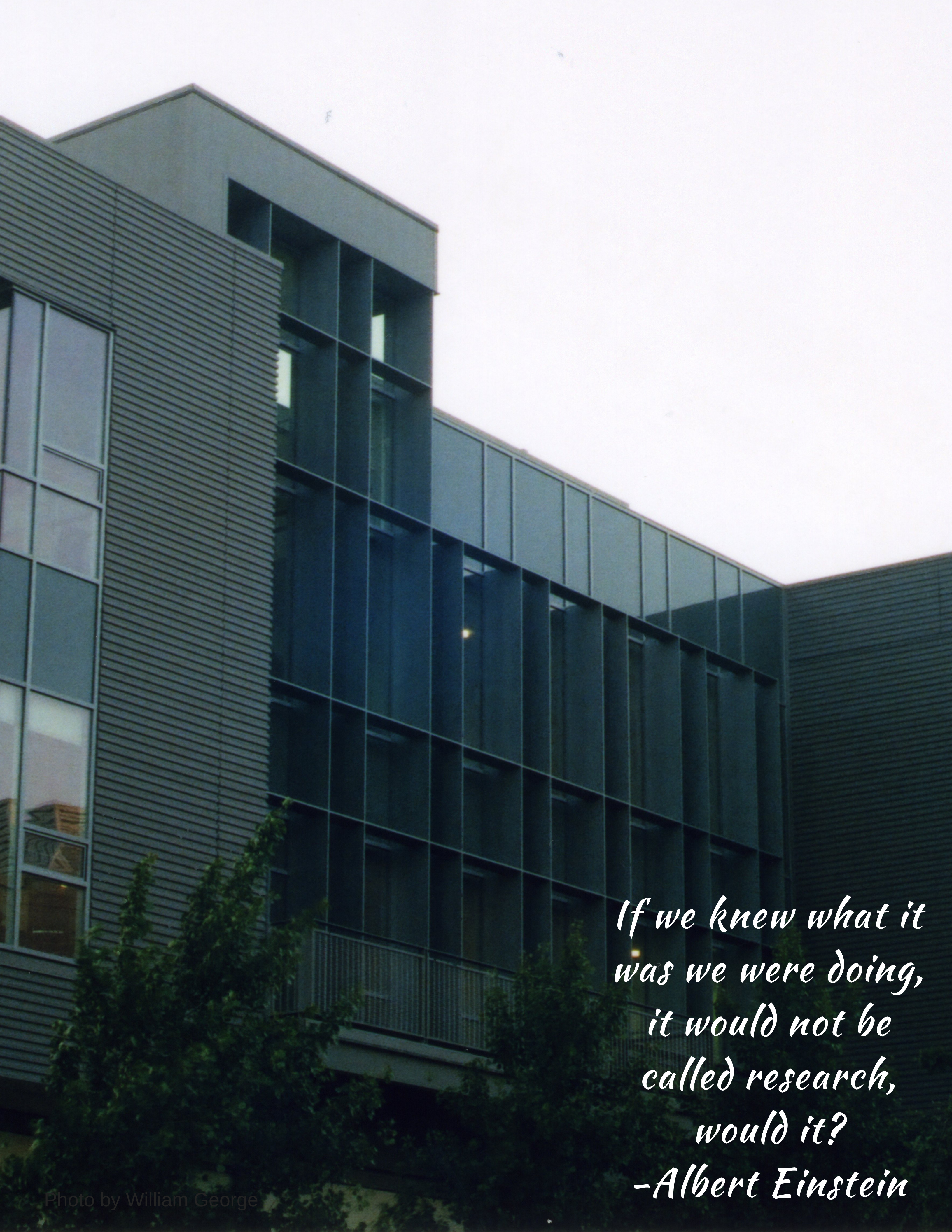
If we knew what it
was we were doing,
it would not be
called research,
would it?
-Albert Einstein
Photo by William George

Species Abundance of Fungi is Greater in Landslide Areas Compared to Undisturbed Areas of the Forest in Monteverde, Puntarenas, Costa Rica

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Costa Rica, Fungi, Forests, Ecosystems

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Abstract

Fungi plays an important role in the ecosystem by decomposing dead plants, and other organic matter. Without this process, there would be an accumulation of organic material in the forest which would go un-decomposed. Fungi, which are saprotrophic macrofungi from the phyla Basidioycota and Ascomycota, have the vital job of recycling nutrients from dead plant material in the forest back into the soil. The abundance of organic material created by the landslides on the reserve behind Estación Biológica in Monteverde, Puntarenas, Costa Rica may have given rise to nearly twice the amount of different species of fungi (31) compared to those alongside undisturbed trails (18) where there was not an abundance of organic material. I found more basidiomycetes compared to ascomycetes in both trails. Some types of fungi require a succession of decomposition to take place before establishing mycelium, whereas I found others which were substrate specific. Species of fungi which were very common were *Agaricales sensu lato*, *Coprinellus disseminatus*, and *Scutellinia scutellata*. Other species were substrate specific, such as the red mushrooms of *Hygrocybe coccinea*.

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Abundancia de Especies de Hongos es Mayor en áreas de Deslizamiento en Comparación con áreas No Perturbadas del Bosque en Monteverde, Puntarenas, Costa Rica

Resumen

Los hongos desempeñan un papel importante en el medio ambiente al descomponer materia orgánica. Sin este proceso, habría una acumulación de material orgánico en el bosque ya que no se descompondría. Los hongos saprótrofos de Basidioycota y Ascomycota tienen el vital trabajo de reciclar los nutrientes de la materia orgánica de vuelta al suelo. La abundancia de material orgánico creado por los deslizamientos de tierra en la reserva detrás de Estación Biológica en Monteverde, Puntarenas, Costa Rica puede ser la responsable de que encontrara casi el doble de la cantidad de diferentes especies de hongos (31) en comparación con junto a senderos inalterados (18) donde no había una abundancia de material orgánico. Encontré más basidiomicetes que ascomicetes en ambos senderos. Algunos tipos de hongos requieren que ocurra una sucesión de descomposición antes de establecer el micelio, mientras otros que se encontraron fueron específicos del sustrato. Las especies de hongos más comunes fueron *Agaricales sensu lato*, *Coprinellus disseminatus* y *Scutellinia scutellata*. Otras especies fueron específicas del sustrato, como las setas rojas de *Hygrocybe coccinea*.

Fungi is a complex and diverse kingdom; it contains nine subkingdoms. Within one of the kingdoms Dikarya, there are two Phylum which can be commonly seen in the field, and they include the macrofungi of Basidiomycota and Ascomycota (Mata et al. 2003). Basidiomycota and Ascomycota make up approximately 98% of all know fungi (Stajich et al. 2009). Ascomycetes make up more than half of the individuals in Dikarya, and have an important role in nature as they act as saprobes, parasites, and mutualists (Stajich et al. 2009). Basidiomycetes contain three subphyla which include Pucciniomycotina, Ustilaginomycotino, and Agaricomycotina. Basidiomycetes appear in nature as plant parasites and mushrooms (Stajich et al. 2009).

Fluctuations in weather and abundance of organic material can directly affect the population and overall species richness of fungi in a specific area (Lodge and Cantrell 1995). Landslides throughout some of Costa Rica's forest as a result of Tropical Storm Nate created piles of debris in the form of tree trunks and dead plant material. The areas in the forest where the landslides took place may have provided plenty of organic material for saprotrophic fungi to thrive. Studies have found that areas of the forest which have been destroyed by clear-cutting for harvesting wood from the United States, and Australia resulted in a different fungal community to grow in the clear cut areas, compared to the fungi which can be found in unaffected areas of the forest (Jones et al. 2003). Saprotrophic macrofungi have the important job of breaking down dead plant material in the forest, and by doing so they recycle nutrients back into the soil (Mata et al. 2003). Saprotrophic macrofungi is the most noticeable of fungi due to the visible sporocarps (Mata et al. 2003). Examples include *Dictyopanus pusillus* , *Phyllipsia domingenesi*s, and *Polyporus phillipenesis* (Mata et al. 2003). My observations in the forest behind the Estación

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Biológica in Monteverde led me to ask the question, what is the difference in species richness of fungi found in areas of the forest affected by landslides, versus areas in the forest which were unaffected by landslides after a storm?

Materials and Methods

I laid out my quadrats behind the Estación Biológica in Monteverde, Puntarenas, Costa Rica where there are several trails. Quadrats are essentially areas which have been chosen at random, and measured for a certain length to analyze the distribution of a specific species within that area. I laid out a total of 24 quadrats between three areas: the Machina river where debris collected from the storm, the trail Cariblancos which was affected by landslides, and the trail El Jiguero which was unaffected by landslides. There were a total of 3 quadrats beside the Machina river. There were 3 parts along both trails which contained a total of 21, 5 x 5 meter quadrats. There were 9 quadrats which took place along the Cariblancos trail, and 12 quadrats along the El Jiguero trail. Each quadrat was created by using a transect tape to measure them out beside the trail, and the edges were marked with red flags. For the Cariblancos trail, I created 2 quadrats on each side of a landslide where there was an accumulation of debris on both the right and left side of the trail. As for the El Jiguero trail, there were 2 quadrats placed to the left of the trail and 2 more to the right of the trail, a total of 4 quadrats for each part. I stepped in each quadrat and searched for mushrooms sprouting from leaf litter, soil, and other organic matter. I identified macrofungi by taking photos in situ using a digital camera then analyzed them on a laptop. Resources I used to identify fungi included field books such as Macrofungi de Costa Rica Volume 1 and 2 by Milagro Mata, and mushroomobserver.org. I also uploaded my photos on mushroomobserver.org to have them identified by a community of mycologists. I kept a species list of all the fungi I found at the different sites. I also made note of whether the species of fungi were from the phyla Basidiomycota or Ascomycota.

Fungi found in the field can be found in mushroomobserver.org under the username slopezucm, and a booklet of pictures of different species can be located in the library of the Estación Biológica in Monteverde.

Results

Altogether, I was able to identify 38 different species of fungi in the Cariblancas and El Jiguero trails. I listed them in order of the most commonly found species to the least common (Table 1). In the same table, I included the 24 different genera in order of the most to the least common. In total, there was 64 different species and morphospecies found across 24 quadrats for both the Cariblancas and El Jiguero trail. It is possible that the accumulation of organic material created by the landslides on the reserve behind Estación Biológica gave rise to nearly twice the amount of different species of fungi (population number for species=31) compared to those found in the undisturbed El Jiguero trail (n=18). There were significantly more fungi found in the landslide quadrats ($\bar{x}$=8, SD=1.94) than the undisturbed trail quadrats ($\bar{x}$=5, SD=2.23) (Figure 1, $t(22)= 3.37$, $p= 0.0006$). The amount of new species found in each quadrat is illustrated by an upward trend (Figure 2). The amount of species found in the landslide quadrats of the Cariblancas trail (from 12 to 49) increased at a faster rate between quadrats than those in the undisturbed El Jiguero trail (from 5 to 30). Overall, I found more basidiomycetes (n=30) in the quadrats of both trails, in comparison to ascomycetes (n=8) (Figure 3). The most commonly found species of mushrooms were *Agaricales sensu lato*, *Coprinellus disseminatus*, and *Seutellinia scutellata*. Among the least commonly found mushrooms were *Cyathus striatus*,

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Ophiocordyceps sphecocephala, and *Cookeina speciosa.* Pictures of the mentioned species can be found in the Appendix.

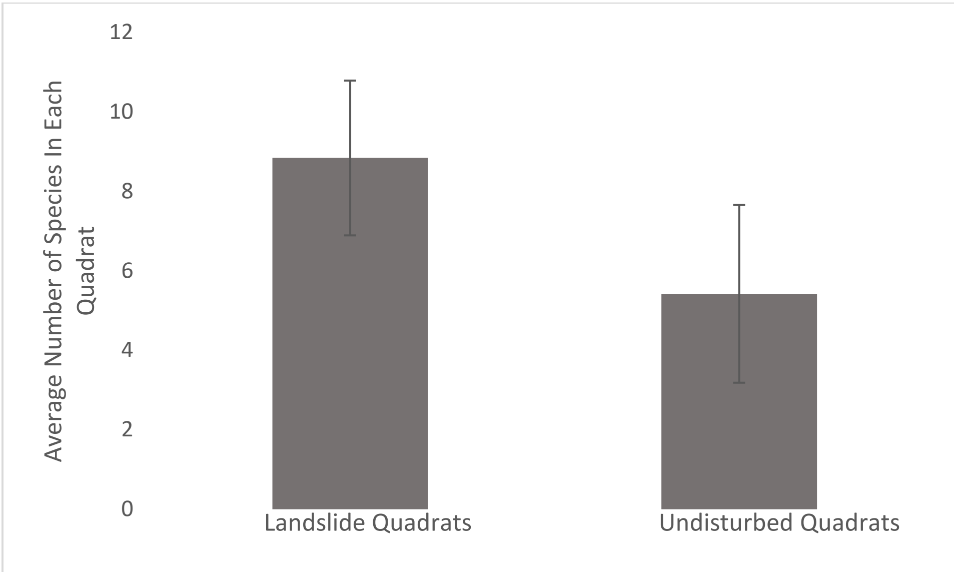

Figure 1. Number of species found in the landslide quadrats of the Cariblancas trail, and the undisturbed quadrats of the El Jiguero trail. t(22)= 3.37, p= 0.0006

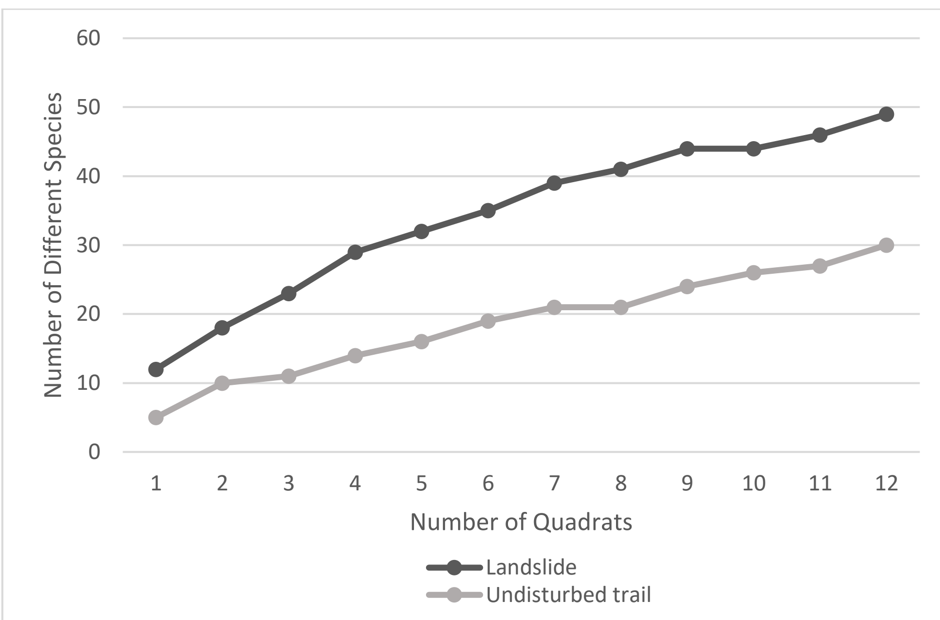

Figure 2. Number of species found in the landslide quadrats of the Cariblancas trail, and the undisturbed quadrats of the El Jiguero trail

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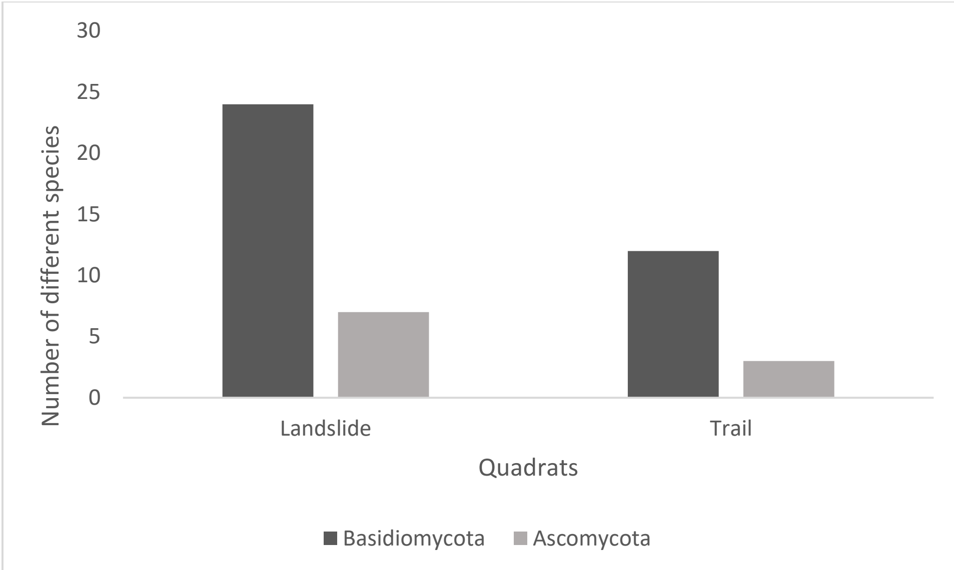

Figure 3. Number of basidiomycetes and ascomycetes found in both the landslide and undisturbed trail sites.

Table 1. Species found in the landslide and trail sites. Genera which did not have the species identified, and were found in the landslide and trail quadrats are also included in this table.

Species	Landslide (out of 12 quadrats)	Trail (out of 12 quadrats)
Agaricales sensu lato	8	5
Coprinellus disseminatus	8	4
Scutellinia scutellata	7	3
Marasmiaceae sensu lato	4	5
Bactridium flavuum	4	2
Xylaria hypoxylon	4	1
Flavellophora parva	1	4
Coprinus comatus	3	0
Xylaria polymorpha	2	1
Mycena reussell	2	1
Poria sensu lato	2	1
Pleurotus sensu lato	2	1
Tubifera ferruginosa	2	0
Auricularia nigrican	2	0
Polyporus tricholoma	0	2
Hygrocybe coccinea	0	2
Cookeina tricholoma	2	0
Panus neostrigus	0	2
Xylaria comosa	2	0
Cookeina speciosa	1	0

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University of California, Merced

Agaricomycetes doweld	1	0
Calistosporum luteo-olivacoum	1	0
Coprinellus comatus	1	0
Sphaerobolus stellatus	1	0
Mycena speira	0	1
Ophiocordyceps sphercocephala	0	1
Mycena chloroxantha	0	1
Clavaria clavalinopsis	1	0
Deflexula flascicularis	1	0
Polyporales sensu lato	1	0
Chlorociboria aeruginascens	0	1
Cyathus striatus	2	0
Dictyopanus pusillus	1	0
Phillipsia domingenesis	1	0
Auricularia nigrican	1	0
Tremella foliacea	1	0
Peziza hemisphoerica	1	0
Schizopora flavipora	1	0
Mycena sp.	6	5
Marasmius sp.	6	3
Clavaria sp.	2	1
Crepidotus sp.	1	2
Bactridium sp.	2	1
Ganoderma sp.	2	0
Discomycetes sp.	1	1
Trichoderma sp.	1	1
Scleroderma sp.	1	1
Coprinus sp.	1	0
Tubifera sp.	1	0
Gliophorus sp.	1	0
Entoloma sp.	1	0
Flabellophora sp.	1	0
Pseudohydmum sp.	1	0
Dictyonema sp.	1	0
Xylaria sp.	0	1
Pezizales sp.	1	0
Isaria sp.	0	1
Discomycetes sp.	0	1
Lactarius sp.	0	1
Heterobasidiomycetes sp.	0	1

Cookeina sp.	1	0
Leucoagaricus sp.	0	1

Discussion

The species richness of fungi in the landslide quadrats of the Cariblancas trail was greater than the species richness of the unaffected quadrats in the El Jiguero trail. This may be due to the difference in the amount of decaying plant matter, specificity of substrate per species, and the succession of fungi between the two trails. In a study which looked at the microfungi of Costa Rica, researchers found varying species composition between four sites in the Osa Peninsula and stated that vegetation under the canopy of the sites impacted the amount of microfungi found (Bills and Polishook 1994). Also, there was a difference in the amount of microfungi found in the samples taken from four levels of substrata in the forest floor since each strata contained organic matter in a different stage of decomposition (Bills and Polishook 1994). Both trails in my study were in the same forest behind the Estación Biológica, but the forest floor of the two trails were very different. The landslide quadrats had an abundance of recently fallen trees and dead plants in them. The quadrats beside the undisturbed trail did not have many fallen trees, but there were a few nurse logs.

When there is an increase in the amount of decaying plant material, it is more likely that the species richness of fungi will be greater (Chaverri and Vílchez 2006). This was especially evident when researchers looked at the species diversity of hypercrealean fungi in forests that were 1-2 years old compared to forests that were 25-27 years old (Chaverri and Vílchez 2006). The younger forests had more decaying plant material, so the diversity was greater than that in the old growth forest (Chaverri and Vílchez 2006). Since Tropical Storm Nate took place in

October, and my study took place in November, much of the organic matter in the landslide site was relatively newly fallen plant material, whereas in the undisturbed trails there was an abundance of organic matter which had decomposed for a longer period of time. Some fungi such as *Lepiota sp.*, can only grow on the leaf litter previously decomposed by *Marasmius sp* ,(Mueller 2011). This makes it unlikely that such species (which require plant matter in the later stages of decomposition) would be found in newly disturbed landslide quadrats.

The most abundant species in the landslide quadrats were the basidiomycetes *Agaricales sensu lato*, *Coprinellus disseminatus*, and an ascomycete *Scutellinia scutellata*. Although climate variability can impact fungal ecology both directly and indirectly, (Andrew et al. 2016), the occurrence of the tropical storm did not inhibit the growth of some of the forests' most important decomposers. Without fungi decomposing dead plant matter, and other organic matter in the forest there would be an accumulation of branches, leaf litter, and tree trunks which would go un-decomposed (Mata et al. 2003). When the fungus is found growing on substrate such as dead leaves, wood, and/or animal feces then it is saprotrophic (Alexopoulos et al. 1996). Basidiomycetes are common saprotrophic fungi found in the forest, and greatly depend on the accumulation of organic matter such as decaying wood to get their nutrients (Stephenson 2010). In a study done on basidiomycetes in Sweden, researchers found that the increase in logging in a boreal forest decreased the amount of decaying wood on the forest floor, and thus also decreased the total species number of basidiomycetes (Stephenson 2010). There were more fallen trees and dead plants in the landslide quadrats which may have allowed fungi such as *Agaricales sensu lato*, and *Coprinellus disseminatus* to thrive. Fungi found in the order *Agaricales* may come in mycorrhizal, parasitic, and saprobic forms (Alexopoulos et al. 1996). I only found *Agaricales* *sensu lato* growing on dead leaves, and wood in both the landslide and undisturbed trail quadrats. *Coprinaceae* Fungi (family of *Coprinellus disseminaus*), are known for being commonly found on the floor in outdoor environments (Alexopoulos et al. 1996). Breaks in the canopy from the landslides allowed windows of sunlight to bypass the towering trees of the forest and reach the forest floor. Fungi in the phyla Ascomycota require sunlight in order to produce fruiting bodies (Boddy et al. 2013). I found *Scutellinia scutellata,* otherwise known as the "eyelash cup" more often in the landslide quadrats of my study, possibly because there was more sunlight exposure along the El Jiguero trail where several landslides took place.

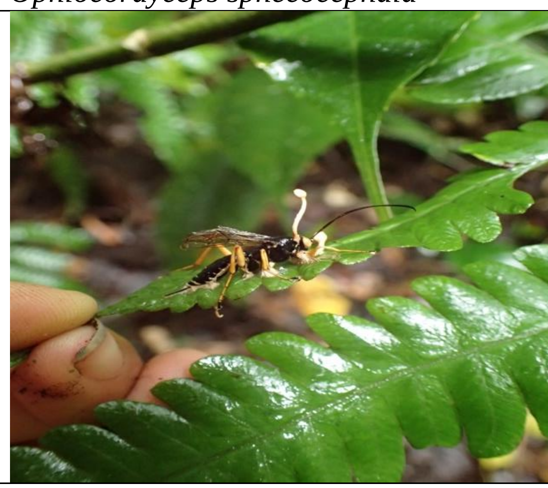
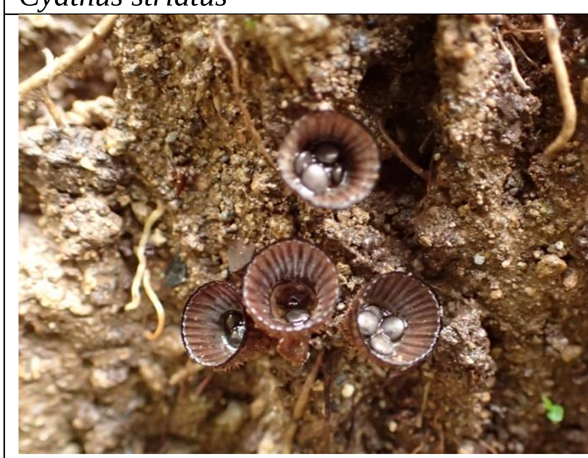
Despite the abundance of some species found throughout the different quadrats, there were quite a few species which were less prevalent including the ascomycetes *Ophiocordyceps sphecocephala*, *Cookeina speciosa* and the basidiomycete *Cyathus striatus*. *Ophiocordyceps sphecocephala*, and *Cookeina speciosa* are from the phyla Ascomycota, and I found them just once in separate landslide quadrats. *Cyathus striatus* is from the phyla Basidiomycota and occurred twice in separate landslide quadrats. My findings contrast a study done on the fungal diversity in different stages of tropical forest succession in Costa Rica, where *Ophiocordyceps* (known as Cordyceps) was the second most diverse genus in the old growth forest (Chaverri and Vílchez 2006). The Cordyceps was found only once on a wasp that it parasitized in a quadrat of the undisturbed trail. Since Cordyceps is more likely to be found in older growth forest (Chaverri and Vílchez 2006) this adds to the reasoning behind why Cordyceps was found in the undisturbed trail quadrats, instead of the landslide quadrats. Also in the same study, they found that the older forests contained more insects, and an increase in the amount of insects can affect the the number of Cordyceps found (Chaverri and Vílchez 2006). Despite *Cookeina speciosa* being the most commonly found fungus from the genus Pezizales in the phyla Ascomycota (Weinstein et al. 2002), I only found it in one quadrat out of 24 quadrats assessed. A possible reason for this finding may be due to the riparian habitat preference of this fungi. In my study area, I found *Cookeina speciosa* in one of the quadrats alongside the Machina river. In another forest where I was casually hiking, I found the fruiting body of the *Cookeina speciosa* alongside a river in San Gerardo in the Guanacaste Province. *Cyathus striatus* is also known as the "bird's nest fungi" and can be found in moist habitats, whether on the soil or in a bed of mulch (Mata et al. 2003). The bird's nest fruiting body is shaped in a peculiar way for the sole purpose of being distributed by rain droplets, as opposed to having its spores dispersed by wind like most fungi (Alexopoulos et al. 1996). As rain droplets fall in the cup shaped mushroom of bird's nest fungi, they eject the spores outward upon impact (Alexopoulos et al. 1996). Therefore, their dispersal depends more on rainfall in the landslide and trail sites, and depends less on the amount of woody substrates found.

Specifically, I found lots of *Mycena reusell* and *Marasmius sp.* in quadrats in the two different trails, and both are known to grow on freshly fallen leaf litter (Lodge and Contrell 1995). I found both of these different species of fungi in the landslide, and undisturbed trail quadrats growing from the top of leaf litter. On the other hand, *Hygrocybe coccinea* is a species of fungi which primarily grows straight from mineral rich soil on the forest floor (Lodge and Cantrell 1995). Despite the fact that fungi in the genus *Hygrocybe* are considered versatile (Mata et al. 2003), I found the bright red fruiting body of *Hygrocybe coccinea* only in the undisturbed trail quadrats. This may be due to the fact that the undisturbed trail has a longer history of decomposing organic matter being integrated in the soil, whereas the trail where the landslide occurred had soil which had recently been mixed from falling down the slope of mountains.

Overall, I found more species from the phyla Basidiomycota in all the different quadrats, and only 7 of the species identified were Ascomycota. The abundance of organic material in the form of plant matter which accumulated in the landslide quadrats provided fuel for the mycelium of more than 30 different species of fungi. There are many factors which affect the ability of fruiting bodies to be produced in different environments and some depend on substrate, light, and disturbance of the environment (Boddy et al. 2013). In a study on logging in Sweden, researchers monitored the species richness of basidiomycetes in the family *Polyporaceae*, *Hymenochaetaeceae*, and *Corticiaceae* and found that the reduction of logs in the forest decreased the species richness of the fungi (Bader et al. 1995). Furthermore, changes in rainfall, tree falls, and even the occurrence of a hurricane can all affect fungal species in a forest (Lodge and Cantrell 1995). The occurrence of Tropical Storm Nate devastated parts of the cloud forest behind the Estacion Biologica with a record amount of rain which resulted in landslides to occur on the El Jiguero trail. The difference in amount of fungal species between the El Jiguero and Cariblanca trails is easier to assess when comparing the fruiting bodies found between the different trails. Although ascomycetes make up 64% of the fungi in the subkingdom Dikarya (Stajich et al. 2009), only the genus Pezizomycotina contains fruiting bodies in the form of macrofungi (Stephenson 2010). A purple fruiting body of an unknown species of fungi from the genus Pezizomycotina was found in one landslide quadrat. The amount of sunlight in an environment has a small effect on the fruiting ability of basidiomycetes, but ascomycetes require sunlight in order for a fruiting body to arise (Boddy et al. 2013). The abundance of sunlight in the landslide quadrats may have provided the vital nutrients needed to allow the seven out of the total eight species of ascomycetes identified to produce fruiting bodies.

Boddy (2013) found that there are many factors which affect macrofungi and fruiting in different environments and some depend on substrate, light, and disturbance of the environment. Environmental disturbances can sometimes invoke a response in the fungal community (Lodge and Cantrell 1995), and so landslides resulted in an accumulation of debris in parts of the forest which was perfect for saprotropic basidiomycetes, the most common type of macrofungi found in my sites. My results point to a couple of reasons why I found differences in species richness, such as the amount of decaying plant matter between the two sites, and the succession of fungi which occurs overtime.

Appendix

Marasmiaceae sensu lato	*Hygrocybe coccinea*
	
Agaricales sensu lato	*Ophiocordyceps sphecocephala*
	
Cyathus striatus	*Scutellinia scutellata*
	

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Cookeina speciosa	
	

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