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ORIGINAL PAPER

Distribution of poroid fungi (Basidiomycota) in the Atlantic Rain Forest in Northeast Brazil: implications for conservation

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Abstract The poroid fungi are macroscopic fungi whose fertile surface is usually poroid. Most of them are saprobes on dead wood and play fundamental role in nutrient cycling, mostly releasing carbon removed from the atmosphere by autotrophic organisms. Despite their importance, little is known about factors affecting polypore occurrence in the Neotropics. In this study, it was tested what abiotic and/or biotic conditions shapes distinct polypore communities in the Atlantic Rain Forest in Northeast Brazil by comparing (1) the composition of the species between coastal and montane forest and between dry and rainy season; (2) the similarities among areas against distance, and (3) the abundance of the species on logs of different sizes and decay stages. One hundred and ten transects (sampling units) were visited from 2008 to 2014, resulting in 138 species of poroid fungi, 80 % of them of infrequent occurrence. According to the Analysis of Similarity and PERMANOVA, the fungal communities did not form distinct groups in relation to the forest type or season, but the areas were different from each other and the variation can be partially explained by the distance among them when using linear regression. The poroid fungi were more frequently recorded in logs of decay stage 1 and 2 and their size had little, if none, effect on polypore occurrence. Thus, we suggest the protection of every fragment of any

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type of Atlantic Rain Forest and that dead wood should be not removed from a forest in order to protect polypore diversity.

Keywords *Agaricomycetes* · Tropical forest · Fungal diversity · Fungal community

Introduction

The polypores or poroid fungi are macroscopic fungi that belong to the phylum Basidiomycota (Agaricomycetes), which is characterised by the production of differentiated cells called basidia where the sexual spores (basidiospores) are formed. In poroid fungi, the basidia are arranged in a well-defined, generally tubular hymenium (a palisade of fertile and sterile structures), being the hymenial surface, thus, usually poroid. They represent an assembly with no evolutionary relation since the poroid condition may have developed many independent times during basidiomycete evolution (Hibbett 2007; Hibbett et al. 2014).

The majority of poroid fungi are wood decomposers, living as saprobes on dead wood, causing white or brown rot (Alexopoulos et al. 1996; Deacon 2006). The white-rot polypores degrade lignin, cellulose and hemicelluloses, the major component of the plant cell wall, by oxidative processes in well oxygenised environments. Furthermore, the white-rot fungi, most of them polypores, are the only organisms capable of substantial lignin decay (Floudas et al. 2012). The brown-rot fungi are able only to degrade cellulose and hemicelluloses. Therefore, polypores play fundamental role in nutrient cycling, releasing among other substances carbon originally removed from the atmosphere by autotrophic organisms (Alexopoulos et al. 1996; Deacon 2006).

Polypores are used as indicator species of conservation of boreal and temperate ecosystems (Christensen et al. 2004; Halme et al. 2008; Norstedt et al. 2001), where several factors account for the distribution of these fungi and are currently referred in polypore and/or forest conservation (Abrego and Salcedo 2013; Brazee et al. 2012; Junninen and Komonen 2011; Juutilainen et al. 2014; Nordén et al. 2004; Penttilä et al. 2013; Ylläsjärvi et al. 2011). In these ecosystems, more polypores are usually found on larger logs and on mid-decay stage rather than initial or late stages, but a significant amount is also found in substrates of smaller size. Selective logging, thus, affects the quantity and quality of dead wood, and consequently the occurrence of polypores. Larger reserves tend to be more important to polypore conservation, as well as fire, that, although destructive in the initial stages of forest recovery, provides input of new dead substrate and increase of polypores richness, specially red-listed species. In the Neotropics, however, little is known about factors affecting polypore diversity and distribution, and consequently the use of information in their conservation, being the characteristics of the substrate (ex.: quality and quantity of wood) and precipitation the most evident at a local level (Gibertoni et al. 2007; Gibertoni 2008; Lindblad 2001a; Schmit 2005). At a large scale, polypore distribution is related to latitude, altitude, precipitation and habitat diversity (Lodge and Cantrell 1995).

At least in Brazil, diversity and distribution of polypores (and fungi in general) are not taken in account when officially protected areas are created or managed (www.icmbio.gov.br), which is unfortunate as polypores are easily collected and preserved, and most of the species can be identified by using already published keys (Gilbertson and Ryvarden 1986, 1987; Núñez and Ryvarden 1995, 2000, 2001; Ryvarden 1991, 2004, 2005; Ryvarden and

Johansen 1980). These characteristics may turn polypores into useful tools in fungal and Atlantic Rain Forest preservation, which, in Brazil, is fragmentary, surrounded by urban areas or plantations and diminished to about 11–16 % of its original size (Ranta et al. 1998; Ribeiro et al. 2009).

The present work is, thus, an effort to assess the distribution patterns of poroid fungi by (1) comparing the composition of species between coastal and montane Atlantic Rain Forest, using nine areas, and (2) between two seasons (dry and rainy); (3) comparing the similarities among areas against distance; and (4) comparing abundance of the species on logs of different sizes and decay stages. The differences to be found in polypore diversity will enable to test which conditions, abiotic or biotic, are most important to shape distinct polypore communities in Atlantic Rain Forest. The elucidation of the importance of these conditions is expected to be a useful tool in polypore conservation.

Materials and methods

Site description, data collection and identification

According to the Federal Decree no 750/93, the Atlantic Rain Forest may represent the whole group of Brazilian extra-amazonic forests: Atlantic Ombrophilous Dense Forest, Mixed Ombrophilous Forest, Open Ombrophilous Forest, Semideciduous Seasonal Forest, Deciduous Seasonal Forest, mangroves, sandbank vegetation, high fields, and montane forests. In Northeast Brazil, it comprises coastal (<100 m elev.), submontane (100–600 m elev.) and montane (>600 m elev.) areas, the latter including isolated, inland islands of vegetation (Veloso et al. 1991; Tabarelli and Santos 2004; Tabarelli et al. 2006; Alves et al. 2009).

During 6 years, two master and two doctorate projects were undertaken in 11 forest fragments in nine areas of coastal and montane forest in Northeast Brazil and the results are combined here. The fragments were visited several times during the dry and rainy seasons, and all resupinate and pileate poroid fungi (excluding agaricoid forms) and were collected in one transect delimited in each area, totalling 110 sampling units (Supplementary Material 1, 2), following the usual methodologies for the group (Gibertoni et al. 2007; Gibertoni 2008; Lindblad 2001a). In seven forest fragments, the logs longer than 1.5 m and wider than 0.1 m were measured and also had their decay stage evaluated (Supplementary Material 3) according to Nordén and Paltto [2001, modified from Renvall (1995)]: in the stage 1 the wood is recently fallen and thus still rigid, and a knife penetrates 2 mm maximum using hand strength; in the stage 2 the knife penetrates easily 2–20 mm, and in the 3 the wood is fragile and the knife penetrates easily through the log.

The basidiomata found in transects were collected, placed in paper bags and dried (Fidalgo and Bononi 1989). The specimens were analyzed macro- (shape, colour, hymenial surface) and micromorphologically (hyphal system, presence/absence and measurements of sterile structures and basidiospores). Microscopical observations were made from slide preparations with 5 % KOH, stained with 1 % of aqueous phloxine, and Melzer's reagent (Ryvarden 1991).

Specialized literature was used for identification (Gilbertson and Ryvarden 1986, 1987; Núñez and Ryvarden 1995, 2000, 2001; Ryvarden 1991, 2004, 2005; Ryvarden and Johansen 1980; Teixeira 1995; Watling 1969). The identified specimens were incorporated to the herbarium URM (Departamento de Micologia, Universidade Federal de Pernambuco).

Statistical analysis

To generate an approximation of the completeness of richness for both each area or for the total sampling, species accumulation curve and estimators Jackknife 1, Jackknife 2, Bootstrap, Chao 1 and Chao 2 for the total 110 sampling and for each area were generated using Estimates 9.1.0.

Analysis of Similarities (ANOSIM) and Permutational Multivariate Analysis of Variance (PERMANOVA), this last analysis being used if PermDisp shows significant dispersion variation, both using Jaccard similarity and generated with Primer (serial number AP6100-P544-8792600 and AA6101-A369-0405057), were used to test the significance of polypore composition differences between forest types (coastal and montane), among the 11 fragments and between seasons (dry and rainy) (Clarke and Warwick 1994). The permutation number to estimate probabilities was 10,000.

Non-metric multi-dimensional scaling (nMDS), generated with Primer, was used to represent the Jaccard similarity matrix graphically in a two-axis space.

Linear regression was used, with the x-variable (distance) log-transformed followed by outlier analyses, to assess if similarity among the nine areas is affected by distances (in logarithm scale) among them. Untransformed distance was chosen to represent this relationship.

Covariance analysis (ANCOVA) was performed using Statistica 12.0 (serial number AXA307F832516FA-D) to detect if differences in polypore abundance among log decay

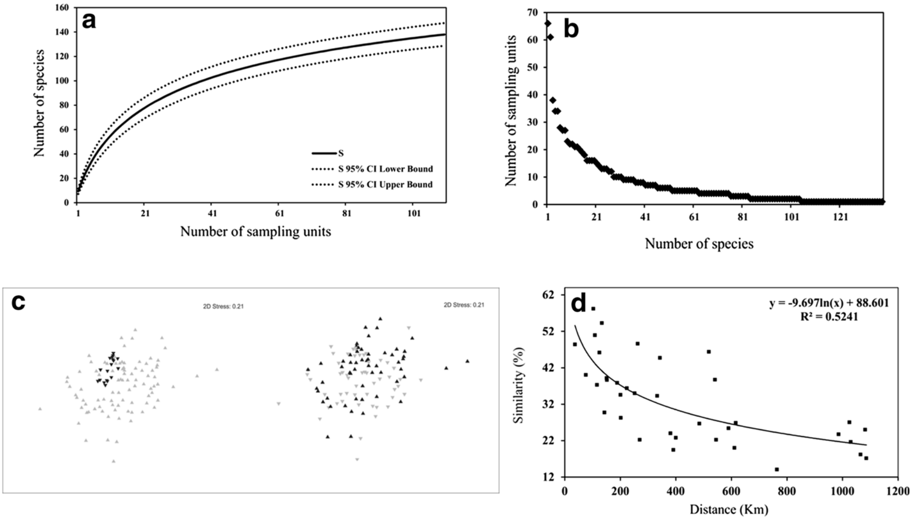

Fig. 1 **a** Species accumulation curve based on 110 sampling units; **b** species rank curve based in frequency of each species in the sampling units; **c** multidimensional scaling ordination of polypore community data according to forest type (*left*, *grey triangle* montane, *inverted black triangle* coastal) and season (right, *inverted grey triangle* dry, *black triangle* rainy). Each *symbol* corresponds to one sampling unity; **d** linear regression between similarity and natural logarithm of distances among areas (note that despite using a linear regression method, a non-transformed distance was chosen for representation of the relationship)

classes could be related only to the amount of substrate available (length and diameter). In this analysis, decay classes were considered as the single factor, total polypore abundance as the dependent variable, and log size as the co-variable. Tuckey HSD was used as a posteriori test to compare average polypore abundance values among trunks rotting classes.

Homocedasticity and normality of residuals were checked for parametric analysis. For all analysis, 0.05 was used as significance level.

Results

After a total of 110 visits (sampling units) to the areas, 138 species of polypores (Supplementary Material 2) were identified (Fig. 1a). Depending on the estimator, this number represents about 75–90 % of the predicted richness (Jackknife 1 = 172, Jackknife 2 = 185, Bootstrap = 154, Chao 1 = 163, Chao 2 = 163) and about 25 % of the poroid species already described for the Neotropics (ca. 555, Ryvarden 2004; Ryvarden, pers. com.). In all areas, the registered number of species attained more than 50 % of predicted richness (Table 1). The most frequently registered species were *Phellinus gilvus* (present in 66 sampling units) and *Funalia caperata* (61). Of the remnant species, 39.85 % were recorded in one or two sampling units, 37.68 % in three to nine, 12.32 % in 10–19, and 8.69 % in 20–38 (Fig. 1b).

Multivariate community structure was represented in a two axis nMDS (Fig. 1c) since three axis did not reduce importantly the stress. PermDisp showed significant differences ($F = 139.96$, $p < 0.001$) in dispersion among forest types (coastal and montane). Despite this result, significant differences in polypore species composition in relation to the forest type were detected by PERMANOVA ($F = 7.42$, $p < 0.0001$) but not by ANOSIM ($R_{global} = -0.125$, number of permutations = 9999, $p = 0.986$) (Fig. 1c). Though PermDisp showed significant differences ($F = 14.27$, $p < 0.001$) in dispersion among

Table 1 Estimators on each area: Floresta Nacional do Araripe (AR), Parque Ecológico João de Vasconcelos Sobrinho (BC), Mata Barragem das Moças (BM), Reserva Particular do Patrimônio Natural (RPPN) Fazenda Santa Beatriz de Carnijó (CA), Mata Caranha (CR), Parque Dois Irmãos (DI), Serra de Ibiapaba (IB), Mata do Estado (ME), Reserva Estadual Mata do Pau-Ferro (MPF), Mata Serra do Quengo (SQ), Sítio Carro Quebrado (TRF)

	Jackknife 1	Jackknife 2	Bootstrap	Chao 1	Chao 2	S	S (%)
BM + CR + SQ*	77	88	67	81	81	59	57–71
DI	39	40	36	36	35	33	83–93
CA	33	34	31	31	31	29	89–94
ME	33	37	29	32	32	26	71–89
BC	33	38	29	35	34	26	68–89
TR	59	59	53	52	51	46	78–90
MPF	69	81	57	77	75	48	59–84
AR	52	63	42	62	56	34	54–81
IB	16	17	14	15	14	12	63–78

* BM + CR + SQ = RPPN Frei Caneca

S number of species in each area, *S%* percentage range of richness (S) in relation to the estimator areas, the areas were different from each other both using ANOSIM ($R_{global} = 0.468$, number of permutations = 9999, $p = 0.0001$) and PERMANOVA ($F = 6.49$, $p < 0.001$), and these results were maintained for all pair-wise comparisons ($p < 0.01$) except for the pairs formed by AR and IB ($p = 0.056$). PermDisp did not show dispersion differences in relation to the season (dry and rainy) ($F = 0.006$, $p = 0.934$). ANOSIM did not show significant differences between both seasons either ($R_{global} = 0.026$, number of permutations = 9999, $p = 0.052$) (Fig. 1c).

Similarities among areas ranged between 14 and 58 % (Table 2) and only three of the 36 possible pairs had values above 50 %, while 50 % of them had similarities below 30 %. About half of this variation may be explained by the distance among them (Fig. 1d).

Fifty-one logs in decay stage 1, 136 in decay stage 2 and 130 in decay stage 3 (totalling 317 logs), ranging from 0.1 to 0.81 m diameter and from 1.5 to 25 m length were surveyed (Supplementary Material 3). Poroid fungi were more frequently recorded in logs of decay stage 1 and 2, regardless their length [$F_{(2,\ 313)} = 7.99$, $p = 0.00041$] or diameter [$F_{(2,\ 313)} = 11.36$, $p = 0.00002$]. When decay stage of the log was not taken in account, the occurrence of poroid fungi is significantly and positively, but weakly, related to the length of the log ($R^2 = 0.04$, $p < 0.00019$) and not significant for diameter ($R^2 = 0.0084$, $p < 0.05540$).

Discussion

Polypore diversity in the areas

In the present study, 110 visits to 11 selected areas in the coastal and montane Atlantic Rain Forest in Northeast Brazil resulted in the collection of 138 species of polypores. This richness was relatively similar to the one found by Gibertoni et al. (2007), who identified 107 species of polypores after 88 samples in transects of different sizes in 13 reserves in the coastal Atlantic Rain Forest also in Northeast Brazil. In other neotropical, highly diverse forests, Lindblad (2001a) identified 86 species of poroid fungi on 270 logs in nine

Table 2 Similarities (Jaccard) among areas: Floresta Nacional do Araripe (AR), Parque Ecológico João de Vasconcelos Sobrinho (BC), Mata Barragem das Moças (BM), Reserva Particular do Patrimônio Natural (RPPN) Fazenda Santa Beatriz de Carnijó (CA), Mata Caranha (CR), Parque Dois Irmãos (DI), Serra de Ibiapaba (IB), Mata do Estado (ME), Reserva Estadual Mata do Pau-Ferro (MPF), Mata Serra do Quengo (SQ), Sítio Carro Quebrado (TRF)

	BC	BM + CR + SQ	CA	DI	IB	MPF	ME	TRF
AR	26.70	38.71	25.40	26.87	22.22	46.34	20.00	35.00
BC		40.00	50.91	54.24	21.62	37.84	46.15	22.22
BM + CR + SQ*			34.29	39.13	17.14	48.60	28.24	34.29
CA				48.39	25.00	36.36	58.18	24.00
DI					18.18	34.57	37.29	22.78
IB						23.73	27.03	14.04
MPF							29.73	44.68
ME								19.44

* BM + CR + SQ = RPPN Frei Caneca

plots in three forest types, and 69 species on 240 logs in four plots in two forest types, both studies after four field trips to tropical forests in Costa Rica. Gilbert et al. (2002) found 43 species in five transects (500 × 10 m) after one field trip to a tropical forest in Panama, while Gibertoni (2008) identified 96 species after four visits to six transects of 1000 × 20 m in one reserve in the Brazilian Amazonia.

The species accumulation curve has not reached the asymptote, as also observed by Lindblad (2001a, b), Gilbert et al. (2002) and Ferrer and Gilbert (2003), but the majority of the estimated species were recorded according to the estimators (approximately 75–90 %), indicating that the sampling effort was reasonably efficient in the area. Nevertheless, the identified species represent about 25 % of the poroid species reported for the Neotropics and this may indicate a high level of species with restrict distribution. As expected for tropical regions, the majority of species were little recorded, as also observed by Lindblad (2001a, b), Gilbert et al. (2002), Ferrer and Gilbert (2003) and Gibertoni et al. (2007).

Vegetation in coastal and montane forests usually have similar plant species composition, but when the montane forests are subject to drier conditions (drought longer than 8 months per year and/or total annual rainfall less than 1000 mm), plant species common to Caatinga [a Brazilian ecoregion characterised mostly by the xerophytic vegetation and hot and dry (BSh) climate] may also be found (Barbosa et al. 2004; Ferraz and Rodal 2006; Pereira et al. 2010; Rodal and Nascimento 2006; Rodal and Sales 2005, 2007; Rodal et al. 2005, 2008;). In contrast, few plant species of the wetter areas are found in the Caatinga. In our study, species of poroid fungi restricted to the Caatinga were not found, and 73 of the 138 species (about 53 %) occur only in the Atlantic Rain Forest when compared to the Caatinga (List of Species of the Brazilian Flora 2015).

The distinction between coastal and montane forests was observed for plant species by Cavalcanti and Tabarelli (2004) and Rodal et al. (2008). The latter found that the difference was caused not by elevation, but by similarities in precipitation and/or months of drought. According to this study, two groups of seasonal forests in Northeast Brazil were recovered: one in which the drought is longer than 8 months per year and/or has a total annual rainfall of <1000 mm, and another with less than 8 months per year and/or a total annual rainfall of >1000 mm. In our study, the distinction between montane and coastal polypore communities was not clearly observed. PERMANOVA detected coastal forests as a sub-group nested among montane areas, but ANOSIM does not indicate them as distinct communities, as it can be also seen in the MDS figure (Fig. 1c), in which montane areas can be found among coastal areas. According to the climate records (www.apac.pe.gov.br, www.aesa.pb.gov.br, www.ceara.gov.br/municipios-cearenses), all surveyed areas had drought of less than 8 months per year and/or a total annual rainfall of >1000 mm. This uniformity in humidity may also explain the lack of difference between dry and rainy season.

According to Clarke and Warwick (1994), dissimilar communities result in R_{global} values above 0.5, thus it may be considered that the surveyed areas had, roughly, distinct polypore communities. Similarities among areas, even if not high, are partially caused by distance among them, as also observed by Gibertoni et al. (2007). Gibertoni et al. (2007) also observed that similarities were influenced by the degree of conservation of the areas. Based on personal communication with the field guides, managers and owners of the areas and on the little literature available (Freitas-Filho and Medeiros 1993; Barbosa et al. 2004; Tabarelli and Santos 2004; Lima and Corrêa 2005; Rodal and Sales 2007), the studied areas are secondary forests in different levels of regeneration. All of them suffered selective logging and/or were occupied by plantations until 20–70 years ago. Thus, distinction among areas may also reflect their anthropisation history, but his hypothesis could not be tested in the present study. Besides, given that differences are not caused by the amount of rainfall and elevation, local, restricted characteristics (niches) (MacArthur and Levins 1967) such as quality and quantity (e.g., decay stage, size) of the substrate may also be affecting the composition of the polypore community.

Polypore abundance in the logs

Most examples of factors determining fungal occurrence in decaying wood come from temperate forests, but the principles are likely to be also applied to tropical to boreal forests (Boddy 2001). Among these factors, the diversity and size of the trees, diversity of microhabitats and the environment can be listed (Stockland et al. 2012).

In the Neotropics, the indifferent colonisation (Lindblad 2001a, b) and colonisation of both initial (1–2) (Lindblad 2001a, b; Gibertoni 2008) and late (2–3) (Lindblad 2001b; Gibertoni et al. 2007) decay stages by poroid fungi are reported. In our study, the species were more abundantly found in the initial stages and probably consist of pioneers quickly occupying the dead wood with large amount of easily decomposable resources and less competition, or secondary polypores more competitive and efficient in cellulose and lignin decomposition (Boddy 2001; Stockland and Siitonen 2012). Species occurring in late stages are usually those whose establishment depend on earlier colonisers, which leave behind a suitable environment for late decayers.

In our study, little or no tendency to occupy larger logs was observed, while Lindblad (2001a), Gibertoni (2008) and Urcelay and Robledo (2009) reported strong tendencies of occupation of large logs by polypores in neotropical areas. Larger logs have larger amount of resources (when the log is not completely decayed) and of microhabitats, are more persistent in time (Siitonen and Stockland 2012), and may also represent larger area for basidiospore landing and dispersal (Edman et al. 2004b). Besides, larger logs have both thick and thin parts and could host fungal species requiring both large and small diameters, while smaller trees could only host species adapted to smaller diameters (Siitonen and Stockland 2012). Additionally, larger logs represent most of the dead wood in a forest and more fungal species would have adapted to a more available substrate (Siitonen and Stockland 2012). However, when equal areas and volumes of both large and small logs are compared, similar number of species will be found (Siitonen and Stockland 2012).

Implications for conservation

Cavalcanti and Tabarelli (2004) recognised differences between vegetation of coastal and montane forests and recommended that preservation policies should include both types of forests, but our results do not support strong or evident differences among polypore communities between these forest types. Therefore, in a superficial analysis, prioritisation of conservation based on forest type would not be justified. However, in a more detailed analysis, our results demonstrate that the studied areas are clearly distinct from each other once they are characterised by low similarity and high number of infrequent species, regardless their forest type, and that the little similarity found was basically caused by distance. Thus, we strongly suggest the protection of every fragment of any type of Atlantic Rain Forest in order to protect polypore diversity, mainly those distant from each other.

The lack of polypore community differences between dry and rainy season would suggest that the occurrence of these fungi are less influenced by precipitation. Consequently, these fungi would not strongly suffer the effects of climate change, what would mostly lead to changes in rainfall regimes (Sitch et al. 2008). However, 53 % of the identified species in our study do not occur in the dryer, surrounding Caatinga, and this indicates that, in case of drier climates and contraction or extinction of wetter forests, there would be important losses in polypore species richness.

Additionally, dead wood should be not removed from a forest, unless it is almost completely decayed. The need of substrate diversity was demonstrated for temperate and boreal forests (Abrego and Salcedo 2013; Brazee et al. 2012; Junninen and Komonen 2011; Juutilainen et al. 2014; Nordén et al. 2004; Ylläsjärvi et al. 2011) and partially now. Besides, forestry would prevent species dispersal, once basidiospore fall very close to their basidiomata and thus dispersal from wood-to-wood would be compromised (Edman et al. 2004a).

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