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DIVERSITY, ECOLOGY AND BIOGEOGRAPHY OF THE FAMILY POLYPORACEAE ALONG AN ALTITUDINAL GRADIENT IN FORESTS OF NAGALAND

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ABSTRACT

Studies on diversity, ecology and geographical distribution of the family Polyporaceaewere carried out in 8 forest stands of Nagaland along an altitudinal gradient for two successive years (January 2015 to December 2016). Both quadrate and transect methods were followed for sampling Polyporaceae members. A total of 37 Polyporaceaespecies were identified. The results showed that the distribution of wood-rotting Polyporaceaespecies depend on different altitudinal zones, decay stages and availability of substrata. The occurrence of Polyporaceaespecies showed an increasing trend from an altitude of 221meters above sea level (msl) to 890msl, thereafter decreased with increase in altitude. The resultant correlation is of negative type. Ordination of species and environmental variables with canonical correspondence analysis (CCA) indicate that at lower altitudes, temperature was the major factor whereas, at higher altitudes, light intensity and relative humidity were the major factors for determining the occurrence of Polyporaceae members. Logs, twigs and wood decay stage III provided essential habitat for the formation of sporocarps of majority of the species. Shannon's diversity index (H') was highest in site 3 (Alt. 890msl). Species diversity was higher in the tropical zone as compared to that of sub-tropical and lower temperate zones. Among the different seasons, species diversity was found to be highest during autumn.

Key words: Altitudinal gradient, Biogeography, Diversity, Ecology, Polyporaceae, Nagaland.

INTRODUCTION

Wood-rotting fungi are the main agent responsible for decomposition of dead wood and play a pivotal functional role in nutrient cycling in forests. They are mainly saprophytic in nature growing on dead, fallen woods and few are parasitic of living trees (Tapwal *et al*., 2013). They have the capacity to degrade major components of plant cell wall such as lignin, cellulose and hemicellulose. Majority of wood-rotting fungi produce poroidbasidiocarpsmainly belonging to the families Polyporaceae, Ganodermataceae and Hymenochaetaceae. Polyporaceae members occur under different environmental regimes at various altitudes and are the most widely distributed in nature. Some species are host specific while some are adapted to a number of host species (Hattori, 2005 and Yamashita *et al*., 2010).Studies on diversity and ecology of polypores in relation to various host trees, vegetation types and biogeographical zones have been carried out worldwide (Hattori, 2005;Pouska*et al*., 2010; Yamashita *et al*., 2010; Dogan *et al*., 2011 and Zhou *et al*., 2011) however, study onthe relationship between diversity, ecology and biogeography of the family Polyporaceae with altitudinal changes is not known or scarce, if any. Several studies on wood-rotting fungi of Arunachal Pradesh, Assam and Meghalaya of north-east India have been carried out in the past and polypore species with important medicinal values such as *Lenzitesbetulina* and *Trametes versicolor* (Hussin*et al*., 2016 and Matijasevic *et al*., 2016) were reported from north-east India (Den and Singh, 2008;Sailo, 2010;Tapwal*et al*., 2010 and Lyngdoh and Dkhar 2014, 2014a). However, not much work has so far been done in the forests of Nagaland. The state Nagaland is located in the north-eastern part of India and is rich in evergreen and deciduous forest vegetation cover at different altitudes ranging from a few hundred to more than 3,000msl. The present study on diversity, ecology and biogeography of the family Polyporaceae was carried out to understand its macro and micro environmental requirements and their distribution in nature and to provide base-line information on the Polyporaceae members which will be useful for further studies.

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MATERIALS AND METHODS

Survey and collection was done from January 2015 to December 2016 on seasonal basis. Eight forest stands with altitudes ranging from 221 to 2316mslwere selected for the study (Table 1). For sampling of fruiting bodies, the recommended protocol of Meuller *et al*. (2004) was followed. Both line transect (100x5m²) and quadrat (100x100m²) methods were used. The number of logs, stumps and twigs present within the sampling plots were also recorded. Identification was done according to standard macroscopic and microscopic characters through consultations with appropriate literatures (Bakshi, 1966; Ryvarden and Johansen, 1980 and Nunez and Ryvarden, 2001). Microscopic characters were studied using Digital Labovision AXL. Reagents used were lactophenol cotton blue, 4% KOH and Melzer's reagent. The current scientific name and taxonomic status of all the species were confirmed from www.mycobank.org (accessed 22ndJuly, 2017).

IV (knife penetrates 6-10cm into the wood) and decay stage V (wood very old, easily disintegrates when lifting).One way ANOVA was done to determine whether there was a significant variation between the occurrence of species and altitude. Hierarchical cluster analysis with Ward's method and squared euclidean distance measurement was performed for grouping the species based on different altitude (sites). CCA was performed to study the relationship between the distribution of Polyporaceae members and environmental variables at different altitudes. The species occurring during late summer to mid-autumn were taken for the analysis. The mean of each variable was tested with Monte Carlo permutation test (permutation at 500) and the statistical significance was set at α = 0.05.Shannon's diversity index (H'), Simpson's Dominance index (D) and species evenness (e^H/S) were used for calculating the diversity of Polyporaceae members in different forest stands and seasons. All the statistical analyses were performed using SPSS 16 and PAST software.

Table 1. Selected forest stands with their altitudes, geographical zones and common tree species

Sl. no.	Study site	Altitude (in msl)	Geogra-phical zone	Common tree species
1	Rangapahar reserve forest (Site 1)	221		*Ailanthus* sp., *Cassia fistula*, *Delonixrigia*, *Tectonagrandis*
2	Ngwalwa community forest (Site 2)	463	Tropical	*Ailanthus* sp., *Terminalia* sp., *Sterculiavillosa*
3	Rusoma community forest (Site 3)	890		*Castanopsisindica*, *Docyniaindica*, *Ficus* sp., *Micheliachampaca*
4	Tuophema reserve forest (Site 4)	1469		*Ficus* sp., Lauraceae members, *Schimawallichi*
5	Kikruma community forest (Site 5)	1515	Sub-tropical	*Prunuscerasoides*, *Pinuswallichiana, Quercussemiserrata*
6	Phuschodu community forest (Site 6)	1819		*Alnusnepalensis*, *Betula* sp., *Pinuswallichiana*
7	Puliebadze reserve forest (Site 7)	2027	Lower-temperate	*Alnusnepalensis*, *Castanopsisindica*, *Prunuscerasoides, Lithocarpus*sp.
8	*Rhododendron* reserve forest (Site 8)	2315		*Rhododendron arboreum*

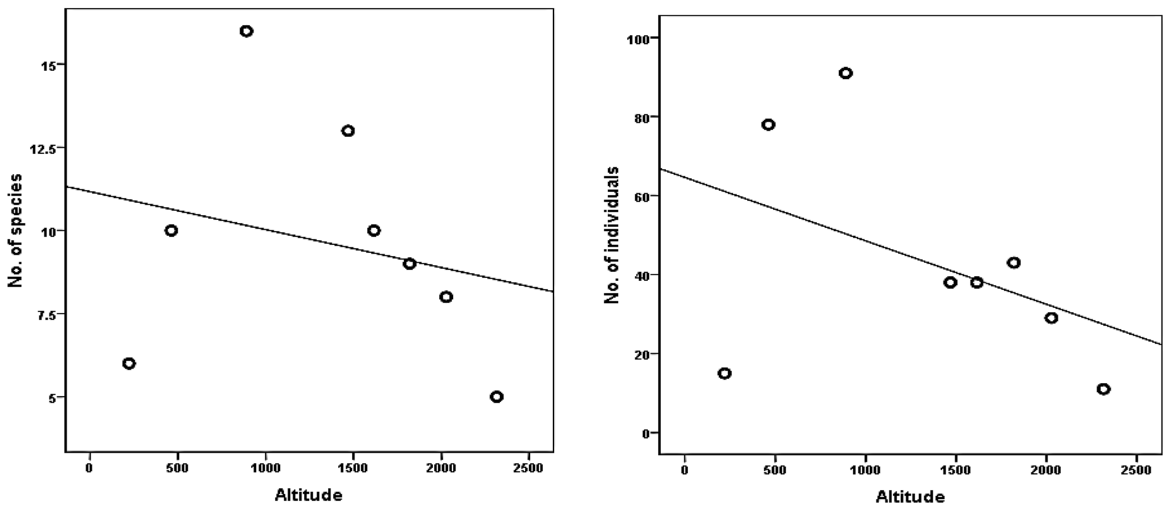

Figure 1-2. Total no. of species and individuals at different altitudes (msl)

Atmospheric temperature (°C), relative humidity (%) and Light intensity (Lux) of all the forest stands were measured using Thermometer, Hygrometer and Lutron LX-101 Lux meter respectively. For differentiating the various stages of wood decay, we followed Pouska *et al*. (2011). Five stages of wood decay were recognized: decay stage I (newly fallen woods; knife penetrates only a few millimeters into the wood), decay stage II (knife penetrates 1-2cm into the wood), decay stage III (knife penetrates 3-5cm into the wood), decay stage

RESULTS AND DISCUSSIONS

Altitudinal variations in diversity of Polyporaceae members

Total of 37 specimens, distributed under 17 genera were identified. Seven species belonged to the genus *Trametes*, 4 species each to *Coriolopsis* and *Lentinus*, 3 species each to *Microporus, Polyporus* and *Trichaptum*, 2 species each to

*Hexagonia and Lenzites*and 1 species each to the genera *Daedalea*, *Earliella*, *Favolus*, *Lopharia*, *Nigrofomes*, *Nigroporus*, *Porodisculus*, *Pseudotrametes* and *Pycnoporus*. Species such as *Earliellascabrosa*, *Lentinusciliatus*, *L. squarrosulus*, *L. velutinus* and *Polyporusarcularius* were confined to tropical zone only, *Favolustenuiculus*, *Hexagoniabadia*, *Nigrofomesmelanopus*, *Polyporusdictyopus* and *P. tuber-aster* were confined to sub-tropical zone only and *L. fasciatus*, *Microporusaffinis*, *Porodisculuspendulus*, *Trametespubescens* and *Trichaptumbyssogenum* were found in lower temperate zone only. *Hexagonia tenuis*, *Lophariacinerascens*, *T. hirsuta*and *T. versicolor* were found in all the three geographical zonesstudied (Table 2).

The number of occurrence of species showed an increasing trend with increase in altitudesfrom 221msl upto890msland thereafter decreased with increase in altitude i.e., from 1469msl to 2315msl. There was a negative correlation between the occurrences of species as well as species richness with altitudes (Figure 1-2). Site 3 harbored the highest number of species (16 species) whereas,site 8 harbored the lowest number of species (5 species). Likewise, Shannon's diversity index was highest in site 3 (2.649) and least in site 8 (1.516). This indicated that diversity of Polyporaceae members was higher in lower altitudes as compared to higher altitudes. Dominance index was highest in site 1 (0.262), where the number of individuals of *H. tenuis* and *M. xanthopus* were

Plate 1. Edible wood-rotting polypore, *Lentinussquarrosulus*(a), and medicinal wood-rotting polypores, *Lenzitesbetulina* (b) and *Trametes versicolor* (c)

Table 2. List of species with their code, altitudes of occurrence, types of substrata, decay stages ofwood

Sl. No.	Scientific name	Code	Altitude (msl)	Type of substrata	Decay stage
1	*Coriolopsisgallica*(Fr.) Ryvarden	Corga	1819	Lo	II
2	*C. polyzona*(Pers.)Ryvarden	Corpo	1515	Lo	III
3	*C. telfairii*(Klotzsch) Ryvarden	Corte	1515-1819	Lo	II
4	*C. trogii* (Berk.) Domanski	Cortr	1469-1819	Lo	II
5	*Daedaleaflavida* Lev.	Daefl	463-890	Lo, St	II, IV
6	*Earliellascabrosa* (Pers.) Gilb. &Ryvarden	Ear sc	221-890	Lo, St	III, IV
7	*Favolustenuiculus* P. Beauv.	Fav te	1469	Lo	II
8	*Hexagoniabadia* (Berk.) Imazeki	Hex ba	1469	Tw	III
9	*H. tenuis* (Hook.) Fr.	Hex te	221-1819	Lo, St, Tw	I - III
10	*Lentinusciliatus* (Fr.) Zmitr	Len ci	890	Tw	III
11	*L. fasciatus*Berk.	Len fa	2027	St	III
12	*L. squarrosulus* Mont.	Len sq	890	St	III
13	*L. velutinus* Fr.	Len ve	463-890	Lo, St, Tw	III
14	*Lenzitesbetulina* (L.) Fr.	Lnz be	463-1469	Lo, Tw	II
15	*L. elegans* (Spreng) Pat.	Lnz el	890	Lo, St	I, II
16	*Lophariacinerascens* (Schwein) G. Cunn.	Lop ci	463-1819	Lo, Tw	III
17	*Microporusaffinis* (Blume &T. Nees) Kuntze	Mic af	1469-2315	Lo, Tw	II, III
18	*M. vernicipes* (Berk.) Imazeki	Mic ve	2027	Lo	III
19	*M. xanthopus* (Fr.) Kuntze	Mic xa	221-2315	Lo, St, Tw	II - IV
20	*Nigrofomesmelanoporus*(Mont.) Murrill	Nifme	1515	St	III
21	*Nigroporusvinosus* (Berk.) Murrill	Nip vi	890-1515	Lo, St	IV, V
22	*Polyporusarcularius* (Batsch) Fr.	Pol ar	221-890	Lo, St	III, IV
23	*P. dictyopus* Mont.	Pol di	1469	Tw	IV
24	*P. tuberaster* (Jacq. ex Pers.) Fr.	Pol tu	1469	Lo	III
25	*Porodisculuspendulus* (Schwein ex Fr.) Murrill	Porpe	2027	Tw	III
26	*Pseudotrametesgibbosa* (Pers.) Fr.	Psegi	1469	Tw	II
27	*Pycnoporussanguineus* (L.) Murrill	Pycsa	221-1515	Lo, Tw	II - IV
28	*Trametesgibbosa* (Pers.) Fr.	Tragi	1819	Li, St	I, III
29	*T. hirsuta*(Wulfen) Pilat	Tra hi	221-1819	Lo, St, Tw, Cu	II - IV
30	*T. lactinea*(Berk.) Sacc.	Tra la	890-2027	Li, Lo, St	I, II
31	*T. pubescens* (Schumach) Pilat	Trapu	2315	Lo	IV
32	*T. tephroleuca*Berk.	Trate	1469	Lo, Tw	III
33	*T. versicolor* (L.) Llyod	Trave	890-2027	Lo, St, Tw	II, III
34	*T. villosa* (Sw.) Kreisel	Tra vi	1819	Lo	II
35	*Trichaptumabeitinum* (Pers. ex J.F. Gmel.) Ryvarden	Tri ab	1469-1819	Lo	III
36	*T. biforme* (Fr.) Ryvarden	Tri bi	890-1819	St, Tw	III, IV
37	*T. byssogenum* (Jungh.) Ryvarden	Tri by	2027-2315	Tw	III

*Lo – Log, St – Stump, Tw – Twig, Li – Living tree, Cu – Bamboo culm, I – Decay stage I, II –stage II, III – stage III, IV – stage IV, V –stage V.

more dominant as compared to other species. Species evenness was highest in site 8 (0.915) and lowest in site 4 (0.612) indicating that the species occurring in site 8 were most evenly distributed whereas, the species in site 4 were least evenly distributed.

Host specificity

The preference of some species to certain host trees was observed from the present study. Most of the Polyporaceae members were found growing on angiosperms as compared to gymnosperms hosts. Species like *Microporusxanthopus, Pycnoporussanguineus*, *Trameteshirsuta, T. versicolor and T. villosa*were found growing on two or more types of host tree species whereas, *T. gibbosa* was found only on *Alnusnepalensis*. *Nigroporusvinosus and Trichaptumabeitimun* were found only on *Pinuswallichiana* which indicated their preference on gymnosperm hosts.

Seasonal variations and light exposure

Species diversity as well as species dominance was highest during autumn (3.043 and 0.567 respectively) however, the species richness was found to be the highest duringsummer season (47.23%). No polypore specimen was found during early to mid-summer (June to mid-August), when persistent and heavy rainfall occur. Most of the Polyporaceae members (95.34%) were found growing exposed to sunlight whereas, only 4.66% were found growing in shaded condition or on the underside of the substrata.

Types of substrata

Among the various substrata, highest number of species occurred on logs (25) followed by twigs (17) however, species richness was highest for twigs. 44.61% of the total number of individuals occurred on twigs, 36.15% on logs, 18.08% on stumps, 0.87% on living trees and 0.29% on bamboo culms. This may be due to the high percentage of occurrence of twigs (51-93% of total available substrata) in all the stands over logs (6-35%) and stumps (up to 20%). Polypore species like *Trametesgibbosa* and *T. lactinea* were found growing on barks of living trees. *T.hirsuta* was the only species recorded from bamboo culms besides logs, stumps and twigs. Based on the wood surface, 53.94% of fruiting bodies were found growing on the sapwood whereas, 46.06% on the barks of different substrata.

Decay stage of wood

In the present study, highest number of fruiting bodies (49.85%) was found on woods with decay stage III, followed by decay stage II (31.49%), decay stage IV (16.62%), decay stage I (1.75%) and least in decay stage V (0.29%). *Coriolopsis* species, *Favolustenuiculus*, *Daedaleaflavida*, *Trametesgibbosa*, *T.lactinea* and *T. villosa* prefer early stages of wood decay whereas, *Nigroporusvinosus* and *T. pubescens* prefer later stages of wood decay. *Microporusxanthopus*, *Pycnoporussanguineus* and *T. hirsuta*were found growing in three or more stages of wood decay in different seasons

Statistical Analyses

One way ANOVA indicated that the variation between the number of individuals as well as species in relation to different altitudes is significant with a significance value of 0.00 at *p*= 0.05. There was significant variation between the species richness with different seasons, types and surface of substrata, decay stages of wood and exposure to sunlight. All the Polyporaceae species were grouped based on different altitudes (sites) using hierarchical cluster analysis technique (Figure 3). *Earliellascabrosa*, *Polyporusarcularius* and *Microporusxanthopus* were clustered together as they were either confined to or abundant in the tropical zone. *Lentinusfasciatus, Microporusaffinis*, *M. vernicipes*, *Porodisculuspendulus* and *Trichaptumbyssogenum* occurred only at lower-temperate zone and were grouped in one cluster. *Favolustenuiculus*, *Hexagoniabadia*, *Polyporusdictyopus*, *P. tuberaster*, *Pseudotrametesgibbosa* and *Trametestephroleuca*, which were found only at an altitude of 1469mslwere grouped in another separate cluster.

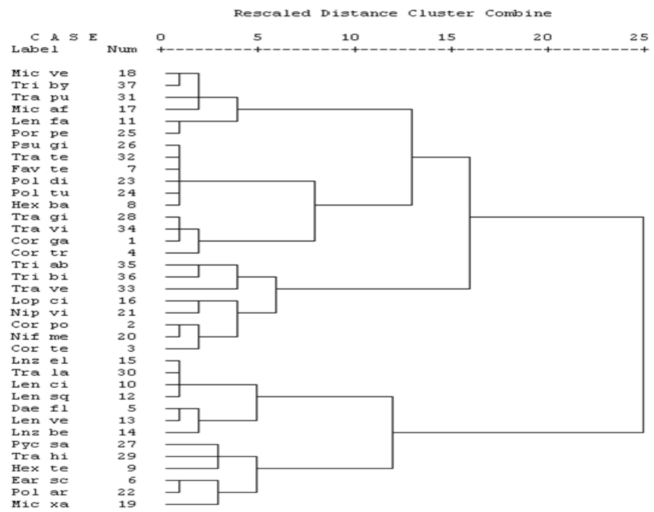

Figure 3. Hierarchical clustering of different species based on different altitudes

Ordination of species and environmental variables with CCA indicated that at lower altitudes, high temperature was the major factor whereas, at higher altitudes, high light intensity and relative humidity were the major factors for determining the occurrence of Polyporaceae members (Figure 4). Consequently, the species in tropical zone and site 4 of sub-tropical zone were highly influenced by temperature (28-40°C) and those at lower temperate zone except for site 6, were highly influenced by high light intensity (110-1837 Lux) and relative humidity (52-71%). Species in site 6 from lower temperate zone and site 5 from sub-tropical zone were influenced by altitudes (1469-1819msl).From the CCA triplot (Figure5), it could be explained that high temperature with low altitude, light intensity and relative humidity favored the growth of species such as *Earliellascabrosa*, *Daedaleaflavida, Polyporusarcularius*, *Lentinusvelutinus* and *Lenzitesbetulina*. *Hexagonia tenuis*, *Pycnoporussanguinus* and *Trameteshirsuta* were found in in all the tree zones studied but weremore abundant in the tropical zone which indicates that they are more favored by higher temperature. High light intensity and relative humidity with low temperature favored the growth of *Microporusaffinis*, *M. xanthopus* and *Trichaptumbyssogenum*. *Coriolopsis* species, *Trametes versicolor* and *Trichaptumabeitinum* were influenced by altitudes. The CCA of Polyporaeae species with different environmental variables produced an ordination where axis 1 and axis 2 were statistically significant at p < 0.05. The Eigen values of axes 1 and 2 were 0.619 and 0.447 respectively and they explained 78.89% of relationship between the species and environmental variables.

Harsh &Bisht (1983) reported a similar trend in distribution of wood-rotting fungi along an altitudinal gradient of Kumaun hills, India.

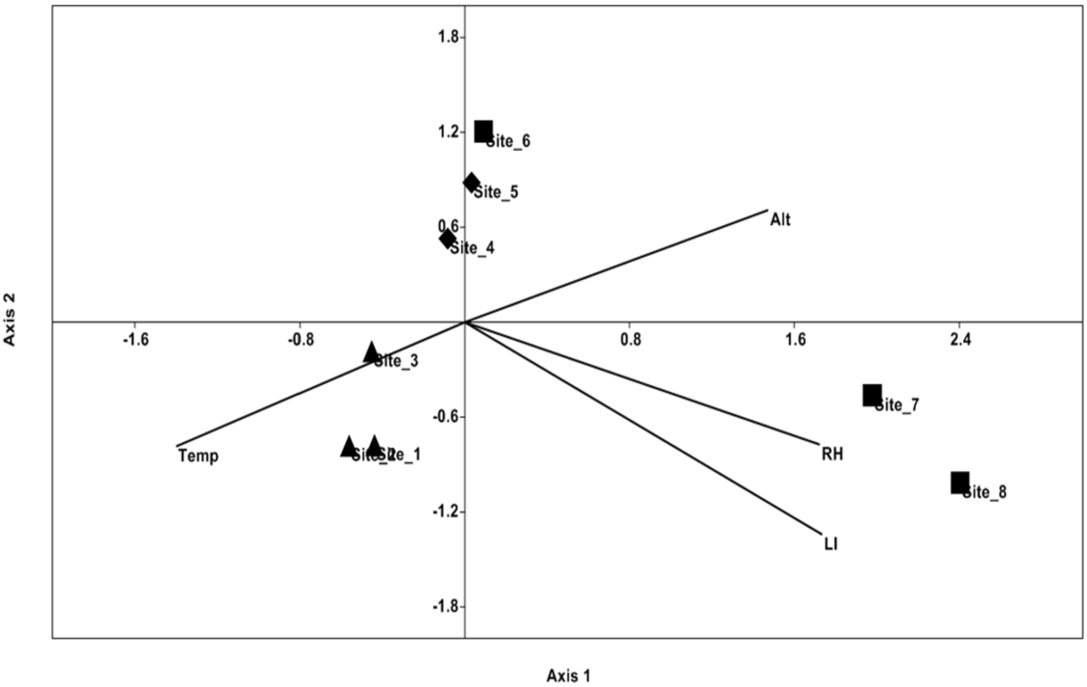

Figure 4. CCA ordination diagram of selected environmental variables (Alt – altitude, Temp – temperature, RH – relative humidity and LI – light intensity) during late summer to mid-autumn, correlated with different study sites (filled triangles represents tropical zone, filled diamond represents sub-tropical zone and filled squares represents lower temperate zone)

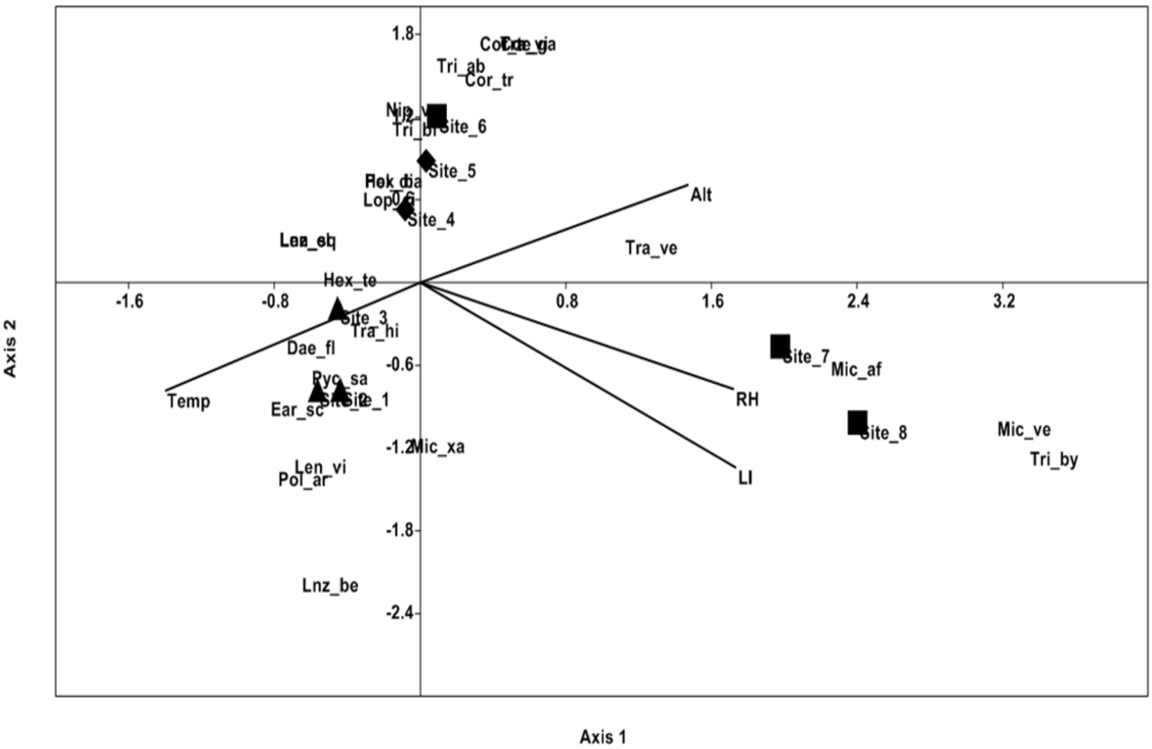

Figure 5. CCA ordination diagram of selected environmental variables (Alt – altitude, Temp – temperature, RH – relative humidity and LI – light intensity) during late summer to mid-autumn, correlated with different study sites (filled triangles represents tropical zone, filled diamond represents sub-tropical zone and filled squares represents lower temperate zone)

DISCUSSIONS

The present study showed that the number of occurrence of species showed an increasing trend with increase in altitudes and thereafter decreased with increase in altitude.

The number of species recorded in the tropical region was greater than those recorded from temperate region which supports the findings of Kuffer & Senn-Irlet (2005) and Yamashita *et al*. (2014).

However, a study conducted by Robledo & Renison (2010) in Argentina showed a contrary result where altitude was positively related to species richness. The decrease in occurrence of species at higher altitude may be due to the decrease in availability of substrata. A study conducted by Pouska *et al*. (2011) also showed that the mean volume of logs is negatively related to altitude and the negative correlation between the mean volume of logs and altitude had a negative influence on the occurrence of wood-rotting fungi. It was observed from the present study that some Polyporaceae members showed host specificity towards angiosperms and gymnosperms. This result confirmed the findings of Lyngdoh and Dkhar (2014). The preference of wood-rotting fungi to certain type of host tree species was also reported by Yamashita *et al*. (2010) and Dogan *et al*. (2011).

Within the tree species, there is a clear distinction between gymnosperm and angiosperm species (Kuffer *et al*. 2008). However, most of the Polyporaceae members were non-specialist and have broad host ranges. Similar result was reported by Gilbert *et al*. (2002) and Iqbal *et al*. (2017). Species diversity and species richness of Polyporaceae members varied with different seasons with late-summer and autumn seasons favoring the growth of Polyporaceae species. Kodsueb *et al*. (2008) and Adarsh *et al*. (2015) reported that there was variation in the occurrence of polypores with different seasons which influence decomposition of wood in a given stand. Most of the Polyporaceae members were found to be growing under light exposed condition. Gilbertoni *et al*. (2007) reported that wood-rotting fungi were found growing densely aggregated in intermediate light exposed conditions and under less light, species usually occupied more decayed woods. Temporal and spatial variations in wood-rotting fungal community may be due to seasonal variations, moisture content and aeration ratio, humidity, temperature and exposure to sunlight (Boddy and Heilmann-Clausen 2008, Bassler *et al*. 2010).

Fallen logs, twigs and decays stage III seemed to provide essential habitat for the formation and growth of the Polyporaceae species. Logs have larger surface area and have a higher chance of being colonized by spores of different polypore species (Gates *et al*. 2011). Only one species (*T. hirsuta*) was found growing on bamboo culms. Occurrence of Polypore species on bamboo culms was also reported by Choeyklin *et al*. (2009). It was reported that the production of fruiting bodies depends on the available resources and energy within the substrata and decay stage of wood (Schimit, 2005, Iqbal *et al*. 2017) and wood-rotting fungi seemed to prefer to grow on wood with barks recently peeled off (Pouska *et al*. 2011) which may also be true for Polyporceae members. Some wood-rotting fungi are early colonizers and grow on newly fallen logs whereas, others are late colonizers and grow on much decayed woods however, majority of the species prefer intermediate decay stage (stage III) of wood (Pouska *et al*. 2011) and this agreed with our result obtained from the present study. Olsson *et al*. (2011) reported that the early colonizers were primarily affected by the stage of wood decay while late colonizers were affected by different factors. Some species were found growing in two or more hosts, decay stages and seasons. Vetrovskey *et al*. (2011) also reported similar findings stating that once a species establishes itself on a fallen wood, it may persist in the community for a long time.

Conclusion

The current study gave an insight into the altitudinal distribution, seasonal variations and substrate preferences of the family Polyporaceae. It can be concluded that tropical zone particularly at an altitude of ±890mslexhibited highest Polyporaceae species diversity. Logs, twigs and wood decay stage III combined with adequate macro-environmental factors provides essential habitat for the formation and growth of the Polyporaceae species. Some Polyporaceae species are reported to have medicinal values, having the potential to treat dreadful diseases like cancer and immunological disorders, besides others. By knowing the ecological micro and macro-environmental conditions, we can create a condition suitable for large scale production and conservation of these species.

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