Current Research in Environmental & Applied Mycology (Journal of Fungal Biology)
11(1): 16–36 (2021) ISSN 2229-2225
www.creamjournal.org **Article**
Doi 10.5943/cream/11/1/2

Small plot surveying reveals high fungal diversity in the Ecuadorian Amazon – a case study

Gates GM[1*], Goyes P[2], Gundogdu F[3], Cruz J[4] and Ratkowsky DA[1]

[1]Tasmanian Institute of Agriculture, Private Bag 98, Hobart, Tasmania 7001, Australia
[2]Multifamiliares el Batán Av. 6 de Diciembre y Louvre N 63-69 Quito-Ecuador 170137
[3]Finca Heimatlos, Via Canelos, km 1.5, Puyo, Ecuador
[4]Microbial Systems Ecology and Evolution research group, Department of Natural Sciences, Biology School, Universidad Técnica Particular de Loja, San Cayetano Alto s/n C.P. 11 01 608, Loja, Ecuador.

Gates GM, Goyes P, Gundogdu F, Cruz J, Ratkowsky DA 2021 – Small plot surveying reveals high fungal diversity in the Ecuadorian Amazon – a case study. Current Research in Environmental & Applied Mycology 11(1), 16–36, Doi 10.5943/cream/11/1/2

Abstract

The diversity and ecology of macrofungi based on fruitbody collections in a small portion of a 25-year-old regenerating forest in tropical Ecuador was investigated over a period of 8 weeks. Maps are provided of the living trees of three 10 m x 10 m plots within the forest. All fungal fruitbodies within the plots were collected every third day, the major substrates being wood, litter and soil. There were 254 collections in total, representing 127 morphospecies of which 17 are Ascomycetes and 110 are Basidiomycetes. Wood supported the greatest number of species overall, but the mycota in the three plots of the study varied greatly, with one plot having twice as many species on litter as on wood. Using canonical analysis of principal components and permutational multivariate analysis of variance, the species assemblage in the plot with the greatest amount of standing and fallen wood was the most significantly different from the other sampling units. It is concluded that a detailed examination of even a small area can provide valuable information on the fungal diversity and assemblages of a forest. This is one of the few studies from Ecuador relating macrofungal diversity to forest structure.

Key words – ectomycorrhizal – litter – Neotropics – soil – wood

Introduction

In Ecuador, the slopes to the east of the Andes descend to the tropical Amazon region where the tributaries of the Amazon River including the Rio Napo (Ecuador's largest river) wind eastwards, supporting tropical rainforests and their associated diverse array of organisms, including macrofungi.

The fungal flora of Ecuador has been studied in the past by many visiting mycologists (see Læssøe & Petersen, website http://www.mycokey.com/Ecuador/HistoryStart.html for a list of visiting and local mycologists until 2008), with the first reliable record being a rust from the Galapagos Islands in 1853 by NJ Andersson; the first agaric was a species of *Lichenomphalia* collected by E Whymper on Volcán Antisana near Quito on the mainland in 1890. Significant contributions include Singer (1975, 1978) on new species, Reid et al. (1980) who surveyed the Galapagos Islands, and Hedger (1985) on the ecology of litter fungi. The expedition of the British Mycological Society in 1993 to Cuyabeno brought forth a flurry of publications (Lodge & Cantrell

Submitted 28 February 2020, Accepted 8 January 2021, Published 19 January 2021
Corresponding Author: Genevieve Gates – e-mail – ggggates@gmail.com

1995, Lodge 1996, Lunt & Hedger 1996). Ullah et al. (2002) and Suárez-Duque (2004) examined fungi and woody substrate. Haug et al (2005) studied mycorrhizal formation in the Nyctaginaceae and Gamboa-Trujillo (2005) presented a seminal ethnomycological work for Ecuador on the species of fungi known to be used by the indigenous Kichwa community. In the past 5 years there have been publications from Ecuador of a taxonomic nature with descriptions of new species using molecular techniques (Barili et al. 2017a,b,c, 2018, Caicedo et al. 2018, Thomas et al. 2016, Flores et al. 2018, Guevara et al. 2018, Schüßler & Walker 2019) and on the edible fungi of Ecuador (Gamboa-Trujillo et al. 2019).

There are many studies from Europe (especially the Scandinavian countries) and North America relating fungal diversity to forest structure parameters such as volume and diameter and decay class of coarse woody debris (CWD), tree species and basal area of living trees (e.g. Renvall 1995, Høiland & Bendiksen 1996, Nordén et al. 2004, Iršėnaitė & Kutorga 2007). Studies in Ecuador are still more inventory focussed, gathering as many species as possible from a reserve or threatened area (e.g. Newman et al. 2019) and publishing new species rather than plot-based projects with regular visits relating variables to diversity. Itinerant visitors with an interest in mycology may contribute records, usually without herbarium material to substantiate the records, to databases, e.g. iNaturalist (https://www.inaturalist.org/) and Mushroom Observer (https://mushroomobserver.org/). The fungal inventories and other studies in Ecuador have covered only a fraction of the habitats that exist. For the most part the fungal flora and fungal ecology of this country is still unknown and will, according to Læssøe & Petersen (2008), take several generations before a clearer picture of Ecuadorian mycological diversity emerges. Unfortunately, this diversity is in danger of never being known, due to the fast disappearance of the Amazonian tropical forests by a continuing barrage of logging and mining activities and climate change.

The first author (GMG) visited the Finca Heimatlos, near Puyo, and made casual collections and identifications of wild fungi at the invitation of the owner of the property for 4 weeks in July–August 2018. The information gathered during that period suggested that a more formal study based upon field plots would be of interest. Therefore, the first author returned 12 months later to do a plot-based project over a period of 10 weeks. The work in 2018 also laid the foundational database of collections as a reference for the present study. As this study took place on the edge of the Amazon Basin it was expected that species in common with other countries such as Brazil and Peru, areas of which are also part of this basin, would be found which would extend the range of such species.

The aims of this plot-based project were:

- to gather information on the fungal species for the construction of a baseline dataset from a secondary forest 25 years of age which would be pertinent for other similar forest types throughout Ecuador,
- to see if there exists a relationship between fungal species richness and the forest structure, taking account of the vegetation within it,
- to examine the species assemblages present in small areas of the forest.

Materials & Methods

Site description

The study took place at the Finca Heimatlos (01° 37′ 05″ S, 77° 50′ 29″ W), an ecolodge and sustainable farming enterprise of 50 ha on Via Canelos ca. 30 km from the township of Puyo (Fig. 1). The climate is typically equatorial, with torrential rain occurring usually every night, even in the winter or ‘dry’ season (30 km away in Puyo the monthly rainfall averages for July–September are ca. 350 mm; https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine, puyo-ec, Ecuador, visited 8 December 2019). At an altitude of 800 m, the temperatures are pleasantly mild and uniform all year round with minimums of about 16°C and maximums around 27°C.

The forest surrounding the ecolodge is regenerating after logging operations in the mid-1990s. The topography is steep and rugged. Three plots measuring 10 m x 10 m were chosen adjacent to the track that descends to the small unnamed river that eventually joins the larger Bobonaza. As priority had to be given to securing the safety of the investigators, level ground, which was difficult to find, was sought for the placement of the plots. The final choice placed Plots 1 and 2 only 30 m away from each other on opposite sides of the track, with Plot 3 further down the slope closer to the river. A transect of 300 m of track commencing from Plot 1 was also surveyed for 0.5 m on either side of its median width to provide some comparison to the plot survey method, the transect area of 300 m^2 being equivalent to the sum of the areas of the three plots.

Fig. 1 – Map of Ecuador; the red star depicts the approximate location of the study site.

The mapping

The location of all living and dead trees for each of the three plots was depicted on sheets of graph paper. The diameters of the live trees were measured, and their heights estimated. The live trees were named to species level when possible, as were some of the understory plants. Fallen wood ≥ 10 cm length and ≥ 10 cm diameter, also known as coarse woody debris CWD, was also measured and plotted on the same graphs.

The fungal surveying, examination and identification

The three plots and the transect were surveyed by at least 3 people for 30 minutes on the same day every third day from 28 July–20 September 2019 inclusive, except for a gap of 5 days between 6–12 August, for a total of 18 visits. A macrofungus was defined as one in which the fruitbody could be seen with the naked eye or occurred in troops, forming a visible group. A species was recorded as being present in a given plot if there was one or more fruitbodies of that taxon at the given visit. No attempt was made to count the number of fruitbodies present. Hence, our assessment of species

richness is confined to noting presence or absence of a species at each visit, rather than its abundance. Fruitbodies were physically removed to avoid recording them again in subsequent visits, but polypores were left in situ and not counted on the subsequent visits. Immature fruitbodies were not included in the survey. Fruitbodies were photographed in the field and their colours, odours and substrate noted. Substrates were categorised as follows: 1. soil; 2. wood, including fallen wood >10 mm diameter, and living trees; 3. litter, including twigs to 10 mm diameter, leaves, seeds, seed pods, bark; and 4. other, e.g. dung, dead animals, parasitised insects. Collections were taken back to the laboratory at the Finca where they were assigned a collecting number and macroscopically and microscopically described using Amscope binocular compound and binocular stereo microscopes.

The following stains were used for microscopic examination of tissues at 400x and 1000x, viz. Melzer's reagent, 10% KOH, 1% phloxine, and Congo Red. Photos were taken of the microstructures down the eyepiece using a Canon Powershot 120S digital camera. Field guides and online fungal sites were used to identify the fungi, with Index Fungorum (http://www.indexfungorum.org/names/names.asp) being the source of the most up-to-date names. In some cases, identification was difficult as the very small size (≤2 mm diam.) of some of the specimens prevented complete microscopic examination, such as sectioning of the pileipellis or spore print determination. Molecular work would probably be needed to accurately assign a genus to these collections. Those species that could not be identified to species level were given a 'tag name'. The difficulties of assigning Latin names to tropical species has been encountered by other researchers (Singer & Araujo 1979, Piepenbring 2015); more than 40% of litter agarics found by Lodge & Cantrell (1995) were undescribed species. The specimens were labelled and dried on a wire rack in a covered wooden box heated by two 100w light globes. They were then placed in plastic clip lock bags and are currently stored in the private herbarium at the Finca. Eventually they will be transferred to the herbarium of the University of Estatal Amazonia or UTPL Universidad Técnica Particular de Loja.

Statistical analysis

Descriptive statistics were used to produce summary tables of the number of records and the number of species collected in the three plots and the transect during the 18 visits. Species richness, taken to mean the numbers of species found in a sampling unit, was computed using the Mau-Tau estimator for 'sample-based rarefaction' available in EstimateS (Colwell 2013), a procedure that effectively removes random variation among the visits and produces a smooth species accumulation curve from the observed data. As there also proved to be differences in the rate of accumulation of records among plots and transect in the early visits, species accumulation curves based upon the visits in the order in which they actually occurred (i.e. non-random) were also prepared.

Species assemblages, which take account of how the species co-occur in space and time, were examined using CAP (canonical analysis of principal coordinates; Anderson & Willis 2003) and PERMANOVA (multivariate analysis of variance using permutations; Anderson 2001), both of which are available in the ecological software package PRIMER Version 6 (Clarke & Gorley 2006).

Results

Vegetation of the plots

Although the plots were in the same forest type and close to each other, detailed examination of the living vegetation and fallen wood revealed they were quite different. Plot 1 had a boggy patch that rarely dried up, a noticeable number of palms, viz. 6 living chontas (palms of the genus *Bactris* in the family Arecaceae), each ca. 2 m tall, 4 palms of another species of the Arecaceae, and although no clinometer was available to make measurements, it was steeper than the other two plots. Plot 2 had two *Cercropia* spp. and lots of seedlings, and a very large toquilla palm (*Carludovica palmata*) as well as tangled prickly vines evocative of disturbed areas. Plot 3 had the largest number of standing dead and living trees with 4 chontas, was easier to walk through and had the ambience of an older plot compared with the other two.

The maps

Plot 3 had the most wood on the forest floor (including a large log 52 cm diam.) and the only standing dead wood (4 stags or stumps), 14 small diameter living trees (ca. 4 cm) and 7 larger diameter trees (Fig. 2). Plot 1 had the next highest amount of downed wood and 17 living trees of ca. 4 cm diameter and 4 trees of larger diameter. Plot 2 was almost devoid of fallen wood and had 12 small diameter living trees and 2 larger diameter trees. Plot 2 had the smallest live tree basal area and CWD volume of the three plots (Table 1).

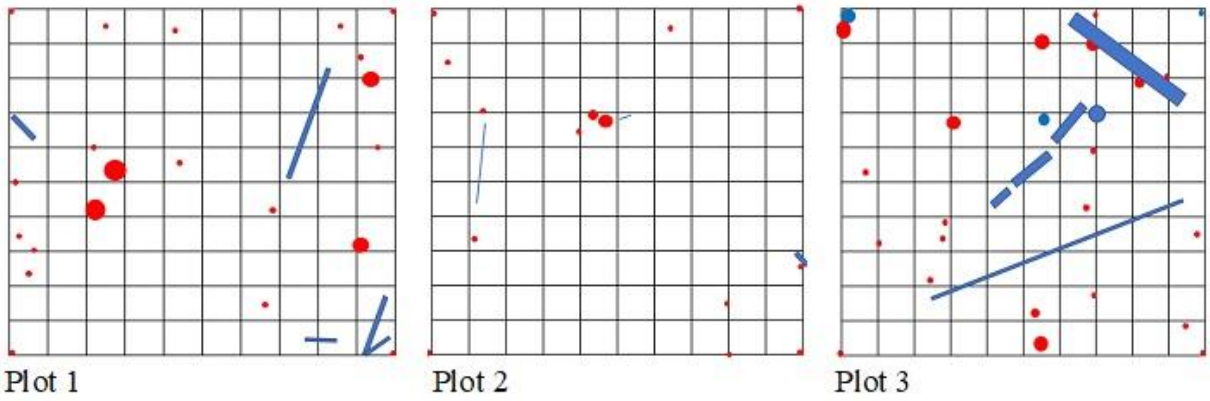

Fig. 2 – Maps of the three plots of the study at the Finca Heimatlos, showing the location of the living trees (red dots), the fallen dead wood (blue rectangular shapes) and stags or stumps (blue dots). The 10 m x 10 m plots are divided into a 100 small squares, each of size 1 m x 1 m. Trees and stags of size 10 cm or more are drawn to scale, but trees of a smaller diameter are shown as same-sized dots.

Table 1 Basal area of living trees and volume of CWD in each plot.

Plot no.	Basal area of living trees, m^2	CWD volume, m^3
1	0.261	0.122
2	0.097	0.021
3	0.374	1.077

Fungal species identification and richness

The 18 visits to the three plots and the transect produced a total of 254 collections (25 Ascomycetes and 229 Basidiomycetes), representing 127 morphospecies (17 Ascomycetes and 110 Basidiomycetes), of which 41 were formally described and 86 were identified using tag names (see Appendix 1 for a list of the species included in this study). Thirteen species could not be identified to the level of genus, although four could be assigned to an 'either/or' pair of closely related genera. Additional species found at the Finca but outside the area covered by the present study, including those from 2018, are listed in Appendix 2.

The highest number of both records and species were from the transect, 73 and 51, respectively. Each of the three plots gave a very similar number of species, viz. 42 from Plot 1, 42 from Plot 2 and 39 from Plot 3 (see Table 2b). Records had a greater range, with Plot 2 having the lowest number, viz. 50, compared to 64 for Plot 1 and 67 for Plot 3. The only species to occur in all 4 sampling units was the common wood-inhabiting species *Oudemansiella canarii*.

Species accumulation curves

Randomized species accumulation curves for each plot and the transect show the number of new species from each visit (Fig. 3a). None of the resulting curves, which randomize the order in which visits were made to result in smoother curves, suggests that an asymptote is being approached. When the visits are depicted in the order in which they were carried out, i.e. not

randomized, the resulting species accumulation curve is quite different (Fig. 3b). This shows that Plot 2 did not have any species present until the 5th visit. It had its major burst of fruiting activity on the 9th and 10th visits. Plot 1 had spurts at the 5th, 8th and 9th visits. Plot 3 had spurts at the 4th and 7th visits but then levelled off until it had a minor burst of fruiting activity at the 11th and 12th visits. The transect was different from the plots, with 11 species found at the very first visit and with other spikes at the 5th, 6th, 9th and 10th visits. The rate at which new species were added remained steady after that.

Table 2 Fungi collected from the sampling units versus substrate (a) number of records, (b) number of distinct species.

(a) Number of records/percentage of row totals

Sampling unit	Substrate litter	other	soil	wood	Totals
Plot 1	22/34.4%	1/1.6%	10/15.6%	31/48.4%	64
Plot 2	24/48.0%	2/4.0%	15/30.0%	9/18.0%	50
Plot 3	11/16.4%	1/1.5%	22/32.8%	33/49.3%	67
Transect	13/17.8%	1/1.4%	22/30.1%	37/50.7%	73
Totals	70/27.6%	5/2.0%	69/27.2%	110/43.3%	254

(b) Number of distinct species

Sampling Unit	Substrate litter	other	soil	wood	Totals
Plot 1	16	1	8	21	42
Plot 2	19	2	12	9	42
Plot 3	10	1	13	18	39
Transect	10	1	16	25	51
Totals	45	4	36	54	127

Notes: Whereas marginal totals for the number of records are the sum of the entries in the body of the table, the marginal totals for the number of distinct species do not add up, as some species are present in more than one sampling unit or on more than one substrate.

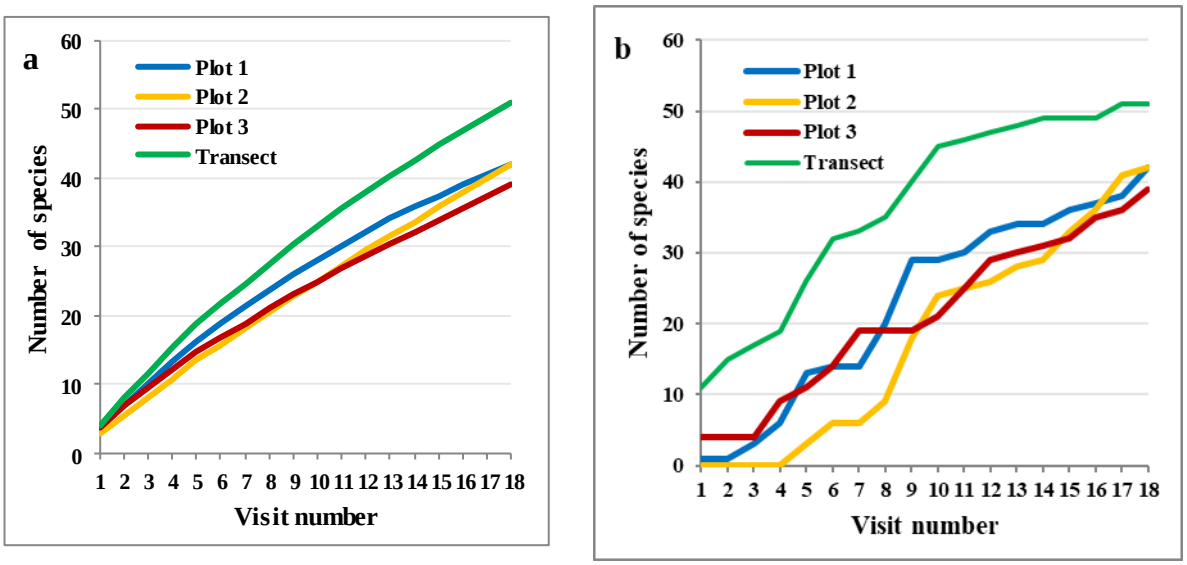

Fig. 3 – Species accumulation curves for the three plots and the transect at Finca Heimatlos. a Randomised. b Non-randomised. i.e. based on the visits in actual order of occurrence.

Substrate specificity

Eight species were found on more than one substrate, but none from more than two substrates. These 8 species included four species from Plot 1, three species from Plot 3 and one species from the transect. Four of them (*Xylaria* aff. *filiformis*, *Hohenbuehelia* 'white', *Marasmius* 'white with pink flush', *Mycena* 'tiny white with distant gills') were on both wood and litter, three (*Deconica* sp., *Marasmius* 'velutinous orange', *Mycena* cf. *pura*) were on both soil and litter, and one (*Galerina velutipes*) was on both wood and soil. From Table 2a it can be seen that in Plot 1 the percentages of records from wood (48.4%) and litter (34.4%) far exceeded that on soil (15.6%), whereas in Plot 2 litter records dominated (48%), being equal to the sum of the percentages on soil (30.0%) and wood (18.0%). In Plot 3, wood supported the highest number of records (49.3%) compared to soil (32.8%) and litter (16.4%). The transect also had the highest percentage of records from wood (50.7%), with soil and litter having 30.1% and 17.8%, respectively.

Fungal species assemblages

The two methods of examining the fungal species assemblages in the three plots and in the transect, viz. PERMANOVA and CAP, gave results that reinforce each other, as both of these permutational multivariate analyses indicate that Plot 3 has assemblages that are the most different from those in any of the other sampling units. The first axis of the canonical discriminant analysis CAP clearly separates Plot 3 from the other plots and from the transect (Fig. 4a), and the P-values from PERMANOVA for the comparisons of Plot 3 with each of the other two plots or the transect are highly significant (P=0.0001, Table 3). On the other hand, comparisons of Plot 1 vs. Plot 2, Plot 1 vs. Transect and Plot 2 vs. Transect all indicate a lesser degree of difference among the fungal assemblages, either pictorially (Fig. 4b) or via a formal statistical test (P>0.01, Table 3).

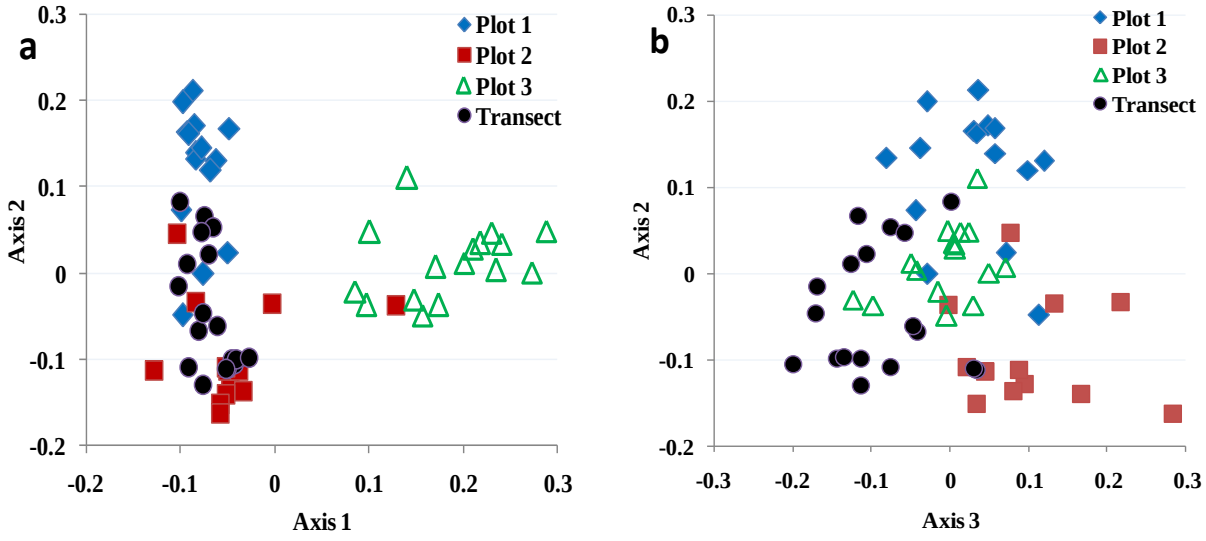

Fig. 4 – Canonical analysis of principal coordinates (CAP) on the species collected during 18 visits to the three plots and the transect between 28 July – 20 Sept 2019; Bray-Curtis similarity calculated using presence-absence data. a Axis 2 vs. Axis 1. b Axis 2 vs. Axis 3.

Table 3 P-values obtained from PERMANOVA (multivariate analysis of variance using permutations) on the species assemblages from the plots and transect.

Sampling unit	Plot 1	Plot 2	Plot 3	Transect
Plot 1	—	0.0177	0.0001	0.0664
Plot 2		—	0.0001	0.0215
Plot 3			—	0.0001
Transect				—

Discussion

Overall species diversity

The ever-increasing species accumulation curves and their steepness indicated that very few species were collected more than once, suggesting that sampling was in the early stages and with time it would be expected that the curves would start to level out as species were recollected. The number of Basidiomycetes was far greater than that of Ascomycetes. Many ascomycete species are very small and easily overlooked (Huhndorf et al. 2004). In fact, production of fruitbodies can be seasonal and very irregular; some fungi may not fruit for years (Straatsma et al. 2001). Culturing of substrate and molecular techniques have given greater insight into the diversity and ecology of fungi, e.g. Allmér et al. (2006) found that molecular techniques on wood revealed hidden ascomycete diversity; large numbers of litter-inhabiting fungal species in Panama were determined using 454 pyrosequencing by McGuire et al. (2012) and Kerekes et al. (2013); studies of above-ground fruitbodies and below-ground root tips have produced a different mycota with not much overlap (Dahlberg et al. 1997, Horton et al. 2017). Fungal ecology studies based on next generation sequencing of substrates have resulted in a huge number of unnamed molecular operational taxonomic units (MOTUs) which remain unnamed thereby limiting the knowledge of ecological functions, making it difficult to compare studies and impeding communication on fungal diversity (Wu et al. 2019). We had neither the financial resources nor the facilities to undertake either culturing or molecular work on any substrate. Fruitbody surveys are generally non-destructive, cheaper, and provide a picture of when the fungus is in a sexual stage of its development. Furthermore, fruiting patterns can be observed and, importantly, species can be targeted for conservation purposes, public education and citizen scientists' projects such as fungi mapping. The vouchered specimens deposited in a herbarium can be used later for molecular work and taxonomic studies. The differing survey methods should be viewed as complementary rather than mutually exclusive (Heilmann-Clausen & Vesterholt 2008); all methods provide important information.

Species assemblages and plot differences

The differences in species and records among the plots show that a 10 m x 10 m area has a mycota different to another 10 m x 10 m area in the same forest. Each of the plots behaved in a distinctive manner, as can be seen from the non-randomized species accumulation curves and the CAP and PERMANOVA analyses. If one uses the randomized species accumulation curves as the basis for interpretation, one might conclude that Plots 2 and 3 are very similar, which would probably be misleading. The maps of the vegetation and wood (Fig. 2) are also very different. For example, Plot 2 had very little living vegetation or fallen wood and was dominated by litter-inhabiting species both in terms of species and as a percentage of its total mycota. Plot 1 was most similar to the Transect with 13 species in common of which 11 occurred on wood. It was not noted where along the Transect the species were found so any attempt to relate wood from inside Plot 1 with wood outside from the Transect as having come from the same large fallen tree was not feasible. It is not possible to tease out the factors responsible for these differences; many more plots would be needed with many more details of variables such as vegetation type and cover, light intensity, litter species, litter depth, litter moisture, soil type, soil pH and soil moisture, wood moisture and interactions of these variables. However, replication in a native forest is difficult, unlike experiments in monoculture plantation forests where trees are of the same species and the same age and are planted the same distance from each other, as well as being further compounded by the capricious nature of fungi.

Wood-inhabiting fungi

In this study, wood was the most productive substrate for fungal diversity. Watling (1977) noted a higher percentage of lignicolous fungi occur in the tropics as in temperate regions related no doubt to the dominant ligno-cellulose habitat as noted by Hedger (1985). Many studies in boreal or temperate forest types have proven the value of leaving wood of different sizes and decay classes

on the forest floor to increase fungal diversity (e.g. Lindblad 1998, Heilmann-Clausen & Christensen 2003, Gates et al. 2011) as wood provides an array of habitats depending on the diameter, decay stage, bryophyte cover, and species. Wood, especially large diameter wood, also provides a buffered environment that withstands desiccation and maintains viable mycelium so that although the fruitbodies (except for the polypores) were removed at each finding in the present study, the mycelium of some species continued to produce fruitbodies for several visits e.g. *Auricularia fuscosuccinea* and *A. delicata* which could bias results. Another example is *Galerina velutipes*, which occurred 13 times in Plot 3 and only once in Plot 2. In Plot 3 it was found on remnants of well-decayed wood from a larger log which was the original colonised wood. It is highly likely that these individuals are genets of their respective original infection on the wood. The few polypore species that were found in this study were on standing dead wood in Plot 3. These stags could have been biological legacies from a pre-logged forest which would give a polypore the longer time needed to develop a hard substantial fruitbody (Heilmann-Clausen & Christensen 2004).

Litter-inhabiting fungi

A very important component of the fungal diversity in a tropical forest is the litter fungi and this is supported by our study. The 70 species found on litter included 22 species of *Mycena*/*Hemimycena* which usually have small delicate fruitbodies and 9 of *Marasmius*/*Marasmiellus* which are also small but tougher with very slender wiry stipes and are often marescent. These genera respond quickly to a rainfall event, by either rehydrating or producing new fruitbodies. The required spatial domain is very small and a piece of leaf from e.g. *Philodendron pastazanum* or *Caladium steudneriifolium*, understory plant species which have leaves with a very large surface area, or a fine twig, can support many fruitbodies of several species. Although leaf-litter substratum is prone to desiccation in a 24 hr absence of rain in tropical forests (Hedger 1985), torrential rainfall events occurred regularly every 1–2 days during the 8 weeks at the Finca and the litter quickly rehydrated. Litterfall in this patch of tropical forest was continuous. The torrential rain brought down small branches and palm leaves daily ensuring an ongoing supply of available substrate (pers. obs.).

Many litter-inhabiting fungi show preferential association with a substratum (Hering 1982, Boddy 1984, Lodge 1996) and this is the case with tropical decomposer fungi too (Hedger 1985, Lodge 1996); however, in the current study the overlap of substrates only occurred once and therefore is not considered to be of any significance.

Soil-inhabiting fungi

This substrate was dominated by species of Hygrophoraceae, Cantharellaceae or Entolomataceae, viz. *Hygrocybe*, *Neohygrocybe*, *Gliophorus*, *Cantharellus* (9 spp) and *Entoloma* (5 spp). No ectomycorrhizal species on wood or soil was found within the plots although the *Gloeocantharellus* sp. and *Albomagister* cf. *subaustralis* were found in the transect. An all-white *Russula* species *Russula* cf. *acuarum* species was collected several times in 2018 and 2019 from outside the study area as was *Clavaria* aff. *schaefferi*. According to Hedger (1985) many mycologists visiting the tropics observe the distinct lack of the larger ectomycorrhizal fungi such as *Russula*, *Lactarius* and *Cortinarius*. This is not surprising as only 6% of neotropical trees are estimated to form ectomycorrhizal associations (Corrales et al. 2016); however, members of the Nyctaginaceae (e.g. *Neea*) form ectomycorrhizal associations with species of the fungal families Russulaceae and Thelephoraceae (Haug et al. 2005) and *Neea* trees were observed in the forest if not in the actual plots. Given that an ectomycorrhizal fungus can fruit 20 m from its host tree (Dickie & Reich 2005) the absence of an ectomycorrhizal host in the plots would not necessarily preclude the fruiting of an ectomycorrhizal fungus species within a plot of 10 m x 10 m that had no host trees.

Comparisons with other studies from Ecuador

Hedger (1985) bemoaned the fact that there were few structured plot studies from Ecuador with which to compare his 2-year study of agarics in cocoa litter in Pichilinque where he surveyed 10 fixed 1 m^2 quadrats weekly for 88 weeks and found 30 species. Results from a litter agaric experiment in Cuyabeno (Lodge & Cantrell 1995) suggested that a single sampling from two areas of 12 1 m x 1 m plots over a period of 7 days was close to the optimum number needed for sampling and that 70% to 80% of the species present were found. They found 70 species of agarics in the litter but we assume these species (no list is given in the article) included species in the soil involved in decomposition of litter in the F layer whereas we assigned these species such as *Hygrocybe* spp. and *Entoloma* spp. to the soil-inhabiting substrate. Studies especially examining woody substrate variables and fungal species diversity are particularly rare.

Ullah et al. (2002), although the collecting was random, did distinguish between wood (all parts of the tree) down to 20 mm diameter, and small litter which included twigs <20 mm diameter, leaves, fruits and flowers and found that the overlap of species between the substrates was only 20% of the total in their study on the production of ligninolytic enzymes by species of macrofungi from Rio Palenque based on over 100 collections made in September 1997.

Suárez-Duque (2004), working in a forest (1600–1800 m asl) in a stage of regenerating of 17 years, collected macrofungi from 10 plots, each 10 m x 10 m, monthly for 5 months. He noted the fluctuations in abundance of the Agaricales and variables such as vegetation cover, volume, size (>10 cm diameter for large wood) and type of decay (whether brown or white rot) of the wood substrate but concentrated on the diversity of non-Agaricales (50 species). He also plotted where each species fruited in the plot to obtain space-time data. Although there was a relationship between abundance of fungi and vegetation cover, there was none with rainfall or wood characteristics; however, the detailed data could be used in further studies. The lack of significance further illustrates the difficulties of obtaining statistically significant data in a native forest.

Gamboa-Trujillo (2005) surveyed transects for an ethnomycological study in the Río Oglán Protector Forest (Arajuno Canton) in mature forest and a farm during April, June, July, August, September, October and November, each excursion involving 8–10 days of field work. The total area surveyed was 7000 m^2, which is more than 10 times larger than that of our study (600 m^2). He collected 185 species of which 64% grew on wood, 5% on soil, 18% on humus and 11% on leaves. We found 127 species, which suggests when the two studies are compared that intensively surveying smaller plots more frequently can capture the majority of the fungal species present. However, as the focus of Gamboa-Trijillo was on finding out which species were used by the local Kichwa community, the species list in his article contains only those 133 species, so genera that were not known to be used are missing, e.g. *Entoloma* and *Pluteus*, which makes it difficult to compare the two studies accurately. It is interesting to note that there are 15 *Marasmius* species and 12 *Mycena* species without specific epithets, similar to what we found in our study, suggesting that these species are difficult to identify and/or are very much understudied in Ecuador.

Compared to these other studies the detailed examination of the plots in our study yielded informative data on the fungal diversity in a relatively short period of time. Possibly the time interval between visits (3-day intervals) was ideal in this tropical forest to capture the species fruiting. Most of these species were collected only once and could be new to science. The natural world is facing an uncertain future with the rapidly accelerating effects of climate change. As well as the usual anthropogenic disturbances such as mining, logging, clearing of land for agriculture and housing, habitat is being destroyed by prolonged droughts, catastrophic weather events, and more intense and severe bushfires as experienced by Brazil (2019, even in the wettest Amazonian rainforest) and Australia (2019-2020). Fungal diversity may be affected and species could disappear along with habitat (Maltz et al. 2017). Fruiting patterns have already been noted as changing in the United Kingdom (Gange et al. 2007) and across Europe (Boddy et al. 2014); therefore, studies acquiring baseline data such as the current one should not be neglected.

Conclusions

- There is valuable ecological information to be obtained at the small-scale level. This study provides a snapshot in time of the fungal diversity found in a 25-year-old forest in the Amazonia of Ecuador and is an important addition to the few structured fungal studies from Ecuador.
- Wood on the forest floor is a very important substrate for fungal diversity and this should be considered in the development of sustainable forestry practices in tropical Ecuador and other countries that are part of the Amazon basin as it has been in other parts of the world.
- More collecting projects are needed with molecular studies examining soil, root tips and woody substrates to further clarify the fungal diversity of Ecuador.

Acknowledgements

We acknowledge Alexandra Vaca, Cecy Cabrero, Jessica Karina, Mathias Haacke Concha, Daniel San Martin, May Aquilar, Lorena Gomez and Jeimy Quiroga, who helped with collecting and identification; Ursula Gelchsheimer for plant identification, the staff at Finca Heimatlos for their friendship; members of the 'Hongos de Ecuador' Facebook page who helped with identification; and Thomas Læssøe for the dryer design and other advice regarding collecting.

References

Allmér J, Vasiliauskas R, Ihrmark K, Stenlid J, Dahlberg A. 2006 – Wood-inhabiting fungal communities in woody debris of Norway spruce (*Picea abies* (L.) Karst.), as reflected by sporocarps, mycelial isolations and T-RFLP identification. FEMS Microbiology Ecology 55, 57–67.

Anderson MJ. 2001 – A new method for non-parametric multivariate analysis of variance. Austral Ecology 26, 32–46.

Anderson MJ, Willis TJ. 2003 – Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology. Ecology 84, 511–525.

Barili A, Barnes CW, Flores JA, Ordoñez ME. 2017a – *Hygrocybe sangayensis*. Fungal Planet/Persoonia 38, 334–335.

Barili A, Barnes CW, Flores JA, Ordoñez ME. 2017b – *Hygrocybe macrosiparia*. Fungal Planet/Persoonia 38, 336–337.

Barili A, Barnes CW, Ordoñez ME. 2017c – *Humidicutis dictiocephala*. Fungal Planet/Persoonia 38, 332–333.

Barili A, Barnes CW, Ordoñez ME. 2018 – *Entoloma yanacolor*. Fungal Planet/Persoonia 40, 278–279.

Boddy L. 1984 – The micro-environment of basidiomycete mycelia in temperate deciduous woodlands. In: Jennings DH, Rayner ADR (eds.). The Ecology and Physiology of the Fungal Mycelium. Cambridge University Press, pp. 261–289.

Boddy L, Büntgen U, Egli S, Gange AC et al. 2014 – Climate variation effects on fungal fruiting. Fungal Ecology 10, 20–33.

Caicedo E, Barili A, Barnes CW, Ordoñez ME. 2018 – *Saproamanita quitensis*. Fungal Planet/Persoonia 40, 320–321.

Clarke KR, Gorley RN. 2006 – PRIMER v6: User Manual/Tutorial pp. 192. PRIMER-E Ltd, Plymouth.

Colwell RK. 2013 – EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. User's Guide and application published at: http://purl.oclc.org/estimates.

Corrales A, Mangan SA, Turner BL, Dalling JW. 2016 – An ectomycorrhizal nitrogen economy facilitates monodominance in a Neotropical forest. Ecology Letters 19, 383–392.

Dahlberg A, Jonsson L, Nylund JE. 1997 – Species diversity and distribution of biomass above and below ground among ectomycorrhizal fungi in an old-growth Norway spruce forest in south Sweden. Canadian Journal of Botany 75, 1323–1335.

Dickie IA, Reich PB. 2005 – Ectomycorrhizal fungal communities at forest edges. Journal of Ecology 93, 244–255.
Flores JA, Barnes CW, Ordoñez ME. 2018 – *Ganoderma chocoense*. Fungal Planet/Persoonia 41, 364–365.
Gamboa-Trujillo JP. 2005 – Diversidad y etnomicología de macromycetos, cuenca alta del Río Oglán, Pastaza-Ecuador. Cinchonia 6, 95–110.
Gamboa-Trujillo P, Wartchow F, Cerón-Martinez C, Andi D et al. 2019 – Edible mushrooms of Ecuador: consumption, myths and implications for conservation. Ethnobotany Research and Applications 18: 38.
Gange AC, Gange EG, Sparks TH, Boddy L. 2007 – Rapid and recent changes in fungal fruiting patterns. Science 316 (5821), 71.
Gates GM, Mohammed C, Wardlaw T, Ratkowsky DA, Davidson NJ. 2011 – The ecology and diversity of wood-inhabiting macrofungi in a native *Eucalyptus obliqua* forest of southern Tasmania, Australia. Fungal Ecology 4, 56–67.
Guevara MF, Salazar P, Mátyás B, Ordoñez ME. 2018 – Xylariales: first results of mycological exploration in the Sangay and Llanganates National Parks, Ecuador. F1000Research 7: 222 Last updated: 16 Jul 2018.
Haug I, Weiß M, Homeir J, Oberwinkler F, Kottke I. 2005 – Russulaceae and Thelephoraceae form ectomycorrhizas with members of the Nyctaginaceae (Caryophyllales) in the tropical mountain rain forest of southern Ecuador. New Phytologist 165, 923–936.
Hedger JN. 1985 – Tropical agarics: resource relations and fruiting periodicity. In: Moore D, Casselton LA; Wood DA, Frankland JC (eds). Developmental Biology of Higher Fungi. Cambridge University Press, pp. 42–86.
Heilmann-Clausen J, Christensen M. 2003 – Fungal diversity on decaying beech logs – implications for sustainable forestry. Biodiversity and Conservation 12, 953–973.
Heilmann-Clausen J, Christensen M. 2004 – Does size matter? On the importance of various dead wood fractions for fungal diversity in Danish beech forests. Forest Ecology and Management 201, 105–117.
Heilmann-Clausen J, Vesterholt J. 2008 – Conservation: selection criteria and approaches. In: Boddy L, Frankland JC, Van West P (eds.) Ecology of Saprotrophic Basidiomycetes. British Mycological Society Symposia Series. Academic Press, UK. Chapter 17, pp. 325–347.
Hering TF. 1982 – Decomposer activity of basidiomycetes in forest litter. In: Frankland JC, Hedger JN, Swift MJ (eds.) Decomposer Basidiomycetes: their biology and ecology. British Mycological Society Symposium 4, Cambridge University Press, pp. 213–225.
Høiland K, Bendiksen E. 1996 – Biodiversity of wood-inhabiting fungi in a boreal coniferous forest in Sør-Trøndelag County, Central Norway. Nordic Journal of Botany 16, 643–659.
Horton BM, Glen M, Davidson NJ, Ratkowsky DA et al. 2017 – An assessment of ectomycorrhizal fungal communities in Tasmanian temperate high-altitude *Eucalyptus delegatensis* reveals a dominance of the Cortinariaceae. Mycorrhiza 27, 67–74.
Huhndorf SM, Lodge DJ, Wang C-J, Stokland JN. 2004 – Macrofungi on woody substrata. In: Mueller GM, Bills GF, Foster MS (eds.) Biodiversity of Fungi: Inventory and Monitoring Methods. Elsevier Academic Press, Amsterdam, pp. 159–163.
Iršėnaitė R, Kutorga E. 2007 – Wood-inhabiting fungi on pedunculate oak coarse woody debris in relation to substratum quantity and forest age. Acta Mycologica 42, 169–178.
Kerekes J, Kaspari M, Stevenson B, Nilsson RH et al. 2013 – Nutrient enrichment increased species richness of leaf litter fungal assemblages in a tropical forest. Molecular Ecology 22, 2827–2838.
Læssøe T, Petersen JH. 2008 – Svampelivet på ækvator. Svampe 58, 1–52.
Lindblad I. 1998 – Wood-inhabiting fungi on fallen logs of Norway spruce: relations to forest management and substrate quality. Nordic Journal of Botany 18(2), 243–255.
Lodge DJ. 1996 – Two undescribed species related to *Mycena ixoxantha* in Ecuador. Mycologist 10(2), 56–57.

Lodge DJ, Cantrell S. 1995 – Diversity of litter agarics at Cuyabeno, Ecuador: calibrating sampling efforts in tropical rainforest. Mycologist 9(4), 149–151.

Lunt PH, Hedger JN. 1996 – A survey of mycorrhizal infection of trees in the *terra firme* rainforest, Cuyabeno, Ecuador. Mycologist 10(4), 161–165.

Maltz MR, Treseder KK, McGuire KL. 2017 – Links between plant and fungal diversity in habitat fragments of coastal shrubland. PLoS ONE 12(9): e0184991.

McGuire KL, Fierer N, Bateman C, Treseder KK, Turner BL. 2012 – Fungal community composition in neotropical rain forests: the influence of tree diversity and precipitation. Microbial Ecology 63, 804–812.

Newman D, Vandegrift R, Battallas R, Dentinger B et al. 2019 – Richer Than Gold: The Fungal Biodiversity of a Threatened Andean Cloud Forest Reserve. Mycological Society of America Annual Meeting, Minneapolis, MN, USA. Poster presentation.
Doi 10.13140/RG.2.2.256725.76001

Nordén B, Ryberg M, Götmark F, Olausson B. 2004 – Relative importance of coarse and fine woody debris for the biodiversity of wood-inhabiting fungi in temperate broadleaf forests. Biological Conservation 117, 1–10.

Piepenbring M. 2015 – Introducción a la Micología en los Trópicos. The American Phytopathological Society, St Paul, Minnesota, USA.

Reid DA, Pegler DN, Spooner BM. 1980 – An annotated list of the fungi of the Galapagos Islands. Kew Bulletin 35(4), 847–892.

Renvall P. 1995 – Community structure and dynamics of wood-rotting Basidiomycetes on decomposing conifer trunks in northern Finland. Karstenia 35, 1–51.

Schüßler A, Walker C. 2019 – *Archaeospora ecuadoriana* sp. nov. from a mountainous biodiversity hotspot area in Ecuador, and transfer of *Palaeospora spainiae* to *Archaeospora*, as *A. spainiae* comb. nov. Mycorrhiza 29(5), 435–443.

Singer R. 1975 – Interesting and new species of Basidiomycetes from Ecuador. Beihefte zur Nova Hedwigia 51, 239–246.

Singer R. 1978 – Interesting and new species of Basidiomycetes from Ecuador II. Nova Hedwigia 29, 1–98.

Singer R, Araujo I. 1979 – Litter decomposition and ectomycorrhiza in Amazonian forests. 1. A comparison of litter decomposing and ectomycorrhizal Basidiomycetes in latosol-terra-firme rain forest and white podzol campinarana. Acta Amazonica 9(1): 25–42.

Straatsma G, Ayer F, Egli S. 2001 – Species richness, abundance, and phenology of fungal fruit bodies over 21 years in a Swiss forest plot. Mycological Research 105(5), 515–523.

Suárez-Duque D. 2004. – Diversity and structural analysis of Aphyllophorales of the protected forest ‘Mindo Lindo’ Pichincha province, Ecuador. Lyonia 7, 83–89.

Thomas DC, Vandegrift R, Ludden A, Carroll GC, Roy BA. 2016 – Spatial ecology of the fungal genus *Xylaria* in a tropical cloud forest. Biotropica 48(3), 381–393.

Ullah MA, Camacho R, Evans CS, Hedger JN. 2002 – Production of ligninolytic enzymes by species assemblages of tropical higher fungi from Ecuador. In: Watling R, Frankland JC, Ainsworth AM, Isaac S, Robinson CH (eds.) Tropical Mycology: Volume 1, Macromycetes. CAB International 101–112.

Watling R. 1977 – An analysis of the taxonomic characters used in defining the species of the Bolbitiaceae. Bibliotheca Mycologica 61, 11–53.

Wu B, Hussain M, Zhang W, Stadler M et al. 2019. – Current insights into fungal species diversity and perspective on naming the environmental DNA sequences of fungi. Mycology. 10(3), 127–140.

Appendices

Appendix 1 List of species in the present study, and the sampling units and substrates in or on which they were found

Ascomycetes:
aff. *Cudoniella* 'small 3 mm diam. cream tacks, spores 7 x 2µm' = FH 167; Transect; litter
Ascomycete 'gelatinous greyish translucent discs ca. 2 mm diam.' = FH 77; Plot 1; litter & wood
Beauveria locustiphila = FH 89; Plots 2 & 3; insect
Cordyceps 'white branched on grasshopper' = FH 207; Plot 1; insect
Cordyceps pruinosa; Transect; insect
Gibellula 'spider pathogen'; Plot 2; spider
Hymenoscyphus 'tiny greyish stalked disc, spores 6 x 2.5µm' = FH 220; Plot 2; litter
Hypocrea aff. *gelatinosa* = 24 FH 2018; Plot 3; wood
Hysterographium sp., lichen = FH 206; Plot 2; litter
Phillipsia domingensis = FH 47; Transect; wood
Scutellinia scutellata = 96 FH 2018; Plot 1; litter
Xylaria 'slender black clubs to 12 mm tall, 6 mm at base, immature' = FH 170; Transect; wood
Xylaria aff. *filiformis* = FH 191; Plot 1; litter & wood
Xylaria aff. *griseo-olivacea* = FH 208; Plot 3; wood
Xylaria cubensis = 53 FH 2018; Plots 1 & 3 & Transect; wood
Xylaria hypoxylon; Transect; wood
Xylaria polymorpha; Plot 3; wood

Basidiomycetes:
Albomagister cf. *subaustralis* = FH 27; Transect; soil
Armillaria 'dark brown with darker centre, hygrophanous becoming yellow-brown, whitish gills, blackish stipe, spores 10 x 5µm' = 57 FH 2018; Plots 1 & 2 & Transect; wood
Auricularia delicata = 15 FH 2018; Plot 1 & Transect; wood
Auricularia fuscosuccinea; Plot 1 & Transect; wood
Auriscalpium cf. *villipes* = FH 100; Transect; wood
Cantharellus 'dry, white-cream concolorous, spores 7.5 x 7.5µm' = FH 69; Plot 3; soil
cf. *Cellypha* 'tiny, 2.5 mm diam., white with reduced gills, on twig' = FH 36; Transect; wood
Clavaria 'single slender white clubs, garlic odour, spores 7 x 7µm' = FH 169; Transect; soil
Clavaria 'white clubs, longitudinally grooved, spores 5 x 5µm, no odour' = FH 91; Plots 1 & 3; soil
Clavulina aff. *coralloides* = FH 119; Plot 3; soil
Clavulinopsis 'orange-yellow clubs to 47 mm tall, single or in groups, dry, spores 6 x 6µm' = FH 86; Plots 2 & 3; soil
Coprinellus disseminatus; Transect; wood
Coprinellus 'ochre cap, purplish spores 8 x 4µm with germ pore' = FH 164; Transect; wood
Coprinellus 'yellow cap, brown spores 5 x 3.5µm with germ pore' = FH 152; Plot 1; wood
Crepidotus 'white fan dorsally attached, spores 10 x 5µm, capitate cystidia' = FH 38; Plot 3; litter
Cuphophyllus pratensis = 7 FH 2018; Transect; soil
Cyathus striatus = FH 101; Plot 3; soil
Deconica 'brown, spores heart-shaped 6 x 4–4.5µm' = FH 151; Plot 2 & Transect; litter & soil
Deconica horizontalis; Plot 1 & Transect; litter & wood
Eichleriella/*Exidia* 'thin grey-brown resupinate jelly, longitudinally septate basidia, spores 15 x 5µm' = FH 162; Plots 1 & 2 & 3; litter

Entoloma ‘dark brown, deeply sulcate cap, dark grey-brown gills, finely squamulose brown stipe, spores 13 x 9µm, 6 angles’ = FH 128; Plot 2 & Transect; soil

Entoloma ‘grey cap and stipe, spores 10 x 7.5µm, spermatic odour’ = FH 116; Plot 2; soil

Entoloma ‘velutinous dark brown sulcate cap, pale grey-brown distant gills, grey-brown stipe, spores 6 angles 8 x 8µm, hymeniform pileipellis’ = FH 146; Plot 2; soil

Entoloma ‘white depressed cap, strong farinaceous odour, quadrate spores 10 x 10µm’ = FH 49; Transect; soil

Entoloma ‘yellowy brown cap, flesh pink gills, whitish stipe, awl-shaped cystidia, spores 5-angled tending to quadrate, 10 x 8µm’ = FH 41; Plot 3 & Transect; soil

Favolus ianthinus = FH 145; Plot 2; wood

Favolus tenuiculus; Plots 1 & 2 & Transect; wood

Filoboletus gracilis = 84 FH 2018; Plot 1 & Transect; wood

Flaviporus brownii = FH 110; Plot 3; wood

Galerina ‘orange-brown cap, pale brown cap and stipe, smooth spores 10 x 5µm’ = FH 132; Plot 1; soil

Galerina velutipes = 35 FH 2018; Plots 2 & 3; soil & wood

Gloeocantharellus ‘stout peglike, burnt-orange bruising brownish violet, whitish thick gills bruising violet-brown, mitre-shaped cystidia, spores with low warts 8 x 5µm’ = FH 159; Transect; soil

Gloiocephala ‘tiny 2–3 mm diam. white pileus ringed with hairs, no pores, no gills, spores 10 x 4µm, in troops’ = FH 133; Plots 1 & 3; litter

Hohenbuehelia ‘pale grey cap and gills, metuloids acuminate-lageniform, encrusted 52.5 x 22.5µm, spores 7.5 x 2.5µm’ = FH 64; Plot 1; litter

Hohenbuehelia ‘white fruitbody, metuloids with thickened walls, some crystals 75 x 17.5µm, broadly lageniform, spores 7.5 x 5µm’ = FH 67; Plot 3; litter & wood

Hohenbuehelia cf. *petaloides* ‘yellowy brown cap, greyish white gills, reduced stipe, no odour, metuloids ovoid-acuminate with encrusted apex 40 x 15µm, aculeate pileocystidia, spores 5 x 2.5–3µm’ = FH 81; Plot 3; litter & wood

Hohenbuehelia ‘lilac-grey fruitbody, spores 9 x 4µm, metuloids apically encrusted ice cream cones’ = FH 194; Plot 3; wood

Hydnopolyporus fimbriatus = 11 FH 2018; Transect; wood

Hydropus irroratus = FH 80; Plot 2; soil

Hygrocybe ‘dry orange-yellow cap, orange-yellow gills, stipe orange at apex, yellow at base, spores 10 x 7µm’ = FH 68; Plots 2 & 3; soil

Hygrocybe ‘dry, orange cap, orange decurrent gills, orange stipe spores 5 x 5µm’ = FH 180; Plot 2; soil

Hygrocybe ‘dry, red hygrophanous cap, golden yellow gills, golden yellow stipe, giant cystidia 75.5 x 17.5µm, spores 6 x 6µm’ = FH 113; Transect; soil

Hygrocybe ‘glutinous red cap, glutinous orange-yellow stipe, whitish gills, spores 8.7 x 5µm’ = FH 61; Plot 1 & Transect; soil

Hygrocybe ‘viscid pale orange cap to 8 mm diam., yellow decurrent gills, orange stipe, spores 7.5 x 5µm’ = FH 78; Plot 1; soil

Hygrocybe conica group = FH 168; Plot 2; soil

Hymenochaete ‘brown turning black in KOH, resupinate with setae, spores globose 5–6 x 5–6µm’ = FH 190; Plot 3; wood

Lentinus ciliatus (= *Panus ciliatus*); Plot 1 & Transect; wood

Lentinus crinitis = 19 FH 2018; Transect; wood

Lentinus tricholoma; Plot 1 & Transect; wood

Lepiota ‘golden brown woolly cap, white gills, golden brown stipe with some woolly scales, spores 10–12.5 x 3µm, trichoderm with clamps’ = FH 46; Plot 1; soil

Leucocoprinus ‘concolorous cream-yellow, torulose cheilocystidia 140 x 10µm, large spores

12.5 x 5µm' = FH 102; Plot 2; soil

Leucocoprinus 'greyish, brown at centre, just free pale brown lamellae, fragile whitish stipe, spores 7 x 6µm' = FH 224; Plot 1; wood

Leucocoprinus 'white with greyish flat scales, small basidia 12.5 x 5µm, spores 5 x 3.5µm' = FH 21; Transect; soil

Lycoperdon cf. *fuligineum* = 83 FH 2018; Plot 1; wood

Marasmiellus 'white cap with flush of pink-brown at centre, white gills, stipe pinkish at base, clavate cheilocystidia with excrescences, spores 10 x 6µm' = FH 157; Plots 1 & 2 & Transect; litter & wood

Marasmiellus 'white cap, two-tone stipe, giant narrowly lageniform cystidia 110 x 10µm, spores 22.5 x 5µm' = FH 37; Transect; litter

Marasmius 'creamy white sulcate cap, distant white gills forming a collarium, hairlike, brown stipe, sphaeropedunculate cystidia with excrescences, pip-shaped spores 6 x 4µm' = FH 75; Plots 1 & 2; litter

Marasmius 'distant gills with collarium, lacrymoid spores 7 x 4µm' = FH 153; Plot 1; litter

Marasmius 'grey-brown, velvety cap, distant gills forming a collarium, blackish hair-like stipe, spores 9 x 4µm' = FH 165; Plot 2; litter

Marasmius 'velutinous blackish brown cap, off-white crowded gills, wiry blackish brown stipe, no spores observed' = FH 131; Plot 2; litter

Marasmius aff. *crinis-equi* = FH 103; Plots 1 & 2; litter

Marasmius haematocephalus group = FH 15; Plots 2 & 3 & Transect; litter

Marasmius 'velutinous ochre orange cap, whitish orange gills, tough 2-tone stipe whitish at apex, brown at base, odour of wet dog, spores 13 x 4µm, broom cells in the pileipellis' = FH 143; Plots 2 & 3 & Transect; litter & soil

Mycena 'conico-convex with obtuse apex ochre cap, whitish gills, translucent white stipe, on wood, hyphal endings hastate in pileipellis, long basidia 50 x 7.5µm, spores 7.5 x 5µm' = FH 79; Plot 1; wood

Mycena 'golden yellow deeply sulcate cap, distant arcuate decurrent gills with brown margin, threadlike stipe, spores 8 x 4µm, cylindro-ventricose cheilocystidia with apical strangulation' = FH 213; Plot 2; litter

Mycena 'grey-brown cap 2 mm diam., with lageniform-acuminate cheilocystidia, with neck bisectioned to swollen base 17 x 6µm, spores 7.5 x 5µm' = FH 198; Plot 2; litter

Mycena 'grey-pink cap, with close narrow grey-pink decurrent gills, grey-pink stipe, broadly cylindro-clavate cheilocystidia, spores 6.3 x 3.8µm' = FH 39; Plot 3 & Transect; soil

Mycena 'pale yellow cap, distant fimbriate gills, white tough hairy stipe, narrowly clavate long spiny cheilocystidia 90 x 5µm and similar caulocystida' = FH 181; Plot 2; litter

Mycena 'pale yellow cap, thread-like stipe, spores 7 x 4µm, globose hyphae with excrescences' = FH 214; Plot 1; litter

Mycena 'pallid orange-yellow cap 2.5 mm diam., decurrent pallid orange-yellow subdistant gills, fragile pallid orange-yellow stipe, spores 7 x 3µm' = FH 202; Plot 2; litter

Mycena 'pinkish brown cap, pinkish brown intervenose gills, tough bright yellow stipe, spores 6.3 x 3.8µm, some apically forked ventricose-lageniform cheilocystidia' = 75 FH 2018; Plots 1 & 2 & 3; soil

Mycena 'small brownish pink cap, brownish pink gills, stipe with pale pink mycelium at base, broadly clavate spiny cheilocystidia, spores 7 x 4µm' = FH 70; Plot 3; litter

Mycena 'small grey-brown, very decurrent arcuate greyish white gills, whitish stipe, spores 7.5 x 3.75µm'= FH 73; Transect; litter

Mycena 'tiny white cap, distant white gills, white thread-like stipe, spiny clavate cheilocystidia, elongated lacrymoid spores 10 x 3µm' = FH 138; Plot 1; litter & wood

Mycena 'white cap 2.5 mm diam. distant white gills, white threadlike stipe, fusiform spores 8–10 x 4–4.5µm, narrow spiny clavate cheilocystidia with a heel' = FH 163; Plot 3; litter

Mycena 'white cap, distant white gills, pinkish stipe, spores 7 x 5µm, cystidia with finger-like

projections' = FH 205; Plot 2; wood

Mycena 'white, no gills, small stipe, spores 8 x 2.5–3µm, cheilocystidia narrowly lageniform with moniliform apex' = FH 155; Plot 1; litter

Mycena 'white, thread-like stipe, spores 7 x 4µm, spiny spherical hyphae' aff. FH 214; Plots 1 & 2; litter

Mycena 'yellowish with thread-like stipe, torulose or misshapen fusoid cheilocystidia, spores 9 x 5µm' = FH 209; Plot 2; litter

Mycena cf. *pura* 'pink-brown, distant vinaceous brown gills, vinaceous brown stipe yellowing at base, radish odour and taste, spores 7.5 x 5µm, on soil' = FH 40; Plots 1 & 3; litter & soil

Mycena spinosissima (= *Amparoina spinosissima*), white with granules = 74 FH 2018; Transect; litter

Mycena 'white club-shaped spiny cheilocystidia, spores 7 x 3µm'; Plot 2; litter

Mycena/*Hemimycena* 'creamy cap with subdecurrent yellowish gills drying deep yellow, raphanoid odour and taste and bitter, spores 5 x 2.5–3µm' = FH 48; Transect; soil

Mycena/*Hemimycena* 'small 3 mm diam., distant white decurrent gills, slender white stipe' = FH 76; Plot 1; litter

Mycena/*Marasmiellus* 'white fruitbody, spiny clavate cheilocystidia, spores 8 x 5µm' = FH 158; Plots 1 & 2; litter & wood

Neohygrocybe 'blackish grey-brown cap, ivory gills becoming blackish grey, greyish brown felty stipe, farinaceous odour, spores 4 x 4µm' = FH 149; Transect; soil

Oudemansiella canarii = FH 148; Plots 1 & 2 & 3 & Transect; wood

Phanerochaete 'bright yellow with yellow subiculum spores 4 x 3µm' = FH 185; Plot 3; wood

Pholiota 'viscid ochre with orange red centre cap and superficial scales, yellow-brown gills, stipe viscid yellow-brown, cheilocystidia clavate with projecting obtuse apex, spores 12.5 x 7.5µm' = FH 87; Transect; wood

Pleurotus cf. *djamor* 'white fan, crowded white gills, stipe much reduced, spores 7 x 4µm, clamps, thickened generative hyphae, no odour' = FH 58; Plots 1 & 2; wood

Pluteus 'brown velutinous cap, brownish pink free gills, translucent white stipe, bent utriform cheilocystidia, spores 5 x 4–5µm' = FH 130; Transect; wood

polypore 'cream, small, friable' = FH 161; Plot 2; litter

polypore 'with coffee hymenium' = FH 111; Plot 3; wood

polypore 'with subiculum' = FH 112; Plot 3, wood

Polyporus 'very thin-fleshed brown at centre becoming greyish cream, tough blackish dark brown velutinous stipe, very fine pores, binding and generative hyphae' = FH 211; Transect; wood

Polyporus dictyopus; Plots 1 & 3; wood

Poromycena 'small greyish brown caps to 12 mm diam. off white gills bifurcate and intervenose to almost poroid, stipe whitish at apex, reddish brown at base, narrowly fusiform cystidia 22.5 x 7.5–8µm, spores 3 x 2.5µm' = FH 42; Transect; wood

Psathyrella 'hygrophanous pinkish brown cap, dark brown gills, whitish slender, stipe to 1.5 mm wide with a sheen, spores 8 x 4.5µm, utriform cheilocystidia 23 x 11µm'= FH 199; Plot 3; soil

Psathyrella 'stoutish medium brown cap to 30 mm diam., dark grey-brown gills with whitish fimbriate margins, white stipe with a white annulus spores 10 x 5–6µm, cheilocystidia ventricose-fusiform 75 x 15µm' = FH 114; Transect; wood

Psathyrella 'pequenita, small grey-brown fruitbodies to 11 mm diam., spores 6.5 x 6µm, sphaeropedunculate cheilocystidia 20 x 12.5µm' = 15 FH 2018; Transect; wood

Pterula 'cream, to 15 mm tall, very finely branched, with hint of a stipe' = 3 FH 2018; Plots 1 & 2 & Transect; soil

Rhizochaete filamentosa = FH 223; Plot 3; wood

Rigidoporus microporus; Plot 3; wood

Schizopora 'pale ochre resupinate, poroid with very thin dissepiments, spores 4 x 3µm' = FH 104; Plot 3; wood

Stereopsis aff. *hiscens* = 72 FH 2018; Plot 3, Transect; soil
Tetrapyrgos nigripes = FH 124; Transect; litter
Tricholomataceae 'ca. 3 mm diam., concolorous orange, very stumpy basidia 15 x 8µm, spores 9–10 x 5µm, ventricose-fusiform cheilocystidia' = FH 192; Plot 2; litter
Tricholomataceae 'small brown cap 5 mm diam., greyish gills, white stipe, spores 6 x 5µm' = FH 184; Plot 1; litter
Tricholomataceae 'cap whitish to 1 mm across with 10 mm stipe, spores 3 x 2µm, cheilocystidia broadly utriform' = FH 182; Plot 3; litter
Tricholomopsis aurea = FH 53; Plot 2, Transect; wood

Appendix 2 Other species found outside the present study, including records from 2018.

Other species from 2018 not found in 2019

Agaricus aff. *rufoaurantiacus*
Beauveria diapheromeriphila
Conocybe 'delicate; small stature, spores 10 x 5µm' = 55 FH 2018
Coprinopsis sp.
Entoloma 'ochre cap, bone stipe' = 41 FH 2018
Entoloma 'pale biscuit' = 58 FH 2018
Entoloma 'pale yellow' = 63 FH 2018
Entoloma 'silky hygrophanous' = 46 FH 2018
Entoloma 'steely blue' = 44 FH 2018
Entoloma 'stripy black' = 42 FH 2018
Entoloma aff. *asprellopsis* = 43 FH 2018
Entoloma dragonospora group 'spores 20 x 20µm' = 89 FH 2018
Entoloma sect. *Entoloma* 'grey-pink with ixocutis, isodiametric spores 6 x 6µm' = 85 FH 2018
Entoloma sect. *Inocephalus* 'with giant cystidia' = 92 FH 2018
Entoloma sect. *Pouzarella* = 65 FH 2018
Gymnopilus aff. *junonius*
Helicogloea aff. *lagerheimii* = 34 FH 2018
Hohenbuehelia petaloides = 14 FH 2018
Hygrocybe (aka *Gliophorus*) 'bruising green and black' = 100 FH 2018
Hygrocybe (aka *Gliophorus*) 'pale orange, lubricous cap and stipe, decurrent gills spores ca. 7.5 x 6µm, pustulate' = 54 FH 2018
Hygrocybe (aka *Gliophorus*) 'pink cap, gills and stipe, spores globose, ca. 7.5–8µm'= 73 FH 2018
Hygrocybe (aka *Gliophorus*) green = 25 FH 2018
Leucoagaricus cf. *bivelatus*
Leucocoprinus 'white with brown lubricous centre disc' = 51 FH 2018
Leucocoprinus 'with large spores 12.5 x 7.5µm' = 47 FH 2018
Marasmius 'greyish vinaceous' = 45 FH 2018
Marasmius cladophyllus = 4 FH 2018
Mycena/*Marasmius* 'very large pink, spores 22 x 4.5µm' = 93 FH 2018
Mycena sect *Caodentes* 'pale pink, on wood, distant gills'
Parasola 'pink'
Peniophora 'purplish brown' = 18 FH 2018
Scytinopogon 'soft, white' = 87 FH 2018
Tremellodendropsis tuberosa = 95 FH 2018

Species found in 2019 outside of the plots or transect

Acervus epispartius

aff. *Leotiomyces* = FH 134
aff. *Mycena* ‘orange with decurrent gills, globose spores 5 x 5µm’ = FH 180
aff. Stereaceae ‘pinkish brown, petaloid’ = FH 105
aff. Tricholomataceae ‘ochre fans, very bitter taste’ = FH 121
aff. Tricholomataceae ‘small, white-spored, petaloid, decurrent gills, no stipe’ = FH 82
aff. Tricholomataceae ‘tiny, ochre, hymeniform pileipellis’ = FH 212
aff. Tricholomataceae ‘velutinous brown on soil, trichoderm, globose spores 7 x 7µm, digitate cheilocystidia’ = FH 222
aff. *Trogia* ‘pale yellow on soil’ = FH 175
Albomagister subaustralis = FH 27
Amauroderma/*Humphreya* cf. *coffeata* = FH 43a
Arrhenia ‘greyish white’ = FH 166
Ascocoryne ‘pale pink’ = FH 8a
Asterostroma cf. *andinum* = FH 90
Auricularia mesenterica = FH 11
Auriscalpium cf. *villipes* = FH 29
Clavaria cf. *schaefferi* = FH 63
Clitocybula azurea = FH 122
Conocybe apala = FH 188
Dacrymyces san-augustinii = FH 32
Dacryopinax cf. *spathularia* = FH 21
Deconica ‘dark brown cap and stipe, spores 7.5 x 3.8µm’ = FH 28
Dictyopanus pusillus = FH 176
Discina sp. = FH 83
Entoloma ‘beige centrally depressed sulcate cap, spores 10 x 7.5µm’ = FH 51
Entoloma ‘black scaly, isodiametric spores 10 x 10µm, trichoderm with pileocystida, radish odour’ = FH 215
Entoloma ‘brown umbonate, isodiametric spores 8 x 8µm’ = FH 201
Entoloma ‘champagne blonde large heterodiametric spores 11–12 x 7.5µm’ = FH 1
Entoloma ‘grey cap, blue-grey stipe, 7–8 angled large spores 10–12 x 7–8µm, spermatic odour, cylindroclavate cheilocystidia’ = FH 57
Entoloma subg. *Entoloma* ‘viscid grey-violet-brown cap, 6 angled isodiametric spores 7–7.5 x 7–7.5µm’ = FH 18
Entoloma ‘ochre cap, golden brown thin stipe, spores 10 x 7.5µm’ = FH 16
Entoloma ‘ochre cap, pale translucent brown stipe, sub-isodiametric spores 7.75 x 7.5µm, narrow cylindro-clavate cystidia’ = FH 57a
Entoloma ‘brown umbonate cap, whitish stipe, spores cruciform 10 x 10µm, awl-shaped cheilocystidia’ = FH 19
Favolaschia ‘white’ = FH 147
Galerina ‘depressed cap, on soil’ = FH 120
Ganoderma applanatum = 33 FH 2018
Geastrum aff. *schweinitzii* = FH 187
Gymnopus ‘brown with smooth orange-yellow stipe’ = FH 196
Gymnopus ‘pinkish brown with velutinous brown stipe’ = FH 62
Hohenbuehelia ‘black’ = FH 92
Hohenbuehelia ‘white, encrusted metuloids, spores 8 x 7µm’ = FH 136
Hydropus sp. = FH 183
Hygrocybe (aka *Cuphophyllus’* ‘olive with grey gills’ = FH 4
Hygrocybe (aka *Gliophorus*) ‘red cap, orange-yellow stipe’ = FH 61
Hygrocybe (aka *Gliophorus*) ‘violet and grey-green’ = FH 141
Hygrocybe ‘blackish brown over orange red, orange gills’ = FH 179
Hygrocybe ‘dark reddish brown, with a trichoderm’ = FH 115

Hygrocybe ‘deep golden yellow’ = FH 95
Hygrocybe ‘dry, orange, yellow at base of stipe’ = FH 68
Hygrocybe ‘greyish red, ruby gills, very large sphaeropedunculate cheilocystidia 70 x 30µm, spores ca. 7 x 4µm’ = 59 FH 2018
Hygrocybe ‘green’ = FH 72
Hygrocybe ‘large dark red with very large basidia (52.5µm long), spores 12.5 x 7.5µm’ = FH 84
Hygrocybe ‘orange-red, bisporic’ = FH 26
Hygrocybe ‘orange-yellow with an ixocutis, spores 10 x 6–7µm’ = FH 118
Hygrocybe ‘pale lemon yellow’ = FH 94
Hygrocybe mirabilis nom. prov. ‘large, whitish with bright red distant gills’ = FH 85
Hymenochaetaceae ‘polypore thin, dark brown’ = FH 10
Lactocollybia cf. *albida* = FH 50
Lentinus concavus
Leucocoprinus ‘pink gills, bruising black’ = FH 8
Leucopaxillus gracillimus = FH 24
Lyophyllum ‘blackish brown, narrow crowded gills’ = FH 135
Marasmiellus ‘terracotta’ = FH 34
Marasmiellus ‘pale brown, tough reddish brown stipe’ = FH 210
Marasmius cf. *crinis-equi* = 28 FH 2018
Moniliophthora perniciosa = FH 6
Morganella/*Lycoperdon* ‘greyish cream, spores 4 x 4µm’ = FH 125
Multiclavula vernalis
Mycena ‘grey-brown with hastate cystidia’ = FH 74
Mycena ‘grey-brown’ = FH 33
Mycena ‘pink-brown, radish odour and taste, distant gills’ = FH 40
Mycena ‘whitish with bleach odour, orangy towards base of stipe’ = FH 60
Mycena aff. *chloroxantha* = FH 139
Mycena sect. Saccheriferae ‘grey-brown’ = FH 196
Neofavolus cf. *alveolaris* = FH 59
Neohygrocybe ‘dark brown’ = FH 45
Panus cf. *lecomtei* = FH 109
Penicilliopsis sp. = FH 173
Phaeoclavulina sp. = 30 FH 2018
Pleurotus cf. *djamor* = FH 7
Pluteus ‘large stature with large utriform cystidia 67.5 x 27.5µm, large sphaeropedunculate cystidia 70 x 52.5µm, spores 6.3 x 6.3µm’ = FH 44
Pluteus cf. *cervinus* = FH 22
Pluteus ‘small stature, digitate cheilocystidia, globose spores ca. 7 x 7µm, trichoderm of utriform pileocystidia’ = FH 222
Polyporus ‘thin-fleshed, very fine pores’ = FH 211
Polyporus ‘brown velvety cap, pore surface bruising brown, on very rotten wood’
Psathyrella ‘farinaceous odour’ = FH 129
Psilocybe caerulescens = FH 20
Pulvinula ‘brown-yellow smooth cushions on soil’ = FH 144
Pycnoporus sanguineus = 21 FH 2018
Rhizochaete brunnea = FH 2
Rigidoporus cf. *microporus* = FH 216
Ripartiella brasilensis = FH 9
Russula ‘pure white, spores 7.5 x7.5µm’ = FH 13
Schizophyllum commune
Stereum aff. *hirsutum* = FH 171
Sulzbacheromyces aff. *caatingae*

Thuemenella aff. *cubispora* = FH 195
Trametes elegans = 17 FH 2018
Xylariaceae ‘small black turbinate balls’ = 16 FH 2018