly fallen and weakly decayed logs. The highest number of fruiting species was found on intermediately decayed logs and on logs lying in contact with the ground[241].

Studies on the polypores of the Norway spruce (*Picea abies*) forests in the boreal zone of Sweden have shown that the greatest numbers of species are found at intermediate stages of decay, i.e. decorticated logs where the wood has started to soften. During these stages logs may contain a mixture of early, intermediate and late successional species. In addition, if spore dispersal is limited, establishment poor, or the growth of mycelia slow, a highly decayed log may support a higher number of species, simply because of its age[246]. Intermediate to late decay classes were preferred by red-listed and frequent species in managed Swedish boreal forests in northern Sweden[238].

Studies on the polypores of tropical rainforest on Borneo Island, Malaysia have shown that the dominant fungal species differed among the woody debris decay classes. More than 50 per cent of the basidiocarps of *Microporus affinis* and *Trametes mimetes* were collected from fresh woody debris, whereas more than 50 per cent of *Phellinus lamaensis* was collected from old woody debris; *Amauroderma subrugosum*, *Ganoderma australe*, *Rigidoporus* sp., *Coriolopsis retropicta*, *Microporus xanthopus* species were predominantly collected from both fresh and medium debris[215].

The effects on decomposition stage of substrata on species of wood-decaying basidiomycetes in Pasoh Forest Reserve, Malaysia. Some species such as *Cyclomyces tabacinus*, *Earliella scabrosa*, *Ganoderma australe*, *Microporus affinis*, and *Rigidoporus microporus* were found mainly found on newly fallen trees while other species such as *Antrodiella* spp., *Nigroporus vinosus*, *Postia* spp., and *Tyromyces* spp. were found on well-decomposed trees. Species richness of wood-decaying *basidiomycetes* was higher in a primary forest plot than in a regenerating forest plot and suggested that a low frequency of tree fall in the regenerating forest reduced the species richness of wood-decaying *basidiomycetes*[210]. In Norway spruce forests, Sweden the early colonizers were primarily affected by the stage of decomposition; secondary colonizers were affected by a variety of within patch and/or between patch variables, maintaining high species coexistence within intermediate stages of decay[244]. Recently, the studies on variety of woody debris as the factor influencing wood-inhabiting fungal richness and assemblages in northern Navarre, in the northern part of the Iberian Peninsula have shown that the Polyporaceae were adapted to coarse wood debris and they appeared mostly on recently fallen or first stage decaying logs[247].

Ecological Characters of Polypores

Beyond the ecological roles, polypores may have diverse industrial applications due to the capability of selective delignification[248]. Polypores possess varying degrees of edibility and many of them are incorporated into the pharmacopeia and medicine of indigenous people worldwide. Many bioactive compounds which impart the medicinal polypore properties are still being isolated[249]. Despite being an extremely diverse, relatively understudied, and ecologically and economically important group, polypore conservation lags behind protection of other taxa such as mammals, birds and plants, due to a combination of lack of knowledge of many species, their often relatively uncharismatic appearance, and the difficulties of assessing polypores using established criteria. An account of frequency, diversity and dominance of polypores in the forest both in disturbed and undisturbed can be used as an indicator of forest quality.

Vegetation type and elevation gradient are also important factors that are related with the occurrence of polypore communities with characteristic distribution pattern in the forests. The tree composition of a forest type has great influence on polypore communities. The host range and preference for certain polypores can be strict to either angiosperm or gymnosperm trees, or even to a single tree species. Most polypores have a broad host range and due to high tree species diversity in the tropical forests and strong host specificity of polypores and other wood-inhabiting basidiomycetes is generally considered to be low. The field studies shown that the polypore fruit body productivity has mostly depended on rainfall and temperature[251]. Familiarizing these responses of the polypores will provide better strategies to adapt and mitigate the environmental consequences of climate change.

Fungal phenology of Polypores

Fungal fruiting phenology is a new field of mycology which requires far more comprehensive studies covering various aspects of fruiting. Knowledge of fungal fruiting phenology covers numerous opportunities to improve the understanding of their community structure but the literature is still lacking. The presence of fruit bodies is direct indication of the presence of the species in the substrate, but absence of fruit bodies does not necessarily indicate absence of mycelia[252]. Also, knowledge of fungal fruiting phenology is important to guide the design of fruit body surveys and a way to explain the findings. If the nature of fungal fruiting is known, the timing and intensity of surveys can be planned[253]. Fruit body surveys are a basis for documenting fungal diversity, as sporocarps can be identified to the species level and recorded in a good systematic system. It can provide an insight into the characteristics of fungi and may explain their associations with their non-living environment. Apart from that, fungal-environmental associations and the effects of any changing environmental factors on fungal fruiting patterns can be predicted. Polypores play an important role in ecosystem functioning especially in the decomposition of organic matter and nutrient cycling in the soil. Therefore, any changes in polypore fruiting could reflect changes in mycelial growth and potentially affect the ecosystem services of the soil biota. Fungal phenology has started to raise attention of several mycologists all over the world. The reported on advanced fruiting for autumnal species in England[254], while studied on delayed fruiting of autumnal species in Norway[255-258]. The surmise reported on advanced fruiting of spring-fruiting fungi in a 47-year survey[257]. The studied of the differences in the fruiting phenology among three common fungal functional groups namely ectomycorrhizal (ECM) fungi, litter decomposers and wood decay fungi[259].

Environmental factors of polypores for production of fruit bodies

A wide range of environmental factors influence the timing and development of fruit bodies, including nutritional factors, gaseous regime, pH, light, microclimate, disturbance and inter and intra-specific mycelial interaction[250]. Understanding the responses of the lowest trophic level is critical if we are to adapt to and mitigate the ecological consequences of climate change[260-261]. The plant host has been identified as an influential factor in the production of fruit bodies, because of the need for some nutritional elements to build *sporophores* in the forest[262]. Influences of climatic variables on fungal physiology in vitro are well-documented[263]. Many field studies have shown that the productivity fruit bodies are mostly related to average monthly rainfall and average monthly temperature[265,265]. Regarding rainfall and temperature, a few attempts to explain the duration of fungal fruiting in relation to climate change have recently been discussed[268-269,254,256]. Furthermore, the productivity of fungi is also determined by habitat characteristics. Generally, forest stands display greater epigeous mushroom productivity than mature stands[267].

Seasonal variation effect of polypore

Effects of climate change on fungal distribution and activity are hard to predict because they are mediated in many different ways, including: fungal physiology, reproduction and survival, host physiology, spatial and temporal distribution of hosts and resource availability, and outcome of competitive interspecific interactions[270]. Mushrooms appear to be collected and consumed during almost the entire year, but most fungi are collected during the rainy seasons, suggesting the importance of rainfall patterns in fungal phenology[271-273]. Such is the case in tropical Africa, where many species are found in the rainy seasons, but there are a few species that are present throughout the year[274-275]. The peak of mushroom fruiting was around late summer to autumn based on their long term survey in the fungal reserve La Chaneaz in western Switzerland and suggested temperature to be the potential triggering factor[268].

The phenology of macrofungi community at the University of Dar es Salaam main campus, Tanzania and observed that the long rains of March- May in the year had the largest number of macrofungi species recorded[224]. He found out a strong correlation between the numbers of fruit body and the amount of rainfall received prior to fructification. He proposed the March-May rains to be the best season for macrofungi surveys and harvesting in the study area and probably in other parts in the region with similar rainfall pattern[224]. Polyporacea and Ganodermatacea were found capable to survive and overcome environmental changes including desiccation unlike other forms which produce simple short lived fruit bodies[291]. Traditionally, surveys of wood-inhabiting fungi in Northern Europe have been conducted between August and October[276,244] which is regarded 'as the peak fruiting season' even though empirical data about the fruiting times of wood-inhabiting fungi does not exist.

The seasonal effect was strongest in agarics and to some extent the polypores. Annual polypores and corticioids seemed to be varying less and perennial polypores showed no seasonality at all. For annual polypores, the relatively low seasonality is partly evident based on the fact that there are many species with relatively tough, sturdy fruit bodies or semi perennial species that have an annual fruit body which hibernates for one winter and is still visible and sporulating in next spring[277]. So it is reasonable and expected that annual polypores are a species group with low variation in their occurrences. The perennial polypores could really be a useful indicator species group, even though there is no knowledge yet about how well their occurrences predict the occurrences of other species groups than annual polypores[276].

Medicinal uses of polypores

Polypores have a long history in disease treatment in various folk medicines such as in Asia, Russia, the USA, Canada, Mexico, Venezuela and are extensively applied in Traditional Chinese Medicine (TCM) up to the present day[278]. Moreover, polypores have been used in various ways as food, tinder, and commodities[279]. In particular, *Ganoderma lucidum* has been extensively used in TCM as a tonic for promoting health, perpetual youth, vitality, and longevity[280]. Many studies on *Ganoderma* lucidum extracts or isolates underline its anti-cancer, anti-androgen, immune-stimulating, anti-diabetic, lipid-lowering and anti-inflammatory activities[281], *Inonotus obliques* remedy to treat cancer, diseases of the digestive system, and tuberculosis[282], anti-AIDS, anti-aging, blood lipid decreasing, blood pressure lowering, and immune-stimulating effects[283] and *Fomes fomentarius* and two objects derived from the birch polypore, i.e. *Piptoporus betulinus*, which he probably used for medicinal and spiritual purposes[284]. The properties of the following spcies have used in ethnomedicinal value.

Ganodrma species: *Ganoderma lucidum* (Leyss; Fr) Karst. (Ganodermataceae) has been reported to produce many biologically active compounds such as sterol, polysaccharide, and triterpenoids. More than 100 triterpenoids have been isolated from *G. lucidum* and the genus Ganoderma[285].

Phellinus species: Phanasomba is a folk medicine used in the Western Ghats of Maharashtra (*i.e.* Konkan region). It is common bracket mushroom causing heart rot disease of *Artocarpus heterophyllus* Lam. (vernacular name: Phanas). Phansomba is also known as Phanas-alambi, Phanas banda. The whole basidiocarp of *Phellinus* is ground in water to make paste and then applied to affected area, like gums in case of excessive salivation in kids, for wound healing, throat problems (antitumor), antimicrobial and anti-inflamatroy agents in rheumatoid arthritis etc[286].

Laetiporus sulphureus: It is also known as 'chicken of the woods' or 'chicken polypore'. However, gastrointestinal problems have been reported after eating this fungus as well as the occurrence of severe adverse effects including allergic reactions, vomiting, and fever[287]. This species of fruit bodies are thought to be capable of regulating the human body, improving health and defending the body against illnesses[288-289]. Moreover, in Europe, the fruit bodies have been used for the treatment of pyretic diseases, coughs, gastric cancer, and rheumatism[290].

Fomes fomentarius (Tinder fungus): *Fomes fomentarius* was widely used as a styptic by surgeons, barbers and dentists, and therefore called "agaric of the surgeons"[291-292]. Furthermore, in European, West Siberian, and Indian folk medicine, a kind of absorbing dressing made of tinder and some iodine is externally applied to wounds and burns[293]. The Khanty people in West Siberia who used to burn the fruit bodies to obtain smoke when a person died to avoid any influence of the deceased on the living[294]. It used as a remedy against dysmenorrhoea, haemorrhoids and bladder disorders, the active substance being "fomitin", and also used for pain relief and for the treatment of oesophagus, gastric and uterine carcinoma[289]. In Germany, Hungary, and in some parts of former Yugoslavia, *Fomes fomentarius* was used for making caps, chest protectors, and other clothing articles[249].

Fomitopsis pinicola (Red banded polypore): It used for the treatment of headache, nausea, and liver problems. Moreover, due to their astringent effects the fruit bodies have been used as haemostatics and anti-inflammatory agents[295].

Piptoporus betulinus (Birch polypore): *Piptoporus betulinus* is one of the few edible polypores. It has strong, pleasant odour and an astringent, bitter taste and also used for various medicinal purposes before modern medicine superseded many natural healing methods. In Siberia, the Baltic area, and Finland, birch polypore tea was also used for the treatment of various types of cancer. Only young, sterile fruit bodies (without developed hymenial layers) were thought to be effective and it was claimed that these develop on birch trees only under certain environmental conditions, particularly when the trees grow on low ground[296]. The velvety surface of the fruit body was traditionally taken as a strop for finishing razor edges[297,298].

Laricifomes officinalis (Conks of larch): *Laricifomes officinalis* fruit bodies have been extensively collected for medicinal purposes (treatment of tuberculosis, pneumonia, cough, and asthma) throughout the whole Alpine area, nearly leading to the extinction of this rare polypore. People collected it to be sold to pharmacies. Therefore, this fungus was called Agaric of Pharmacy or "Apothekerschwamm" in German speaking regions. However, applied in the form of bitter liquor the intake of *Laricifomes officinalis* was frequently accompanied by diarrhoea, colic and other side effects. In folk medicine, the bitter fruit bodies were traditionally used to treat coughs, gastric cancer, and rheumatism[299]. To indigenous people of the northwestern coast region of North America and Canada, this fungus is known as "Bread of Ghosts". It had an important spiritual as well as a medicinal role in their society[300].

Conclusion

This work suggests that polypore flora reflects forest vegetation type as well as the diversity of polypores is reduced in simplified landscape and maintained in various forest types at a regional level. The species richness of wood-decaying basidiomycetes was higher in primary forest plot followed by regeneration plot. Among the common species in tropics, like, *Coriolopsis retropicta, Microporus xanthopus, Fomitopsis palustris, Hexagonia sulcata, Rigidoporus lineatus, etc*. exhibited restricted distribution and very narrow host range. Among the *Fomitopsis dochmius* and *F. rhodophaeus* were the most widespread in occurrence as well as they exhibited a wide host range. Some species such as *Cyclomyces tabacinus, Earliella scabrosa, Ganoderma australe, Microporus affinis,* and *Rigidoporus microporus* were found mainly found on newly fallen trees while other species such as *Antrodiella species, Nigroporus vinosus, Postia species,* and Tyromyces species were found on well-decomposed trees. In Forest ecology the role of polypores is irreplaceable since it helps in decomposition and nutrient cycling. Because of the presence of biologically active metabolites polypores have many medicinal uses and fifty percent posses varying degree of edibility.

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