Edible macrofungi of Namibia's thorn bush savanna bioregion and their potential for sustainable development

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Abstract

Namibia is the driest country in sub-Saharan Africa, yet, despite a variable rainy season lasting roughly December to April, plentiful macrofungi have been observed in the thorn bush savanna region of the country. Lack of research and public education regarding these species resulted in virtually no knowledge of the country's fungi and limited fungal knowledge and use among its peoples. Consequently, Namibia is missing a sustainable development opportunity, namely, the growing worldwide popularity of fungi as food, medicine, and means for crop diversification. Therefore, in the 2015-2016 and 2016-2017 rainy seasons, this study aimed to inventory the species growing in the thorn bush savanna region and determine edible species available for domestication and cultivation. Field data was collected using regular site visits and specimen collection, plus DNA analysis. A statistical analysis using R statistical software showed species richness and abundance had a positive correlation with rainfall. In total, 67 species were found, with 13 edible species, and six were highlighted for domestication/cultivation research (*Agaricus campestris, Calvatia lilacina, Coprinus comatus, Ganoderma sp., Schizophyllum commune, Volvariella volvacea*). In addition, three species of termite fungi (*Termitomyces)* were found which have been overlooked as a food source in the country. The possibility for more edible macrofungi remains, as does the need for more research regarding Namibian macrofungi species and their ecology.

Language: English Key words: Namibia, macrofungi, sustainable development

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1. Introduction

The world over, despite the many benefits to humans and the rest of nature, fungi are most often a misunderstood and understudied group of organisms (Hawksworth, 2009). In southern Africa, use of wild fungi by indigenous peoples is common. Numerous scientific articles, books, and field guides have been published on the subject (Crous et al., 2006; Härkönen et al., 2015). Yet, many southern African fungal species remain unidentified and undescribed. (Crous et al., 2006; Gryzenhout et al., 2012). Furthermore, the nutritional and medicinal value of the region's macrofungi fruiting bodies, commonly known as mushrooms, has been neglected in scientific study. Therefore, they are considered one of the greatest untapped resources for feeding, and providing income for, Africa's growing population. (Muandingi and Chimwamurombe, 2012)

Namibia is known to be the driest country south of the Sahara. The landscape is dominated by desert, arid, and semi-arid savanna, with annual rainfall in the thorn bush savanna region averaging 550 mm during the roughly December to April rainy season. (Jacobson, K.M., 1996) This climate has led to the underestimation of fungi in Namibia and their importance in arid ecosystems (Barnard, 1998). Indeed, very little research has been done on wild fungi in Namibia and the extent of their diversity in the country remains unknown. However, the research that has been undertaken has shown that there is a wealth of species growing in the rainy season, at least a few of which are used by indigenous peoples of Namibia, and there are many more edible and/or medicinal species that could be beneficial to the country's citizens. These species could, therefore, be considered an underutilized resource for tackling some of the nation's most persistent problems, such as unemployment, food security, reducing poverty, and empowering disadvantaged populations (Gryzenhout et al.,2012). If these beneficial species can be domesticated and cultivated their rewards to society increase even more. Thus, the goal of this study is to determine how many edible macrofungi species grow in the thorn bush savanna region of Namibia and determine edible species available for domestication and cultivation.

Around the middle of the twentieth century, the taxonomic domain of Eukarya was finally split into the three current kingdoms: animals, plants, and fungi. A main determining factor for this was how each group receives its nutrients. Animals ingest, plants photosynthesize, and fungi absorb externally digested food. Other differing characteristics include main components of cell membranes and differing developmental gene sequences. The kingdom of fungi is now considered one of the oldest and largest groups of organisms. (Moore et al., 2011, 29)

All animals and plants are primarily made of carbon, in some cases, up to 50% of their dry weight (Woods Hole, 2014). When something dies, fungi are the best organisms on earth at breaking down the dead material and returning it to the soil so it can be used again (Buckley, 2008). They also engage in a symbiotic partnership with many plants providing them with nutrients and water that they need. In fact, fungi are essential to almost every aspect of ecology, agriculture, and medicine. Yet, most aspects of fungi remain unknown to the majority of people and it is estimated as few as 7% of the world's species have been described (Hawksworth, 2009). In Boa's authoritative report *Wild Edible Fungi: A global perspective,* Namibia has only 4 species listed. This is based on all available published information at the time (2004), which for Namibia, was only three documents, all approximately 20 years old. Even in a country like China, which has a long history of fungi use (Boa, 2004), of the 1500-2000 estimated edible species in the country, only 981 have been identified (Chang, 2008).

According to Chang (1996), although humans have been consuming fungi for centuries, research on edible fungi has only just begun and is limited to specific institutions in developed countries. One possible explanation for this neglect is that, until recently, fungi were always considered relatives of plants, starting with Linnaeus' Species Plantarum in 1753. It is now known that they are more closely related to animals, yet they still continue to be lumped in with plants. Mycology, the study of fungi, is not even listed as a science by UNESCO; fungi are mentioned simply as mushrooms, listed under botany, and yeasts, under microbiology (Hawksworth, 2009). Universities also hide mycology programs in botany or microbiology and as a result, the field is suffering from a depletion of professionals. Hawksworth (2009, 2) notes that 26% of fungal species described since 1980 were from only 50 authors, and several of them are now retired or deceased.

Without proper training facilities and collections of information, anyone who does study fungi will be working on assumptions. For example, fungi are generally thought to grow in cool, moist, and dark places, so a country like Namibia is assumed to lack significant fungal diversity. This explains the modest mycological research that has been done in the country (Mannheimer and Jacobson, 1998). Indeed, worldwide, research on desert fungi is lacking despite one study finding 185 species in the very hot Makhtesh Ramon desert in Israel (Grishkan and Nevo, 2010) and another, which identified 12 genera residing in the Atacama desert in South America, known to be the driest location on earth, some places not having seen rain for decades (Conley et. al., 2006). Moreover, some species are found mainly in arid or semi-arid habitats, such as the majority of the genus *Calvatia* puffballs, including some in the high arctic desert (Coetzee & van Wyk, 2009).

It is essential, however, to inventory species and learn of their ecosystem functions due to their pivotal role in regulating life on earth (Hawksworth, 1991). In drylands, their work as decomposers of organic material is especially important to enrich the nutrient-poor soil (Jacobson and Jacobson, 1995). Indeed, it is generally believed that the majority of the remaining fungi species to be identified are in Africa. Overall, little information is available for ethnomycological practices in Africa, and therefore, which species would be most useful. This is attributed to the fact that the information already collected is scattered throughout multiple sources and not always available to the international community (e.g. published in an indigenous language, only passed down orally). (El Enshasy et al., 2013).

1.1 History of Fungi Use in Society

It is assumed that prehistoric humans collected certain species of wild fungi as food and medicine. Greek, Roman, Egyptian, Chinese, and Mexican civilizations also utilized fungi for food, medicine, and religious ceremonies. (Miles & Chang, 2004, 1)

"The Iceman", a 5000-year-old Neolithic man found preserved in ice in the Alps carried three "fungal products" on his person Two pieces were *Piptoporus betulinus*, (the purpose remains unknown, but the genus has active substances which have been noted to reduce fatigue, a useful property to a man travelling through the Alps). The other piece was of *Fomes fomentarius,* also known as the tinder bracket, a polypore with a long history of use as fire tinder. (Moore et al., 2011, 273)

Today, it is estimated that about 1200 species are used in 85 countries for food, medicine, and cultural purposes (Boa, 2004). Fungi are collected in the wild, as well as cultivated, with many new species coming to markets in North America and Europe in the last 25 years, expanding the public's idea of edible fungi beyond the usual button mushroom, or champignon. (Dugan, 2011, 2)

1.2 Fungi as Food

It is generally accepted that humans have always used fungi as food. In fact, a desert truffle, *Terfezia arenaria,* is mentioned in the bible as "bread from heaven" and "manna of the Israelites" (Pegler, 2002). Archeological studies show that fungi (including polypores) have been a source of food and medicine since before documented history. (Moore et al., 2011, 266)

Fungi are very nutritious, being high in protein, carbohydrates, and fiber, as well as many vitamins and minerals (De Roman, 2010; Moore, 2011; Mshandete & Cuff, 2007; Stamets, 2005). In a world struggling to feed its growing human population, protein, the building block of the human body, is perhaps the nutrient most in demand. Developing countries especially, lack enough protein sources for their citizens and continually seek new methods to provide it, sometimes turning to expensive imports (Mshandete & Cuff, 2007). Although fungi contain less protein than animal meat, they contain more than most other foods, including milk. On average 3.5-4% of the fresh weight of fungi is protein. To compare, fish and chicken are 18-20%, beef 12-20%, 2.9-3.3% in milk. They contain twice as much protein as onions and cabbage, 4-12 times as much as oranges and apples, and more protein than rice, maize, and wheat, falling only behind soybeans. They also contain all 9 essential amino acids which human bodies require. (Chang, 2008)

Fungal diversity can also contribute to food security in Namibia, where 11% of the poorest people are malnourished (Speybroeck et. al., 2012). If people are taught which of the wild fungi are edible, they could feed themselves and their families or sell them for income at markets or roadsides. Familiarization with fungi may also lead to increased cultivation which will help feed Namibia as well, especially in urban areas where growing space is limited. With over half of Africa's population expected to be in cities by 2030, urban food security is increasingly an issue that fungi cultivation could help (Crush et. al., 2011).

1.3 Fungi as Medicine

Currently, 400 fungi worldwide are identified to have medicinal properties. However, it is estimated that about 1800 species have the potential to be medicinal (Chang, 2008). That leaves 1400 left to be discovered. Indeed, the medicinal properties of fungi are one of their greatest benefits to people. Medicinal fungi such as *Lentinus edodes, Ganoderma lucidum*, and *Cordyceps sinensis* have been used for centuries, and not only for treatments of diseases, but in prevention as well.

126 medicinal properties are thought to exist in fungi, including antitumor, immunomodulating, antioxidant, radical scavenging, cardiovascular, anti-hypercholesterolemia, antiviral, antibacterial, anti-parasitic, antifungal, detoxification, hepatoprotective, and anti-diabetic effects. In Asia, fungi are already used, successfully, in the fight against cancer (Chang and Wasser, 2012). Their anti-viral and immuno-boosting agents also have been shown as a successful treatment against HIV/AIDS (a possible boon for Namibia), proving fungi to be a major, untapped source of new pharmaceutical products (Khatun et. al. 2012) - another income potential for Namibians. Other species found in Namibia also have medicinal properties – *Volvariella volvacea* lowers blood pressure, *Schizophyllum commune* has significant effects against cancer, and *Ganoderma lucidum* contains antioxidants and helps in the fight against HIV/AIDS (Khatun et al., 2012). Additional biomedical applications include boosting of energy and immune-system, pain relief, anti-relapse medicine for cancers, improving blood circulation and heart function, anti-diabetic treatment, and many more (Wasser, 2005).

Likewise, the protein extracts of *Volvariella volvacea* and *Calvatia lilacina*, also found in Namibia, as well as *Pleurotus ostreatus*, a common cultivated species in the country, may be important sources for new anti-cancer drugs (Wu et al., 2011). The desert truffle genus *Terfezia* is known to have antibacterial and antiviral properties (El Enshasy et al., 2013).

If medicinal fungi could be cultivated in Namibia, this would be an excellent source of income for communities struggling with unemployment and poverty. The world market for fungi and their products was valued at US$24 billion in 2011 (Zhang et al., 2014) and will only expand further as the medicinal properties of fungi continue to be researched and exploited as more countries learn of their value. (Chang, 2008)

1.4 Toxic Fungi

It is also important to identify toxic fungi, although less than 1% of the identified fungi in the world fall into this category (Chang, 2008). First, in order to reduce poisonings, both human and livestock (Gryzenhout et. al. 2012), but also to reduce mycophobia and open the world of edible and medicinal fungi to the Namibian public (Nwordu et. al. 2013).

1.5 Identification of Fungi

To facilitate people's trust of fungi, they must learn about them, and to learn about them, they must be able to identify them. However, fungi are notoriously difficult to identify for a number of reasons. Firstly, many still need to be properly described and formally classified. Also, one must have access to the appropriate literature, if literature exists for their region, as well as a microscope, plus enough training to know how to use them. Furthermore, one must collect every piece of evidence available to ensure proper identification. This includes specimens of the species ranging from immature to fully mature, any pieces growing underground, samples of substrate in which the specimen is growing, or nearby plants or trees to which it may be associated. Thus, the recording of features and the subsequent identification process must be done the same day before the samples begin drying out or decomposing, and losing color, smell, or other identifying characteristics. (Wang, 2011, 21-22)

Local and indigenous people can be a tremendous resource in identifying a region's macrofungi, especially if literature is not available. Often, the people will have lived in the region their whole lives and learned the fungi from previous generations (Härkönen et al., 2015, 74-75). Fungi sold at local markets or by roadside vendors can offer insights into edible species and speaking with the collector can reveal the habits and habitats of the species. (Wang, 2011, 24) Therefore, collection of indigenous mycological knowledge should be made a research priority in Namibia (Barnard, 1998, 113) and be expedited. Urban migration is rapidly increasing (Crush et al., 2011) and traditional knowledge is often lost once people leave their rural homes (Härkönen et al., 2015, 75)

1.6 Fungi for empowerment

Another benefit is women empowerment. 70% of the world's poor are women, and from the Americas, to Asia, to Africa, women are most often the ones who collect, sell, prepare, cook, and store fungi (Garibay et.al 2012). This wild fungi harvesting is a potential and sustainable solution to their poverty and to their improvement of overall quality of life (Ahenkan and Boon, 2011). In Tanzania, fungi harvesters can earn from US$400-900 annually - a significant increase from the average income per capita of US$340. In Zimbabwe, fungi harvesters could earn US$90-130 per month in the December-March rainy season, more than agricultural workers earned (Masuka, 2002). Other disadvantaged groups, like children, elderly, sick, unemployed, or undereducated, can also generate income from wild fungi because no capital is required, only time for collecting (De Roman, 2010; Tibuhwa, 2013). Yet this fungal connection to livelihood improvement and the empowerment of disadvantaged people has been understudied to date (Ahenkan and Boon, 2011, Tibuhwa, 2013).

Mycotourism, a relatively new model of ecotourism, which invites tourists to partake in fungi hunts, thereby getting to know more about the local people and their culture, is also a possibility for income, as seen in Spain (Büntgen, 2017). The Kalahari truffle (*Terfezia pfeilii*) would be an excellent species for mycotourism in Namibia due to the popularity of truffles worldwide. Truffles grow underground at a depth of between 5 and 10cm and generally require someone experienced to find them (El Enshasy et al., 2013). Termite fungi are also very unique, and an exciting find due to their often large size. Namibians with the proper training could take tourists through Namibian landscapes in search of these edible species, earning themselves an income and offering a unique experience to their guests. In Spain, the mycotourism initiative also increased public interest in picking and eating fungi as well as providing a method of sustainable management for wild species and their habitats (Büntgen, 2017).

1.7 Cultivation of Fungi

Fungi cultivation began in 600AD when the Chinese began growing *Auricularia auricula* on logs. In the following centuries, *Flammulina velutipes* and *Lentulina edodes*, the enoki and shiitake mushrooms respectively, were also cultivated. But it was France which began cultivating *Agaricus bisporus* on compost in 1600AD, which led the way to the mass production of today's button mushroom, or champignon. (Miles & Chang, 2004, 1)

A debate is underway whether wild fungi, as well as cultivated species, should be promoted to 'crop' status (Tibuhwa, 2013). Crop diversification is important for food security, climate change adaptation, and poverty alleviation, and fungi cultivation research, which is severely lacking in Namibia, would be the driving force in making large-scale fungi cultivation a reality (Horn, 2005). Horn also mentions that fungi are an ideal crop for an arid land such as Namibia because they are grown indoors and require less water than normal crops.

Desert truffles are also a crop of high potential due to their low water requirements and high market price. They are not as valuable as their European relatives because they are not as fragrant or flavorful, yet they grow in greater quantities and can therefore be used in greater volumes. (Morte et al., 2008) They also contain more protein than most vegetables and other fungi, approximately 20% of their dry weight. A 250 g serving of desert truffles is about a quarter of the daily recommended protein serving for an adult, making this a valuable food in developing countries. (Murcia et al., 2003) Cultivation of fungi can also relieve pressure on wild stocks which can be overharvested (Cunningham, 2011, 177), as is the case with a valuable fungus, like truffles. Cultivation of desert truffles can also help rehabilitate unproductive lands by reducing erosion and introducing an alternative, low-water crop. (Morte et al., 2008).

With a rising world population, food production must increase, but arable land is becoming overtaxed and ever scarcer. However, one resource that is underutilized and that the world has an abundance of is lignocellulose, the main component of wood and plant material. Large volumes of lignocellulose waste is produced around the world via agriculture, forestry, and food processing. Fortunately, fungi are designed to break down this material and their cultivation is one of the most efficient and high-value food production options for converting lignocellulose into nutritious food. (Chang, 2008; Mshandete & Cuff, 2007)

1.8 Obstacles to Exploiting Wild and Domesticated Fungi in Namibia

Namibia's climate is harsh, and, as in other dry regions, fungi occur only in adequate rainy seasons. The pattern of rainfall, not just quantity, is also important. For example, if rainfall is heavy but infrequent, few species may fruit. (Chang, 2008) The months in which rainfall occurs, as well as quantity and distribution, also have been found to be a factor in the fruiting of desert macrofungi and truffles (El Enshasy et al., 2013; Morte et al., 2008). Also, changes in climate are having an effect on fungal growth and while ecological and environmental complexities make predictions for the future difficult (Boddy et al., 2014), already variable climates such as Namibia's may have fewer seasons with conditions conducive to fungal growth.

If fungi are to be the subject of a thriving industry in Africa, much more research and development is needed, and consequently mycological education (Barnard, 1998, 113). Information obtained from research and development must also be accessible and understandable to the layman. Furthermore, those involved in fungal research, development, and cultivation must also communicate and share knowledge and techniques. (Chang, 1996)

Indigenous peoples should also be consulted. Around Africa, urbanization is taking youth away from traditional lands while habitat loss is reducing populations of fungi, resulting in younger generations not being taught which species are usable. Thus, indigenous mycological knowledge must be recorded before it is lost (Guissou et al, 2008; Gryzenhout et. al. 2012, Tibuhwa, 2013). Teaching youth the benefits they can receive from wild products will also encourage them to conserve their land resources and reduce destruction of fungal habitats (Ahenkan and Boon, 2011, Tibuhwa, 2013).

Another problem is that, although mycological research institutions are expanding into developing countries nowadays, this is mainly because of financial aid from developed countries and organizations (Chang, 1996). This may result in an initial interest in fungal research and cultivation, but the interest, and funding, may fade over time. This can be witnessed in Namibia, where fungal cultivation projects are quick to launch, backed by generous funds, in order to provide income to a rural community or women's group, but after a few obstacles are encountered, like poor fruiting, lack of water, or hard-to-access supplies, the project is abandoned (Absalom, 2013). A basic mycological research facility with properly trained staff would also be beneficial for Namibia (Barnard, 1998, 113).

Obtaining and sharing knowledge and skills can help fungi cultivators. While some fungi are touted as easy to grow (e.g. oyster mushrooms), even they require proper training and some skill. Cultivators also need high quality cultures and/or spawn, yet the process requires exact procedures and expensive equipment (Gwanama et al., 2011, 6-7). This makes it difficult for small-scale growers to make spawn themselves and they become dependent on others from whom they must purchase their spawn. Non-immediate results or delays in returns on investments must also be taken into account during the growing process. Furthermore, growing fungi is only half the battle; cultivators must also learn marketing skills in order for their business to be profitable (Gwanama et al., 2011, 33).

Therefore, this research aims to determine how many species of wild edible fungi there are in Namibia's thorn bush savanna bioregion and the relationship between rainfall and species richness and abundance. It is hypothesized that rainfall has a positive correlation with species richness and abundance and that this region has many wild edible fungi species that remain unknown to science and the public and are therefore an underutilized resource for sustainable development.

2. Materials and Methods

2.1 Field Collection

For this study, three sites were marked off on an 11,000-hectare cattle farm in the thorn bush savanna bioregion of north central Namibia. In order to analyse macrofungi growth in different land-use areas, the plots were located at a man-made dam dominated by clay soil and camelthorn acacias (*Acacia erioloba*), a cattle pasture in use for part of the year with a water point dominated by sandy soil heavily infiltrated by cow manure and *A. erioloba*, and a former maize field where thorn bush savanna has partially regrown dominated by Kalahari sand and swarthaak acacias (*A. mellifera*) (Figures 1-3).

Figure 1. Site 1, cattle pasture dominated by sand/manure soil and camelthorn acacias (Acacia erioloba).

Figure 2. Site 2, man-made dam dominated by clay soil and camelthorn acacias (Acacia erioloba).

Figure 3. Site 3, former maize field dominated by Kalahari sand and swarthaak acacias (Acacia mellifera).

Each site measured 30 meters long by 30 meters wide with seven transects five meters apart dissecting the sites (see Figure 4). Transects were walked once every week in which it rained from January to March. Any fungus visible from the transects was recorded. Known species were recorded each time they were seen and how many fruiting bodies were seen; unknown species were described using the field record sheet (Appendix I), identified to genus or species if possible.

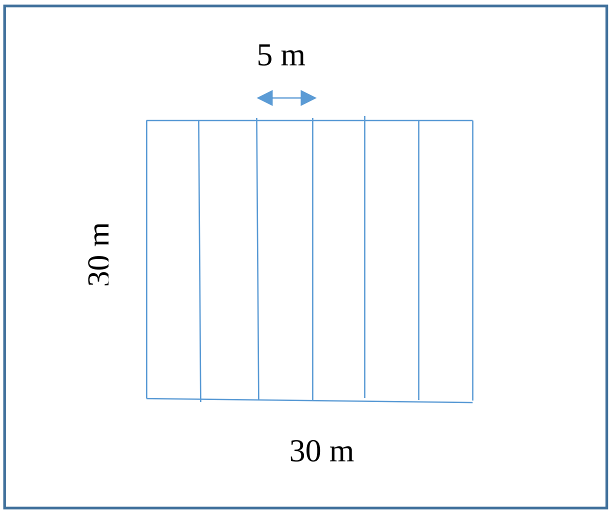

Figure 4. Diagram of a site with transects.

However, records of species found at the study sites and other regularly visited sites around the farm, including photographs and descriptions, have been kept by the researcher for the past five years. Daily rainfall was also recorded on the farm for the past 20 years using a manual rain meter located at the farm house. Rainfall hypotheses were then tested using a general linear model (GLM) and correlation test with the R statistic software (R Core Team, 2017).

2.2 DNA Analysis

The first 32 specimens collected in the 2017 season (in order to avoid bias) were sampled for direct molecular analysis to determine the species. Specimens were dried, a sliver of lamellae or spore mass was removed, and stored in plastic packets to avoid cross-contamination.

DNA extraction for each specimen was done using PowerSoil®DNA Isolation Kit (MoBio, Carlsbad, CA, USA) following manufacturer's instructions at University of Tartu, Estonia. Methods are outlined in Anslan et al. (2016). Primers were manually designed as described in Tedersoo et al. (2008).

The resulting nucleotide sequences were then analyzed using the National Center for Biotechnology Information (NCBI)'s Basic Local Alignment Search Tool (BLAST) program and the UNITE fungal DNA database.

3. Results

The 2-year study took place over the rainy seasons of 2015-2016 and 2016-2017. The first season was considered a drought year, with much of the country receiving far below average rainfall for the third year in a row. The study farm received 421 millimeters (mm), which is below the 20-year average of 528.5 mm (Fig. 5 and 6), but still more than many farms in the country. The second rainy season was above average, with a total of 775 mm. This resulted in a difference of over 350 mm in rainfall between the two study seasons. A clear difference in overall species abundance and species richness as compared between study sites was noted (Fig 7. and Fig. 8).

In total, 67 species were found on the farm over 5 years, and a total of 49 species among the three study sites in the two years of the study. Site 1, the cattle pasture, had 41 species overall; site 2, the man-made dam, had 33 species overall; and site 3, the former maize field, had 38 species (Fig. 7). Species abundance (Fig. 8) was only counted during the two-year study period. Site 1 had a total of 885 fruiting bodies, site 2 a total of 1034 fruiting bodies, and site 3 a total of 739.

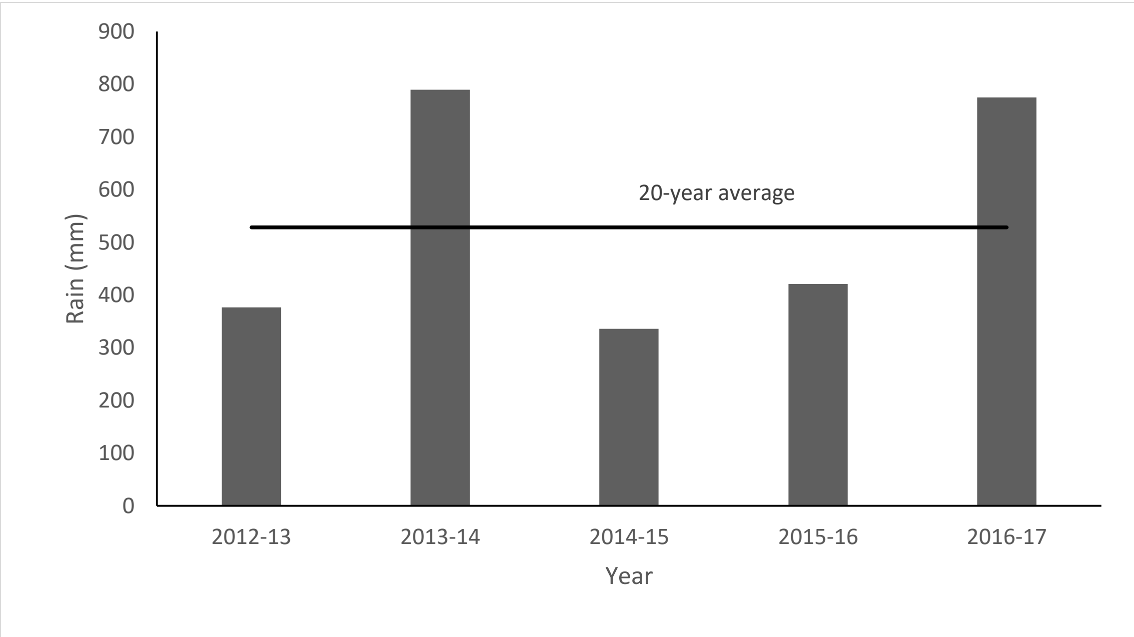

Figure 5. 2012-2017 Study Farm Rainfall Totals (mm/year). Note three of the five years are below average (see Figure 3).

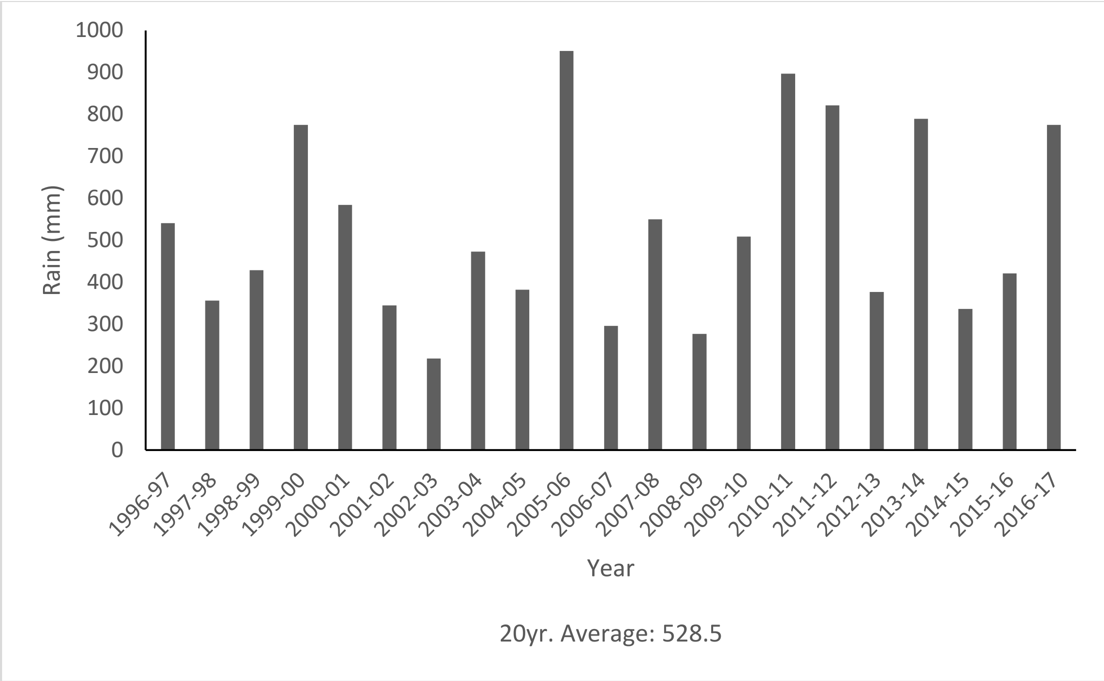

Figure 6. Study Farm Annual Rainfall 1996-2017 (mm/year).

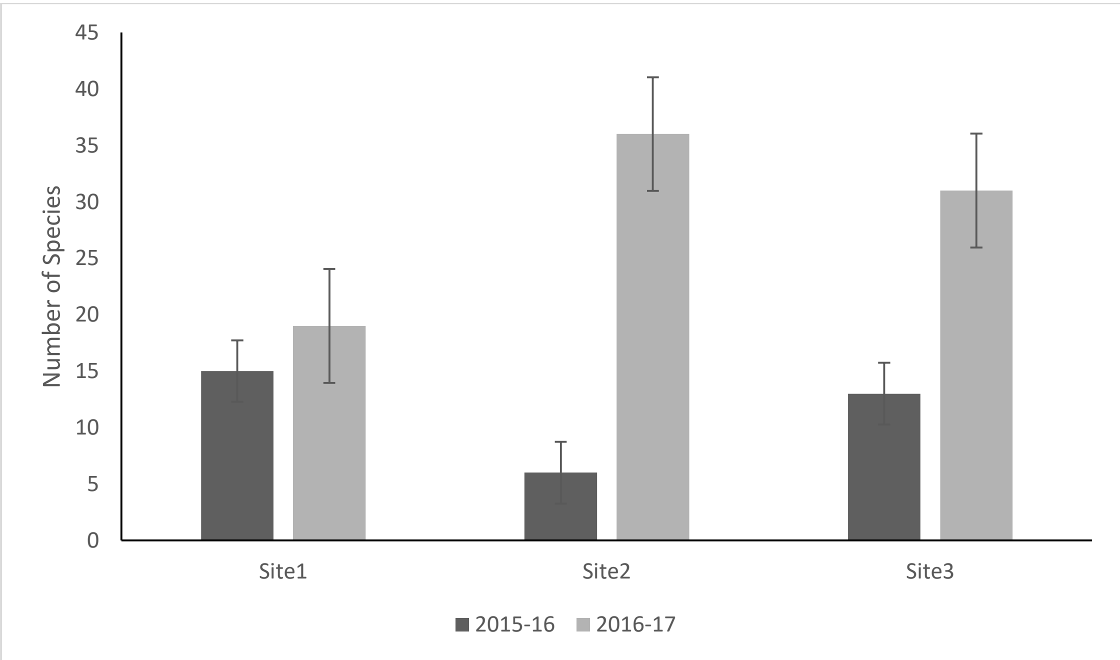

Figure 7. Study site species richness.

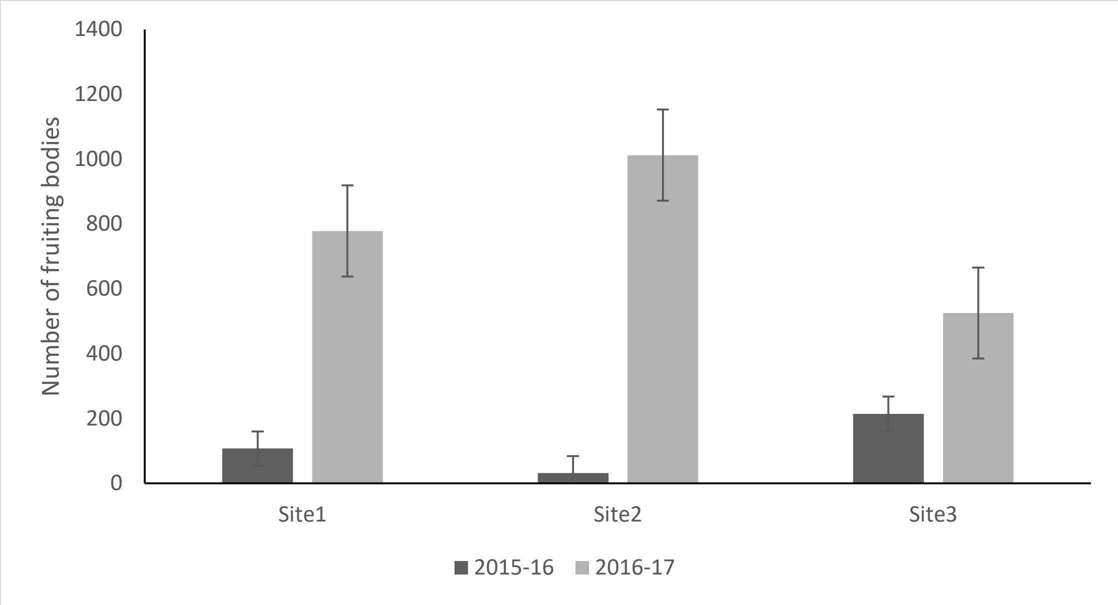

Figure 8. Study site species abundance.

Of the first 32 species to be collected in the 2017 season (Appendix II), using the DNA analysis, 26 were identifiable to the genus level, 3 only to family level. Only two were conclusively identified, *Agaricus subsaharianus* and *Lepista sordida*. One was unable to be analyzed. Fifteen additional species collected over the five years were identified to species level and three to genus level using field guides (Appendix III).

Results of the statistical analyses showed a strong positive correlation between rainfall and species richness looking at 5-year data, with a correlation test resulting in a p-value of 0.03972. (See Fig. 9, 10 and Table 1). Likewise, a positive correlation was found between monthly rainfall and species abundance looking at 2-year data. P-values from the GLM test were far below .05, indicating rainfall as a factor in species abundance (Table 2). Results also showed a significant difference in species richness among the three study sites (Table 3).

Dependence of the variables on the fixed factors were calculated using the following equations:

Species richness- cor.test (rainfall, species.number, alternative= “two.sided”, method= “spearman”)

Species abundance- glm(species ~ site*year, family=poisson(identity)

Difference between sites - glm(N ~ month*site, family=poisson(identity)

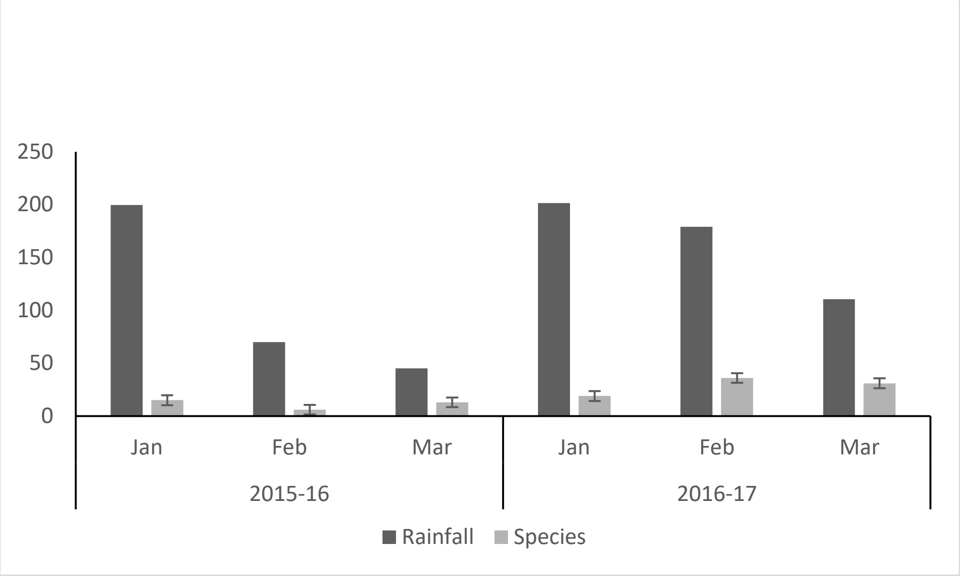

Figure 9. Rainfall (mm/year) compared to species richness in the three study sites combined.

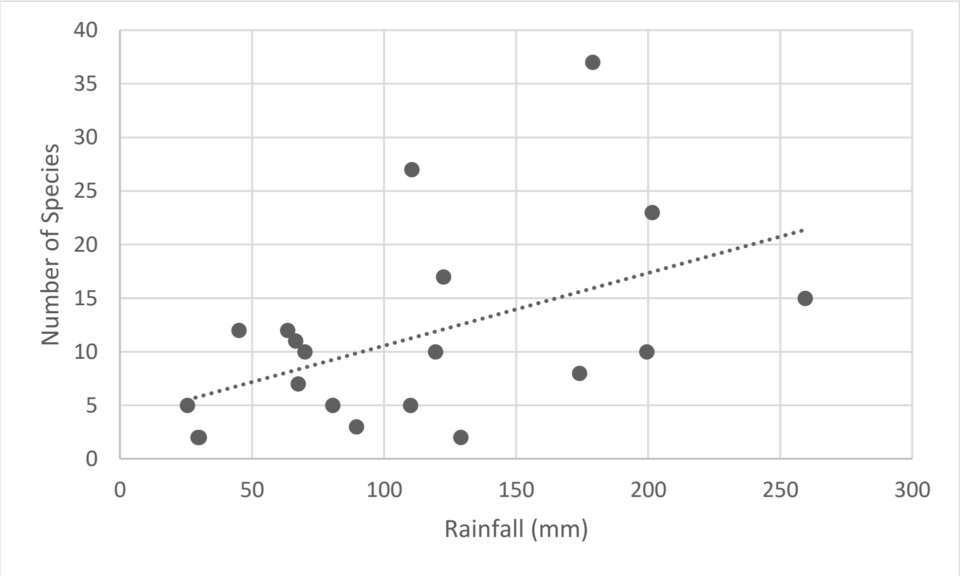

Figure 10. Species richness compared to rainfall (mm/year) over five years (20 months) during 2012-2017.

Table 1. Species richness compared to monthly rainfall

Spearman's rank correlation test			
	p-value	rho	N
Species Number Rainfall	0.03972	0.463171	20

Table 2. Species abundance compared to site and year (rainfall)

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.6212	0.1567	10.344	< 2e-16
site[T.2]	-1.1515	0.178	-6.47	9.83e-11
site[T.3]	1.6212	0.2715	5.972	2.34e-09
year[T.2]	10.1667	0.4507	22.555	< 2e-16
site[T.2]:year[T.2]	4.697	0.6653	7.06	1.66e-12
site[T.3]:year[T.2]	-5.4545	0.6106	-8.933	< 2e-16

Table 3. Species richness compared to site and month

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-0.60248	0.12852	-4.688	2.76e-06
month	0.95881	0.05507	17.411	< 2e-16
site	0.04569	0.05801	0.788	0.430918
month:site	-0.08917	0.02471	-3.608	0.000308

For estimating edible species in thorn bush savanna, the following equation was used (Tibuhwa et al., 2011) :

Species%= (edible species/all species) * 100

Thus: 13/67 * 100 = 19.4%

4. Discussion

This study shows rainfall in the thorn bush savanna region of Namibia varies greatly from year to year, with droughts occurring frequently. Data also indicates that rainfall affects the number of fungi species found (species richness) each year, as well as the number of individual fruiting bodies found (species abundance). Studies have recognized this to be the trend, although a longer-term study taking into the different factors (e.g. temperature, humidity, rainfall) would be more informative and conclusive (Straatsma et al., 2001), but also because not all fungi in a given area fruit every year and fruiting bodies themselves are often short-lived and may take several surveys to be spotted (Schmit et al., 2007).

Furthermore, the research of Straatsma et al. (2001) showed tendencies of fungi to have annual fruiting sequences, with mycorrhizal species fruiting earlier than saprotrophic species. While this study did not take these ecological groups into account, sequences were also recognized. Indeed, certain commonly found species fruited with the first rains (e.g. *Coprinus comatus, Calvatia lilacina, Agaricus* spp.) and if rainfall continued, only then was a higher species richness seen.

Thus, Namibia's tendency toward drought means collecting wild fungi, while a boost to income in good rainy seasons, should not be relied upon annually as a regular income. This speaks, however, to the benefit of developing fungi cultivation programs in the country, as fungi harvests will then be more consistent.

Namibia's already variable climate makes predictions for the future regarding climate change difficult, but trends show "statistically significant increases in length of the dry season, and decreases in the number of consecutive wet days" and an overall 10-20% reduction in rainfall (Ministry of Environment and Tourism, 2011). If this is the case, fungal growth may become increasingly limited in the wild, as well as the overall species richness found. Therefore, collecting germplasm for future use in domestication and commercialization as is mentioned in the national climate change adaptation measures should be undertaken with urgency.

This study also indicates where wild fungi may be more likely to be found in the thorn bush savanna region. Over the 2-year study period, among the three study sites, site 3, the former maize field returning to thorn bush savanna, had the highest species richness, though site 2, the man-made dam, came in a close second. Site 2, however, had by a wide margin, the highest species abundance (see Figs. 4 and 5). In the 2016-17 season, one species alone, *Vascellum praetense,* had 463 fruiting bodies, far more than were found at the other sites. *V. praetense* also happens to be an edible species, known in southern Africa as the common puffball.

However, whether the abundance of this species was due to the soil type, level of vegetation cover, disturbance from wildlife, or perhaps another factor, remains unknown and requires further study. There is scientific support for the theory that plant diversity in a given region proportionately predicts fungal diversity (Schmit & Mueller, 2007), thus, the fact that the cattle pasture had the least number of species found could perhaps be due to grazing or trampling by the cattle. On the other hand, fungi with different ecological roles may allocate varying amounts of resources to fruit-body production, thereby making species abundance an incomplete estimator of an area's productivity (Schmit et al., 1999)

The results of the DNA testing were mostly inconclusive as far as determining species. This is likely due to the fact that African species are underrepresented in genetic databases (L. Tedersoo; C. Sharp, personal communication, 2018), further testimony to prioritizing the study of these organisms.

However, finding genus or family names is also valuable information, mainly by emphasizing important areas for future research. For instance, 10 analyzed specimens were found by BLAST to be in the *Agaricus* genus. This is considered a very important genus because it contains the button mushroom, *A. bisporus*, the world's most commonly cultivated and eaten mushroom, as well as many other highly-sought after edibles. It is, however, also particularly difficult to identify species amongst this genus, as they are often very similar to each other and can be easily influenced morphologically by their environment (Arora, 1986; Elliott, 1978). Thus, there is much research to be done on Namibia's *Agaricus* species, their edibility, and the possibility for cultivation. Indeed, the one *Agaricus* properly identified by this study, *A. subsaharianus*, a large and fleshy mushroom, is known to be edible and consumed in other parts of Africa (Hama et al., 2010), yet has very little literature available to date.

The other identified species, *Lepista sordida*, is also edible and grew in great numbers at the study site where it was found. It has medicinal benefits as well, including anti-cancer properties, has been successfully domesticated and cultivated, and is considered a strong candidate for commercial production (Thongbai et al., 2017).

According to the data collected in this study, an estimated 19.4% of thorn bush savanna macrofungi species are edible. Unfortunately, there is too little data available on African species to make specific regional diversity estimates, so whether this estimate is high or low, is indeterminable. However, one study put the total number of recorded macrofungi species worldwide at 56,679 (Mueller et al., 2007). Another study found 1097 different species to be edible (Boa, 2004), although, the authors state their totals are conservative due to lack of data. Thus, using the same equation as above:

Species%= (edible species/all species) * 100

Then, the worldwide estimate of edible species identified to date is:

1097/56,679 * 100 = 1.9%

This is far below the estimate found in this study. Therefore, it is likely this study's estimate is closer to an accurate amount of edible species in a given bioregion, and the worldwide estimate is lacking due to underreporting and lack of research. Nevertheless, the list of macrofungi and edible macrofungi is, with certainty, incomplete in both cases. Also, due to the limited time frame of this study and relatively short list of species found, a species richness estimator was not used in this study. In past studies, they have been found to be inconsistent, especially with a small sample size. (Schmit et al., 1999; Straatsma et al., 2001)

4.1 Other Edible Fungi and Possibilities for Sustainable Development

Namibia's national climate change adaptation measures list several technological options for the agriculture sector which the country already utilizes (Ministry of Environment and Tourism, 2011). These include: crop diversification, low-water-use crops, and indoor crops. Large-scale fungi cultivation, especially of domesticated species which are known to grow in Namibia, would further all of these measures.

Three edible species were highlighted by this study for domestication consideration due to their frequency and apparent willingness to grow. *Agaricus campestris, Calvatia lilacina*, and *Coprinus comatus* were found every year since 2010, the year the author's collections started, even in the below-average rainy seasons of 2012-13, 2014-15 and 2015-16. The ability to grow in sub-par seasons, plus the fact that each one is known to be edible, and all three species are easy to identify makes them ideal species to begin introducing new wild species to the public and promising candidates for cultivation.

Agaricus campestris is a cosmopolitan mushroom, a favorite edible in many countries, including several countries in Africa, due to its pleasant mushroom flavor and probably also because of its close resemblance to the store-bought button mushroom. It can be cultivated and has medicinal benefits as well, including antibiotic and anticarcinogen (Molitoris, 1994).

Calvatia species are used around the world as food and traditional medicine. Research on African species, however, remains "completely lacking" and apart from reports of species being eaten in Nigeria, "no further confirmation regarding the culinary use of *Calvatia* in Africa could be found" (Coetzee & van Wyk, 2009). Ecological studies for this genus also have not been done, though it is known that they are terrestrial saprophytes, and with some clues about the preferences of *C. gigantea* (e.g. nitrophilious, shade-loving, and preference for disturbed areas), attempts at finding suitable substrate and conditions for cultivation can be made. Coetzee and van Wyk (2009) agree that the pleasant taste and pharmaceutical possibilities make *Calvatia* an enticing group for cultivation, yet report that as of the date of their publication, endeavors toward producing fruiting bodies in controlled environments had seen few results.

Coprinus comatus is a well-known edible species the world over and is already cultivated in many countries with several benefits to human health (Stojković et al., 2013). It is also a dominating and fast-growing species, to the point that it can be considered a weed in other mushroom beds (Reyes et al., 2009)

Other choice edible candidates for cultivation programs in Namibia also found on the study farm are *Volvariella volvacea, Schizophyllum commune,* and *Ganoderma* sp. All three of these species are commonly cultivated for food and medicinal properties around the world (Boa, 2004). All three are also collected in the wild for food and medicine in other countries in Africa as well as cultivated using low-cost technology in rural and urban areas (Chang, 2008; Osarenkhoe et al., 2014).

However, when individuals of the local Ovambo, Damara, and Ovahimba ethnic groups were asked if they used *Agaricus campestris, Calvatia lilacina,* or *Coprinus comatus* for food, the answer was an almost unanimous "no". In fact, many believe these species to be poisonous (personal communication, members of Ovambo, Damara, and Ovahimba ethnic groups, March 2014). In reality, there are a greater number of macrofungi species that are simply not worth eating (e.g. unpalatable or too hard) than there are deadly species. Yet, this small toxic group often taints all unfamiliar fungi, limiting the potential of new edible species to a group of mycophobic people (Boa, 2004). Although introducing new foods to local populations may become less challenging as people move away from traditional lives, lands, and knowledge and into cosmopolitan urban centers where they are exposed to new foods and cultures (personal communication, C. Sharp, 2018).

On the other hand, urban migration, and subsequent loss of traditional ways, can also make people more wary of wild fungi or decrease the number of species they consider edible (Lowore & Boa, 2001), and urban migration is widespread in Namibia. As Kuhnlein and Receveur (1996) note: "To practice and retain cultural knowledge and values, peace, stability, and prosperity are needed". Compared to neighboring countries, Namibia is considered peaceful and stable, and indeed, many of its citizens are prospering as indicated by the World Bank which now ranks the country as upper-middle income. The distribution of this income, however, is one of the most unequal in the world and rural citizens in particular are left behind in the country's development, the very citizens most likely to practice and retain that knowledge, with 20% considered severely poor (Cole et al., 2014). Without income opportunities on traditional lands, many flee for the city.

Luckily, Namibia has an effective program in place to halt this trend; the community-based natural resource management program, or CBNRM, which allows communities to manage their own resources. This has proven to be a highly effective program since communities have shown greater drive to maintain the resources than the government because they depend on them for their livelihoods. (Cole et al., 2014) The system also provides an economic incentive to manage communal natural resources, diversifies livelihoods and incomes, and has proven itself so successful that it has taken an official role in the nation's Poverty Reduction Strategy, Food Security Strategy, and the National Drought Policy and Strategy (Jones, 2004). Most communities involved in the program currently focus on wildlife and tourism for income, though wild plant products are growing in popularity.

Additionally, Namibia's Ministry of Agriculture, Water, and Forests (MAWF) established the Indigenous Fruit Task Team (IFTT), later, the Indigenous Plant Task Team (IPTT), to organize a multi-stakeholder group which would develop a strategy to commercialize Namibia's indigenous natural products (Cole et al., 2014). Members include producers, NGOs, and research groups, but also government divisions. Their main objectives are food security, agricultural diversification, and development of income opportunities (Indigenous Plant Task

Team, 2016). Estimates of Namibian wild plant products' current contribution to the Gross Domestic Product are N$30-50 million (€ 2,056,000 – 3,465,000). (Cole et al., 2014)

With training on identification and ecology or even cultivation methods, these programs can be expanded to include Namibia's fungi, thus making further strides towards the IPTT's objectives, plus a bigger boost to the country's GDP, while also offering solutions to some of the major threats to fungi, namely lack of research, urban migration, traditional knowledge loss, unsustainable resource use, and poor land management.

4.2 *Termitomyces* – The termite fungi

A common, yet underutilized genus in Namibia is *Termitomyces*, the genus farmed by termites. 27 species have been identified throughout their habitat in Africa and southeast Asia, with 23 recorded as edible and 3 medicinal (Boa, 2004). The genus also includes *T. titanicus*, the world's largest mushroom, with the cap sometimes measuring a meter wide (Moore et al., 2011). There are several species in southern Africa, among them the most coveted macrofungi by local populations (Crous et al., 2006). In fact, often the name for a *Termitomyces* species in indigenous languages shows how the people consider it a food equal to meat, which protein analyses show to be true (Boa, 2004; Härkönen et al., 2015).

In Namibia, only one species appears to be regularly consumed, or even known, by the country's citizens, the robust *Termitomyces schimperi* (Figure 8), or the *omajowa* as it is known to locals. Yet, three other species were found growing on the study farm, *T. umkowaani*, *T. microcarpus*, and *T. tyleranus*, all edible, and the chance is good that others grow in the region as well. Moreover, the fact that there are approximately 100 species of fungus-farming termites in Africa, yet only 18 described species of *Termitomyces* (Table 6), suggests plenty of opportunity for more species to be discovered (Kuja et al., 2014).

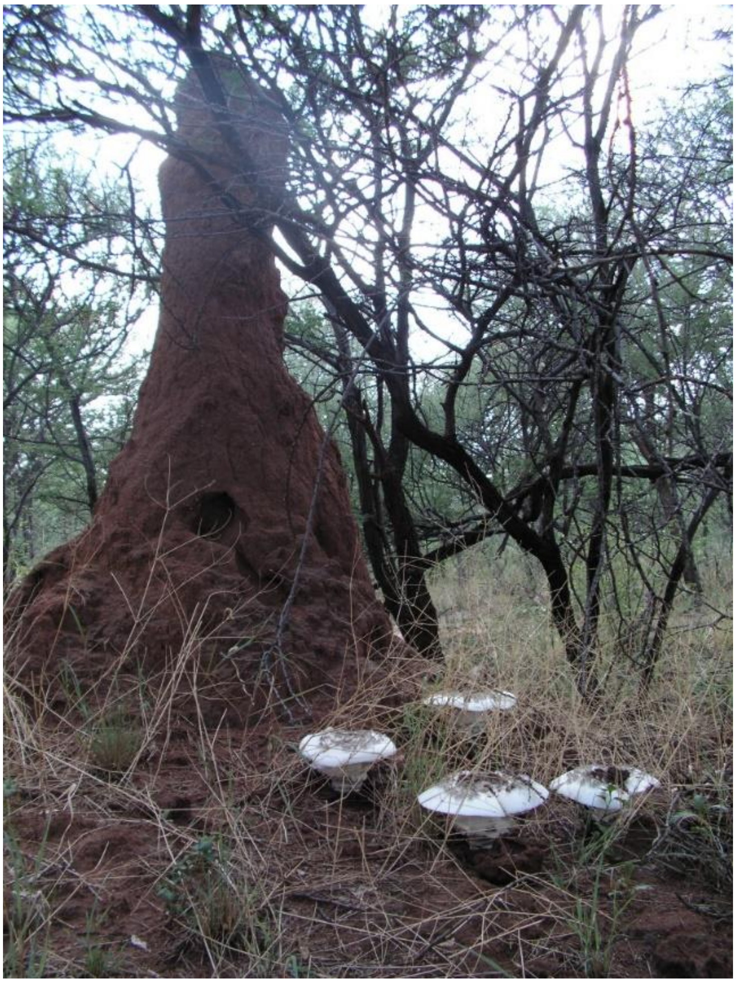

Figure 8. Termitomyces schimperi

Table 4. Species of Termitomyces *in Africa. Note: Several countries in* Termitomyces *range notably missing from this list (e.g. Namibia)*

Species	Region of Collection
T. clypeatus	Nigeria, Kenya, Uganda, Tanzania, South Africa
T. robustus	Nigeria, Kenya, Uganda
T. microcarpus	Nigeria, Kenya, Tanzania, Uganda, South Africa
T. aurantiacus	Tanzania, Uganda

T. globulus	Kenya
T. letestui	Tanzania, Kenya, Uganda
T. mammiformis	Tanzania
T. rabuorii	Kenya
T. schimperi	Kenya, Ethiopia, Tanzania, South Africa
T. singidensis	Tanzania
T. tyleranus	Kenya
T. striatus	Kenya, Uganda, Congo, South Africa
T. eurrhizus	Kenya, Tanzania, Uganda, Congo
T. umkowaani	Tanzania, South Africa
T. titanicus	Tanzania
T. saggitiformis	Tanzania, South Africa
T. reticulatus	South Africa
T. heimii	Kenya

Source: Kuja et al., 2014

It is not for lack of trying that termite fungi have not yet been cultivated, but laboratories cannot yet match the ideal conditions provided by the termites (Härkönen et al., 2015). While the process continues to be tested, locals can collect and sell these species for a good price (from personal experience, large specimens can go for N$30, about US$2). It is, therefore, recommended that emphasis is placed on further research regarding which *Termitomyces* species grow in Namibia, plus education programs to teach locals to identify the edible species as well as to harvest using sustainable methods.

4.3 Domesticating and Cultivating Macrofungi in Namibia

As mentioned above, fungi-related industries can positively impact social and economic issues therefore, domestication and cultivation of wild edible species could be help Namibia in these areas. In order to find appropriate fungi to be industrialized, it must first be determined if the fungi is edible (or medicinal) and establish if it can be cultivated. To this end, local indigenous knowledge is extremely helpful. Field collection is also important. Here, new species may be found, as well as new strains of known species. Then, the best strains and the right growth parameters must be determined. (Thawthong et al., 2014) Furthermore, scientists and others involved in the research, collection, and analyzation of fungi must share information and expertise in order to facilitate the process (Chang, 2008)

In Namibia, a further challenge facing such an industry is the often hot and dry climate. Because fungi need specific environmental conditions to grow (Chang, 2008; Gwanama, 2011), care must be taken to manufacture the proper climate in a secure room, a common problem for African fungi farmers (Osarenkhoe, 2014). This is also crucial to keeping it a low-water-use enterprise which is essential to its success in Namibia. Yet, there are low-cost methods to achieve these conditions, such as positioning the grow room under a tree to protect against direct sun and wind, or partially or completely underground (Gwanama, 2011).

Alternatively, any potential industry should not struggle with the acquisition of substrate. The substrate is essential to the growth of fungi and may differ depending on the species. But agriculture waste is often used for this purpose (Boa, 2004; Chang, 2008), a resource which, to the best of the author's knowledge, remains unexploited in Namibia. It is also possible to cultivate fungi in a "semi-industrial" format, where natural environments (e.g. soil or dead trees) are inoculated with fungi and then produce fruiting bodies when environmental conditions are right. Here again, indigenous knowledge is useful in order to discern the ecology of the fungi and improve chances of successful inoculation. (Thawthong et al., 2014) This system may be easier for rural communities without access to supplies needed for the more industrial processes. However, the flow of fungal products will be limited to the rainy months of the year.

5. Conclusion

This study has concluded that, despite highly variable rainfall and an as-of-yet uncertain estimate of species richness, Namibia has a vast, untapped natural resource in its macrofungi, which can help national issues such as poverty, malnutrition, food security, unemployment, women empowerment, and sustainable land management. In the thorn bush savanna region, several species were found which are known to be edible, indeed, eaten in other regions in Africa, as well as used for medicinal purposes, and cultivated around the world using low-cost technologies. Yet, they remain either unknown or considered useless in Namibia. This, plus the dozens of other unidentified species found and lingering ecological questions highlights the need for more research to be done in this field, plus a public education series regarding hitherto unknown or untrusted species and sustainable harvesting techniques. There is also ample opportunity for a fungal-product industry in the country with institutions already in place for facilitation. Ultimately, social and environmental conditions, including changing weather patterns due to climate change which are expected to negatively impact the region’s rainy season, make the matter of conserving knowledge and specimens of Namibia’s macrofungi increasingly urgent.

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Appendix I

Field Record Sheet

Date:

Location:

No.:

GPS:

Photo:

Habitat:

Habit:
Solitary
Scattered
Group
Clustered

Substrate:
Sand
Clay
Wood
Termite Mound (TM)
Dung
Disturbance

Last burn:

Prox. to TM:

Prox. to nearest tree/tree species:

Taste:

Odor:

Bruising/color:

Latex:

Pileus Size:

Pileus Color/texture:

Pileus shape/margin:

Location of stipe:

Stipe length/width:

Stipe shape/base:

Stipe color/texture:

Stipe hollow:

Lamellae orient./color:

Lamellae attachment/margin:

Annulus:

Volva:

Spore print:

Notes:

Appendix II

DNA-analyzed Species and Descriptions


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1 – *Agaricus* sp. - In grass or sandy soil. Bruises yellow quickly when cut. In pairs or solitary. Mild mushroomy smell and taste.
Pileus – young 4 cm, mature 10 cm. White flesh with brown, depressed apex and brown scales radiating out from center. Convex when young and nearly all brown, plane with age. Margin shaggy with veil remnants.
Stipe – Central, 5-8 cm long, 1.5-2 cm wide, white, smooth, single annulus, bulbous base on one, hollow.
Lamellae- Light pink when young, dark brown with age, crowded, covered with veil when young, free.
Spores – dark brown

2 – *Agaricus subsaharianus* - In vicinity of termite mounds. Gregarious, some under acacias or rocks. Clustered to solitary. Strong odor –like mushroom mixed with paint. No bruising.
Pileus – 6 cm when young to 22 cm when mature. White with brown shaggy scales that become raised when mature. Square to round when young, convex to nearly plane when mature. Margin closed when young with thick, floccose veil becoming a sheath-like ring, which quickly disappears. Margin inrolled with shaggy veil remnants which also disappear with age.
Stipe – central, long, thick. 9 cm – 20 cm long, 2-6 cm wide. Straight to wavy, tapers at base, single rhizome, white, smooth.
Lamellae – pink when young to light brown to dark brown with age, free, crowded.
Spores – dark brown

3 – *Agaricus* sp. - In disturbed sand. Solitary to clustered. Distinct almond extract smell when fresh, disappears with time. No bruising.
Pileus – 1 cm when young to 4.5 cm when mature. Golden yellow/orange when young, white at margin. Mature only yellow/orange at apex, otherwise white. Both young and mature have light brown, appressed scales throughout. Conical with flat apex when young to broadly convex to plane.
Stipe – central, 2 -2.5 cm long, 1 cm wide. Fairly straight and even with bulbous base. White, fibrillose when young. Intermediate age white, fibrillose only below annulus but light pink above. Mature is smooth and darker white.
Lamellae – White when young, light pink when intermediate, mature are wine-colored brown. Free. Thin, floccose veil when young becomes skirt-like annulus, then gone with age.
Spores- brown

4 – ***Agaricus* sp. –** In vicinity of termite mounds by dam and at bases of several surrounding umbrella acacias (*Acacia tortilis*). Clustered. Chemical smell. No bruising.
Pileus – 2.5 cm to 10 cm. Brown with brown appressed scales when young to becoming white with brown scales with age. Mature are often covered with spores of others in the cluster but appear to be white with

scales still visible. Squarely convex when young to plane when mature. Stipe – central, 2-2.5 cm when young to 9 cm long when mature. 2 cm thick when young, thins with age. Straight to wavy, white, smooth. Lamellae – light brown when young to dark brown, almost black with age. Never pink. Close, free, veil thick when young. Semi-persistent, upturned ring, remains with age.
Spores – dark brown

5 – *Coniolepiota* sp. – In vicinity of termite mounds. Often under swarthaak acacias (*Acacia mellifera*). Solitary to clustered, usually at least two together. Pleasant mushroom odor. No bruising.
Pileus – youngest measured 1.5 cm. Mature size of a dinner plate. Young are coated with fine, lavender fuzz. Large black scale at apex. Mature often have faint remnants of lavender fuzz, otherwise all white, thick, fleshy, smooth. Squarely convex to broadly convex and finally plane when mature. Margin is closed with veil when young.
Stipe – central, 10-15 cm long, 2 cm wide. Wavy, base slightly bulbous, white, striate. Annulus lavender, floccose, and skirt-like.
Lamellae – always white, crowded, free.
Spores – white

6 - *Leucocoprinus* sp. – In soil, possibly growing on woody debris underground. Solitary or in pairs. Mushroom odor. No bruising, but white powder rubs off of stem revealing off-white to yellow stem.
Pileus – (no juveniles or very mature specimens) 4 cm, all white with white scales. Conical to broadly conical. Margin striate.
Stipe – central, 0.5 cm wide, 6 cm long, wavy, smooth, white powder rubs off easily. Widens at base, stipe hard, snaps open like green bean. Thin, fragile, skirt-like annulus.
Lamellae – white, close, free.
Spores – white

7 – *Agaricus* sp. – Grows on termite mounds. Solitary, in pairs, or clustered. Strong smell of unwashed feet.
Pileus – Smallest specimens have unformed pileus, just an extension of stipe. Expands to 5 cm, mature 12 cm. White but covered with fine, brown hairs that rub off with slightest touch. They are appressed when pileus is below ground but once out, they become clumped and uplifted, giving a 'spiky hair' appearance. Young are convex and inrolled. Mature are thick, fleshy and significantly uplifted.
Stipe – central, 3 cm wide by 5 – 8 cm long, narrows at both ends. Light brown, smooth, does not break cleanly.
Lamellae – Light brown when young with pink tinge, dark brown with age, close, free. Small, thin veil when young.
Spores – dark brown

8 – *Agaricaceae* - In grass in disturbed sandy soil. Grouped or small clusters. No odor.
Pileus – 1 cm to 7 cm. White but nearly solidly covered with red flecks/fibrils which become less dense with age. Smooth but slightly rubbery texture. Convex to broadly convex. Margin retains some veil remnants giving a shaggy appearance.
Stipe – central, 2.5 – 8 cm long by almost 1cm thick. White with reddish tinge toward base. Smooth with light fuzz toward base. Straight to wavy, even thickness throughout. Does not break cleanly.
Lamellae – white, browning with age, close, free.
Spores – milk chocolate

9 – *Lepista sordida* - In disturbed, sandy soil. In scattered clusters. Mushroom odor.
Pileus – 1 cm to 6cm. Translucent light brown/gray/purple color when moist, dries to a dirty white/light brown/gray. Smooth, deeply indented with inrolled margin. Less pronounced and less inrolled when young. Margin striate. Thin and fragile flesh.
Stipe – central, 2.5 – 6 cm long, 0.5-1.5 cm wide. Straight to slightly wavy. When young, color is that of pileus. When mature, base is tinted lavender. When broken, also turns lavender. Striate, smooth.
Lamellae – distant, color of pileus, decurrent.

Spores – beige

10 – *Agaricus* sp. – On termite mound. Clustered. In significant shade. Plastic odor.
Pileus – 3.5- 10 cm. White with fleshy, yellow scales covering most of pileus. Thick yellow skin at apex with brown flecks. Young are convex, mature become broadly convex (probably plane when fully mature).
Stipe – central, 5-10 cm long. Wavy, thins toward base, striate, smooth. Brown when broken open. White above annulus, darker below.
Lamellae – close, free, faint olive green when young which darkens with age. Partial to full veil when young, thin and cottony with heavy cottony chunks throughout.
Spores – black

11 – *Volvariella volvacea* – In shade. At foot of termite mound. Scattered. Mushroom taste. Smell like rotting mushroom.
Pileus – 8 to 14 cm. Light brown with darker flecks radiating out from apex. Smooth, viscid when wet. Convex when young, plane when mature. Margin has darker brown flecks and is shaggy.
Stipe – central, 7 cm long, 1.5 – 2 cm wide. Straight, but angles slightly at the bulbous base. White to light brown with fine white fibrils easily rubbed off. Smooth and snaps cleanly.
Lamellae – Crowded when young, spread out slightly with age. Cream colored when young, pink with orange tint when mature. Free, upturned when mature. Universal veil (egg), persistent, but gone at maturity. No ring.
Spores – Rusty to dark brown
Note: Appears to also have a white-capped variety

12 – *Lepiota* sp. - In sand, near base of acacia (*A. tortilis)*. Solitary, scattered. No odor. No bruise.
Pileus – 1 mm to 2 cm when mature. Thin, fragile. Solid orange when young, to white with orange/brown apex when mature. Round when young to conical then plane or concave. Orange/brown flecks radiate out from apex when mature. Ridged radially (rivulose).
Stipe – central, 2 cm long, 1 mm wide when mature. Straight, even. White, with white fibrils.
Lamellae – free, distant, some intermediate. White, margin scalloped when mature. No annulus or volva.
Spores- Not able to collect

13 – *Ganoderma* sp. – On dead swarthaak. White, globose when young. Matures to fan-shaped, rusty red, off white margin. 6 cm wide, 1 cm tall. Spores - brown

14 - *Phellinus* sp. – On swarthaak.

15 – *Inonotus* sp. – On dead tree.

16 – *Panus* sp. – On dead wood.

17 – *Bovista* sp. – In sandy soil. Solitary. 3 cm wide, 2 cm tall. One or two spore spouts at apex. Leathery brown flesh.
Spores - brown

18 – *Auricularia* sp. – On dead wood.

19 – *Termitomyces tyleranus* – Amongst grass in sand. Groups. No termite mound or tree nearby. No odor. No bruise.
Pileus - 0.5-1 cm when young, mature up to 3.5 cm. Young off-white, old light gray/brown. Always has darker brown umbo. Smooth. Convex when young, matures to plane. Margin even when young, splits as ages.

Stipe – central, free. 1 cm long when young, 5 cm when mature, 0.5 cm wide. Straight, fibrillose, white, slightly curved at ground level. Short, white, fragile pseudorhiza bent at right angle at connection to fungal garden.
Lamellae – white, close, fairly eroded when mature. No annulus.
Spores – beige

20 – *Panaeolus papilionaceus* – In soil or on cow dung. No odor.
Pileus - Conical when young, plane when mature, 2-3 cm. White or gray, darkens toward apex, sometimes faintly iridescent. Darkens with age.
Stipe- 5 cm long, 0.5 cm wide, white turns reddish brown with age or when bruised.
Lamellae- Black, mottled gray, distant, free. Intermediate lengths.
Spores - black

21 – *Vascellum praetense* – In sand. Solitary to grouped.

22 - *Amanita* sp. (*foetidissima*?) - Amongst grass in sand. Scattered. Sweet, faint mushroom odor. Bruise slightly to dark yellow.
Pileus – 4-9 cm, thick and fleshy. Light yellow to white. Floccose scales, easily damaged. Convex when young, hemispheric when mature. Margin slightly incurved with hanging wooly bits.
Stipe – fairly central, same color as pileus. 2.5-7 cm long, 2-3 cm wide. Base slightly bulbous on two specimens. Powdery, rubs off easily. Fleshy.
Lamellae – close, free, even margin. Same color as pileus. Skirt-like annulus, single edged.
Spores – white or cream

23 – *Agaricaceae* – At base of raisin bush (*Grewia falcistipula*) in sand. Clustered. No odor.
Pileus – 1-5 cm, white, yellow tint darkening toward apex to greenish tint. Smooth, broadly convex in all ages, smooth margin.
Stipe – central, 3.5-7 cm long, 0.5-1 cm wide. Even, smooth, shiny white.
Lamellae – free, close, smooth margin. White in all ages. Annulus thin, skirt-like, present when mature.
Spores – milk chocolate

24 – *Hymenagaricus* sp. – At base of termite mound, in shade. Grouped. Faint, slightly sweet odor. Bruise light brown when damaged.
Pileus – 1-3 cm, thin. White with distinct yellow/green coloring darkening toward apex. Apex olive green/brown. Smooth, some olive green flecks. Conic when young to broadly convex or plane. Smooth margin.
Stipe – central, 5-8 cm long, 2 mm wide. Even, wavy, white, smooth.
Lamellae – white to gray when young, brown when mature. Close, free, even margin.
Spore – dark brown with yellow/green tint

25 – *Agaricus* sp. (*diminutivus*?) – At base of termite mound. Scattered to clustered. Strong mushroom smell. Bruise darker pink. Often fruit in large numbers.
Pileus – 1-2.5 cm. White to light pink with dark pink to purple scales at apex. Slightly pubescent. Squarely parabolic when young, mature convex. Margin striate.
Stipe – central, 4-5 cm even when young. Less than 0.5 cm wide. Straight to slightly wavy, white with white fibrils, appresses easily.
Lamellae – white to off-white when young, age to light pink. Crowded, free. Persistent annulus, white, floccose, skirt-like.
Spores – milk chocolate

26 – *Agaricus* sp. – Clustered on side of termite mound. Strong almond extract smell when fresh. No bruise.

Pileus – 5-8 cm, white with brown apex and brown radiating scales. Slight yellow tint. Broadly convex to plane but wavy. Margin even, though often scalloped.
Stipe – central, 5-9 cm long, 1 cm wide. Fairly even, widens toward base where clustered with others. Wavy, soft and fleshy. Smooth and white.
Lamellae – light pink becoming light then dark brown. Close, free, even margin. Annulus white, skirt-like, fragile.
Spores – dark brown

27 – *Agaricus* sp. – In sandy soil.

28 – *Lepiota* sp. – Amongst grass in sand. Scattered. Distinct mushroom odor.
Pileus - 0.5-2 cm. Dark orange apex with pronounced umbo, lightening toward margin. Parabolic when very young to broad with umbo when mature. Smooth, even margin.
Stipe – central, 1-3 cm long, 2 mm wide. Even, dirt clumps around base. Same color as pileus, smooth.
Lamellae – spaced, cream-colored, free, margin even.
Spores – cream?

29 – *Lyophyllaceae* – In soil in shade of swarthaak (*Acacia mellifera*). Scattered, some groups. Odor of plastic/mushroom.
Pileus – 2.5-5 cm, white to off-white, smooth, no flecks. Convex, margins irregular, decurved. Convex striations around margin 0.5cm in length. Hard, scratches remain visible.
Stipe – off-center, 2-5 cm long, 1 cm wide. Curved, smooth, white, bulbous base.
Lamellae – close, some intermediate. Off-white, slightly decurrent, even margin. Appear to peel away from pileus.
Spores – white?

30 – *Termitomyces* sp. – At base of termite mound. Scattered. No odor.
Pileus – 4.5-10 cm, white, smooth, mature has striations from apex to margin. Convex when young, plane when mature with small umbo. Margin slightly in rolled when young, mature even, thin.
Stipe – central, 5-8 cm long, 1-2 cm wide. Tapered at base and apex. White, smooth to halfway down then fine white scales to base. Fleshy.
Lamellae – close, free, cream colored, even margin. Long, white pseudorhiza, striated, at least 8cm long.
Spores – beige

31 – *Amanita* sp. – Scattered. In sand in shade. Faint odor, indistinct. Bruises pink when cut.
Pileus – 1-7cm. White with faint yellow umbo. White flecks radiating toward margin. Rub off easily. Conic and parabolic when young, ages to plane with gills uplifted. Margin strongly decurved when young, striate in all ages.
Stipe – central, 1-6 cm long, 0.5-1 cm wide. Even, white, smooth, some striations on mature stipe.
Lamellae – free, close, white, slightly graying with age, even margin. Double-edged annulus.
Spores – white

32 – *Macrolepiota* sp. - In sand. Solitary. Strong odor of honey detectable from a distance. Only one, mature specimen.
Pileus – 10 cm wide, 1.5 cm thick. White to off-white with light brown scales radiating from apex. Broadly convex, slight veil remnants perhaps, hanging over margin. Rolled. Margin even.
Stipe – central, 12 cm long, 1 cm wide. White, smooth, even, slightly bulbous at base. Cleaner, whiter above where annulus may have been. Some white scales beneath.
Lamellae – free, spaced, cream colored. Short and intermediate lengths. Margin even. Possible annulus.
Spores – off-white

Appendix III

Additional Identified Species Found 2012-2017

***Agaricus campestris* –** Edible.
Agaricus trisulphuratus
***Calvatia lilacina* –** Edible.
***Chlorophyllum molybdites* –** Poisonous.
Coprinopsis nivea
***Coprinus comatus*-** Edible.
Deconica coprophila
Geastrum triplex
Itajahya galericulata
Lentinus velutinus
***Macrolepiota* sp.**
Myriostoma coliforme
Parasola plicatilis
Termitomyces microcarpus – Edible.
Termitomyces schimperi – Edible.
Termitomyces umkowaani – Edible.
***Tulostoma* sp.**
***Xylaria* sp.**