

Towards an Integrated Approach of Conducting Fungal Research in Costa Rica

Hacia un enfoque integrado de investigación micológica en Costa Rica
Em direção a um enfoque integrado de pesquisa micológica na Costa Rica

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Abstract

Costa Rica is a small country in Central America with a recent history of fungal research. However, comparative differences with other territories in the Mesoamerican Biodiversity Hotspot region have promoted the study of fungi and the integration of fungal information with natural resource management. Even though there is still a large number of multidisciplinary aspects to cover in Costa Rica for robust incorporation of fungal data in conservation and political and developmental agendas, regional advantages have allowed this country to move towards such goal more rapidly than other countries in this part of the world. Mycoliteracy-centered and citizen science initiatives seem to be the next step in order to normalize disparities in fungal perception across regions within the country and promote social interaction with fungi. However, in general terms, the Costa Rican society seems to be aware of the potential of fungi as a source of food and medicines and their remarkable contribution through ecosystem services. In this manner, fungal conservation and management seem easier to conduct in this territory than in other regions of the world where less information on fungi has reached the general population.

Keywords: bioliteracy; Central America; fungi; natural resources

Resumen

Costa Rica es un país pequeño en la región centroamericana, con una reciente historia de investigación micológica. Sin embargo, algunas diferencias comparativas con otros países de la región biológica



mesoamericana han promovido el estudio de los hongos y su integración con el manejo de los recursos naturales. Aun cuando todavía existe un sinnúmero de elementos por cubrir en Costa Rica, para una incorporación robusta de datos micológicos en la conservación y el desarrollo de agendas políticas sobre recursos naturales, algunas ventajas regionales han permitido que este país avance hacia tal objetivo más rápidamente que otros. Iniciativas de micoalfabetización y ciencia popular parecen ser los siguientes pasos para normalizar desequilibrios en la percepción sobre los hongos, que tienen diferentes regiones en Costa Rica, con el propósito de instar interacciones con estos organismos. No obstante, en términos generales, la sociedad costarricense parece estar más atenta al potencial de los hongos como fuente alimenticia y medicinal, al igual que a reconocer el rol de dichos organismos de facilitar servicios ecosistémicos. De esta forma, la conservación de hongos y su manejo parecen ser más fáciles de llevarse a cabo en este territorio que en otras áreas del mundo, donde mucho menos información sobre ellos ha llegado a la población general.

Palabras claves: alfabetización biológica; Centroamérica; hongos; recursos naturales.

Resumo

A Costa Rica é um país pequeno localizado na região centro-americana, com uma recente história de pesquisa micológica. Porém, algumas diferenças comparativas com outros países da região biológica mesoamericana têm promovido o estudo dos fungos e sua integração com o manejo dos recursos naturais. Ainda que exista inúmeráveis elementos a serem cobertos na Costa Rica para uma incorporação robusta de dados micológicos na conservação e no desenvolvimento de agendas políticas sobre recursos naturais, algumas vantagens regionais têm permitido que este país avance em direção a este objetivo mais rapidamente do que outros. Iniciativas de alfabetização micológica e ciência popular parecem ser os seguintes passos para normalizar desequilíbrios na percepção sobre os fungos existentes em diferentes regiões da Costa Rica, com o propósito de instar interações com estes organismos. Não obstante, em termos gerais, a sociedade costarricense parece estar mais atenta ao potencial dos fungos como fonte alimentar e medicinal, assim como ao reconhecimento do papel de estes organismos facilitarem os serviços ecossistêmicos. Desta forma, a conservação de fungos e seu manejo parecem ser mais fáceis de serem levados a cabo neste território do que em outras áreas do mundo, onde muito menos informação sobre eles chegaram à população geral.

Palavras-chaves: alfabetização biológica; América Central; fungos; recursos naturais.

The study of fungi in Costa Rica is very recent in comparison with other countries in the world. Even for standards within the Neotropical region, mycology in Costa Rica became established later than in other territories. However, the current extent of mycology and the developments of the last three decades have allowed Costa Rican mycology to be recognized internationally. This review briefly examines

the history and potential of this discipline for integrated future research with applied benefits for Costa Rica and other countries with similar conditions. This paper also focuses on the attempts to carry out interdisciplinary and multi-institutional mycological work in Costa Rica with support from public Costa Rican institutions.



The Multidisciplinary Extent of Fungal Research in Costa Rica

Fungi have been said to be more diverse in tropical regions (Aime and Brearley, 2012), but estimates on the number of potential species in these areas of the planet have yet to be revised (Hawksworth, 2012). Modern techniques of study have created a revolution in both the rate of description of new species and the use of fungi for bioprospective research. Ironically, most of the tropical regions in the world, particularly in Africa, still lack basic elements to cope with the increasing demand to study fungi (see Gryzenhout *et al.*, 2012). The most important of those elements is perhaps the availability of qualified personnel conducting research according to local interests. In Latin America, for example, some countries such as Costa Rica have had such human element present during the last 50 years or so, and mycological research, albeit limited in some ways, has rapidly progressed during this time.

As it was the case in many other territories, earlier studies of fungi in Costa Rica focused on the documentation of terrestrial macroscopic forms (i.e., Rowlee, 1924; Stevens, 1927; Gray and Dodge, 1934). More complex analyses were carried out later (i.e., Farrow, 1954; Denison, 1963; Bazan and Segura, 1970), but still within the framework of biodiversity studies. Foreign researchers have conducted most of these studies, but these studies have allowed the Costa Rican academy to develop an interest in mycology. The latter derived in professional training that allowed local researchers to start developing research projects independently. For instance, the effort of the local researcher José Alberto Sáenz, a founding member of the University of Cos-

ta Rica's School of Biology (García, 2009), is remarkable in this sense since he founded the mycology section at that venue during the 1960s. Some decades later, however, the local researchers Marissia Nassar, Ana Victoria Lizano, Luis Diego Gómez-Pignataro, and Julieta Carranza were responsible for training the current generation of Costa Rican mycologists. Currently, Priscila Chaverri and Melissa Mardones carry out their work as part of highly-qualified international teams.

Even though the history of mycological study in Costa Rica is very recent, the development of mycological research in this territory has been more prominent than in other countries within the Central American region (see earlier prominent studies such as Singer and Gómez-Pignataro 1984; Gómez-Pignataro, 1996). Such a result is a partial product of a strong research-oriented academia, better comparative research infrastructure than other regional countries, political stability, and more developed historical-professional networks. The development of research on myxogastrids, a group of amoebae once considered part of the fungi, is an example of that type of coordinated effort taking place in Costa Rica during the last 50 years (Rojas and Doss, 2013).

Estimates show that there are about 3,800 species of fungi recorded in Costa Rican lands (Obando, 2007). This number accounts for about 6% of what it is expected in Costa Rican territory and about 5% of what it is known in the world today (Obando, 2013). As a reference, the Global Transboundary Conservation Network (www.tbpa.net) acknowledges that the Mesoamerican Biodiversity Hotspot, where Costa Rica is located, may have up to 10% of the global biodiversity. Considering that fungi in most of the regional territories have not been studied as



much as in Costa Rica (even in some of the biodiversity-rich southern states of Mexico), the potential biodiversity values for the Mesoamerican region are remarkable.

Of course, the importance of biodiversity studies relies on the use of data for conservation decisions and policy development (Margules *et al.*, 2002) in an integrated manner with socioeconomic development and research initiatives. According to Cantú-Salazar and Gastón (2013), a discrepancy between biodiversity-rich areas and lands designated for protection does have a strong negative impact promoting truly effective public conservation efforts. In developing regions like Mesoamerica, such disconnection may have enormous consequences when ecosystem services and bioprospection studies are considered. In Costa Rica, the Biodiversity Law (Ley 7788, 1998) defined in article 7 that fungi are part of biodiversity, and therefore fungal resources are fully regulated by law in Costa Rican territory. The simple addition of the word “fungi” in such law has promoted both fungal research and fungal conservation efforts within the country. Even though there is still much work to do, Costa Rica counts on an attractive model of integrated biological conservation when compared with other regional countries. As such, the chapter on biodiversity in Costa Rica’s periodic report about the state of the nation includes an estimate of fungal biodiversity and guidelines for fungal conservation (see Obando, 2013).

This connection between fungal resources and government policy in Costa Rica was promoted rapidly with the work carried out by the researchers Milagro Mata and Loengrin Umaña at the National Institute of Biodiversity (INBio, www.inbio.ac.cr), between 1989 and 2015, when the most recent conservation legislation was created.

The effort of the research team at this institution allowed the characterization of about 50,000 specimens of fungi during that time (Vargas, 2016). These specimens protect the biochemical and genetic components of fungal biodiversity according to Costa Rica legislation and are currently deposited at the National Herbarium of Costa Rica (CR) as natural heritage of the nation. Along with the collection of about 5,500 fungal specimens at the CR Herbarium (Armando Ruiz-Boyer, pers. comm.) and approximately 16,000 specimens at the University of Costa Rica Herbarium (Mitzi Campos, pers. comm.), Costa Rica has the largest scientific collection of fungi in Central America with about 1.4 specimens per square kilometer of terrestrial land. As a collateral reference of the work carried out on fungi, Costa Rica is also one of the best studied tropical countries in the world in relation to myxogastrids (Rojas *et al.*, 2010), with about 25% of the global diversity of these organisms (Lado *et al.*, in prep).

Currently, fungal research in Costa Rica still covers the basic biodiversity aspect (Desai *et al.*, 2016, Coronado-Ruiz *et al.*, 2018). However, applied bioprospective studies have gained momentum (Rojas-Jiménez *et al.*, 2016; Lee *et al.*, 2016) after the work of Giselle Tamayo in the National Institute of Biodiversity (see Gámez, 2007). Ecological studies dealing with fungal dynamics are rare but have also been carried out in the last years (Rojas and Calvo, 2014; Rojas *et al.*, 2017; Looby and Treseder, 2018). Fungal studies for agricultural purposes, the focal point of mycological research in Costa Rica for many years, are still conducted in this territory (Marín-Chacón *et al.*, 2017; Castro-Chinchilla and Umaña-Rojas, 2017, McGee *et al.*, 2018), and medical mycology has been



recently approached for applied purposes (Jaikel-Viquez *et al.*, 2015). Interestingly, one of the few ethnomycological studies carried out in Costa Rica was also conducted recently (Molina-Murillo *et al.*, 2015).

Mycology has greatly expanded its range of application across multiple disciplines in Costa Rica during the last decades. It is simply expected for this trend to continue in the development of future research. Mycology in Costa Rica has evolved to be a multidisciplinary field, and fungi have been acknowledged to be important for lifestyles and modern integrated approaches to manage natural resources such as forests (Molina-Murillo and Smith, 2016). There are still several fields of applied study and multiple opportunities to promote the integration of fungal resources with other aspects of modern life, such as food security, human health promotion, and engineering or industry applications. Along with the development of computer science modeling using fungi, these areas represent, the direction where most of the mycological efforts would probably yield quantifiable results for the Costa Rican society in this part of the 21st century.

Comparative Fungal Dynamics in Costa Rican Forests and Potential for Integrated Management Strategies

Fungi are essential for ecosystem functioning (Dighton, 2016), and services provided by working ecosystems are pivotal elements of development and lifestyle for human societies (Newbound *et al.*, 2010). However, due to a modern personal disconnection from natural elements of their surroundings (Nisbet and Zelenski, 2011; Rojas *et al.*, 2016), most individuals fail to

recognize the existing links between fungal components of nature and their own personal life. For instance, unfamiliarity with the role of fungi for soil health in terrestrial ecosystems, a traditional function of fungi on the planet, carries on importance when soil management is not considered in productive lands. The deprivation of soil fungi by extensive soil compaction or overuse of external nutrients creates an imbalance in fungal populations that influences the rest of the ecosystem (see Garbeva *et al.*, 2011) and increases dependence on external inputs. In Costa Rica, significant differences in the activity of soil microorganisms, including fungi, have been documented in different productive systems. These records have shown that intensive agricultural practices have a strong negative effect on the activity of microorganisms in the soil (Sibaja *et al.*, 2018).

The simple understanding of natural processes involving fungi and the provision of ecosystem services, mediated by the different species within the group, are still necessary in most parts of the world, including Costa Rica. Recent multidisciplinary approaches involving specialists in education, tourism, biology, public policy, and conservation have been set up and will be tested in the upcoming years. From a biological perspective, strong ecological documentation of fungal species and assemblages over time is necessary. However, the design of the latter type of studies should also consider national priorities and regional inequalities to also promote some socioeconomic development during its execution.

Ecological studies on fungi are critical to reaching tangible conservation guidelines, since analyses at the ecosystem level, where fungi are essential, show the importance of the group more prominently. In Costa Rica,



most of this type of studies have been carried out in the last three decades. Examples of this are the early efforts of [Bills and Polishook \(1994\)](#) who studied leaf litter fungal dynamics, focusing on fungus-epiphyte associations, and [Lindblad \(2000\)](#) who examined the host specificity of wood-inhabiting fungi. More recently, [Halling and Mueller \(2005\)](#) examined macrofungal associations with *Quercus* forests, [Puschendorf et al., \(2006\)](#) studied the relationship between chytrids and amphibian declines, and [Del Olmo-Ruiz and Arnold \(2013\)](#) documented endophytic fungi dynamics associated with ferns.

Interestingly, one of the patterns observed in these studies is that they have focused on across-kingdom taxonomic relationships rather than ecosystem dynamics. Even though the former documentation is important for scientific purposes, such research does not necessarily generate outcomes that are translatable into information for human societies to grasp, digest and apply. This phenomenon is a partial consequence of higher education training in Biology, in which curricular structures tend to neglect socioeconomic implications ([Bazzul, 2014](#)). In this sense, within biological or environmental sciences, few studies have been produced in Costa Rica where fungi are documented within the framework of ecosystem service provision and potential socioeconomic impact on local societies.

During the period 2011–2014, researchers at the Engineering Research Institute of the University of Costa Rica started a monitoring project intended to evaluate the dynamics of fungal populations in the context of forest performance. For this project, two areas in the country were selected, where two different 25- to 30-year-old forest sections of 0.2 ha were studied, for a total of four different forest biosystems un-

der examination. One of the general areas was a seasonally dry forest and the other a premontane wet forest with macroclimatic differences in rainfall, temperature and cloud cover. For this reason, all plots were instrumented with temperature, atmospheric humidity, and luminosity loggers; and hemispherical photographs were obtained for canopy cover characterization performed every three months. At the same interval, field surveys of macrofungi and a characterization of carbon stocks were carried out in all plots. A complete soil characterization was also performed for all forest types. The most important results were summarized in [Rojas and Calvo \(2014\)](#) and [Rojas et al., \(2017\)](#).

Overall, the two forest patches in the seasonally dry forest showed lower tree density values, lower canopies, and less voluminous trees than premontane wet forests. Similarly, average ground biomass and carbon dioxide equivalent units per hectare, an estimate of potential contribution to carbon neutrality programs, were lower in the seasonally dry forests. The average temperature value in the dry forest was 26.6 ± 4.1 versus 16.6 ± 1.6 in the premontane wet forest; and average humidity was 73.6 ± 18.1 versus 78.5 ± 19.9 for the same comparison. Canopy dynamics, average number of seedlings, and luminosity were more variable in the seasonally dry forests than in the premontane forests. From a forestry perspective, carbon stock-related and microenvironmental values looked better in the premontane wet forests despite significant differences in temperature (but not in humidity). However, when the fungal component was included in the analysis, results showed a more complex scenario.

Macrofungal dominant forms in the seasonally dry forests were classified in the



genera *Collybia* and *Marasmius*, whereas *Laccaria* and *Lactarius* dominated the pre-montane wet forests, and no differences in the number of fruiting bodies or total fungal biomass per hectare were found. In general, soil and wood-associated macrofungi had larger reproductive structures but were less heavy, in terms of dry weight, in the seasonally dry forests than in the pre-montane wet forests. These results were interesting since dominant forms in seasonally dry forests were mostly saprophytic, whereas dominant forms in pre-montane wet forests were mostly mycorrhizal. Even though mycorrhizal forms were significantly heavier than saprophytic ones, the allocation of biomass resources also differed among these two. Macrofungi in forest patches with higher carbon-stock values allocated less resources in the production of hymenial areas than macrofungi in forests with lower carbon values. The relationship between a hymenial area and dry weight was $3.34 \text{ mm}^2/\text{g}$ for mycorrhizal versus $8.26 \text{ mm}^2/\text{g}$ for saprophytic fungi. Interestingly, the latter measurement showed strong correlations with temperature ($r=0.99$), light intensity ($r=0.94$), and canopy openness ($r=0.99$). Even though most visually appealing forms (mycorrhizal) were present in pre-montane wet forests, the ecosystem service, provided in the form of decomposition by the more diverse saprophytic forms in the seasonally dry forests, was an important finding of those studies and has not been considered for forest management plans in that part of the country.

Further analyses showed that canopy openness and phosphorus, a forest structural variable and a chemical soil parameter, resulted to be the two most important variables explaining the general microclimate of the two studied areas. These two variables

also explained, in detail, the diameter of the pileus and the hymenial area to biomass ratio for the complete dataset suggesting that the functional variability of macrofungal populations was associated with forest performance. In this case, when fungal data was included in the analysis, it was clear that a simplistic forestry-based only perspective would only provide a partial perspective of the complete story. Interestingly, when all the variables calculated in the study were analyzed over time, differences were observed in 2012 versus other years, particularly for the macrofungi documented in the pre-montane wet forests. Considering that 2012 was a wet La Niña year on the Pacific coast of Costa Rica, results suggested that macrofungal assemblages in the pre-montane wet forests (mostly mycorrhizal) were less resilient than those in the seasonally dry forest. It is imperative to study these results more thoroughly for management of natural resources (Figure 1) since they suggested that, despite the lower carbon-stock value, seasonally dry forests in Costa Rica also function as resilient environments for microorganisms inhabiting them, fungi among them. In addition, these results also showed that the less resilient mycorrhizal assemblages, a potential source of food, require a differential management approach.

Perception of Fungal Resources and Lessons for Integrated Management

Empirical information is the source of science and the primary fuel of scientific publications. Despite known limitations on communicating science (i.e., Gilgun, 2005; Besley and Tanner, 2011), most researchers spend quite some time preparing documents showing their experimentation



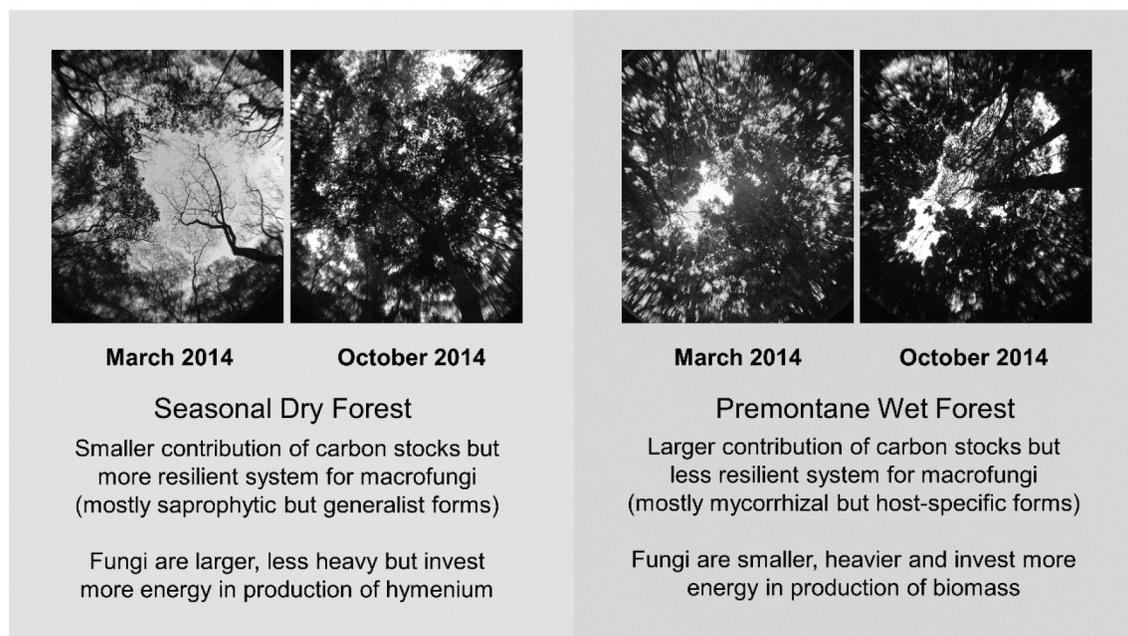
results. In academic environments, scientific publications are still highly regarded although it has been known for decades that other forms of information exchange are extremely relevant to translate scientific content to the non-scientific public (Garvey, 1979). Even today, in the internet era, when communication is fast and versatile, there is a disconnection between the scientific community and the public (Fischhoff and Scheufelec, 2014).

In Costa Rica, mycological information has been generated for nonprofessionals in the form of field guides and textbooks (i.e. Mata, 1999; Mata *et al.*, 2003; Calderón, 2005; Mata *et al.*, 2010; Mata and Navarro, 2010; Chaverri *et al.*, 2010, Carranza *et al.*, 2017). These documents have been extremely useful to increase mycoliteracy

in the Costa Rican population. Even though the country is geographically located in the intermediate anthropological area, the point of confluence of the mycophilic Mesoamerican region and the mycophobic Chibcha region, few documents have been generated to understand the perceptions of the Costa Rican population towards fungal resources. This type of non-biological works is highly relevant to provide an integrated approach to manage fungal resources in the country, along with more standard information on fungal biology.

An ongoing effort in the University of Costa Rica during the last years has permitted a basic characterization of the population perception on fungi. For example, Molina-Murillo *et al.*, (2015) studied two groups of people in university environments in Honduras

Figure 1. Temporal canopy differences in seasonally dry and premontane wet forest patches of Costa Rica and characteristics of fungal assemblages in them based on Rojas and Calvo (2014) and Rojas *et al.* (2017). Note: the present study is the source for the construction of this figure.





(Mesoamerican) and Costa Rica (Intermediate) and attempted to address the reduced availability of information at this level in the Central American population. The group of researchers found that the Costa Rican population was more aware of ecological functions performed by fungi, but the Honduran population was more aware of medicinal uses of fungi. Remarkably, for both populations in the 16-35 age group, participants seemed more aware of ecological processes than participants in other age groups. More Costa Ricans (76%) than Hondurans (48%) responded to have consumed mushrooms in the month before the survey was conducted. Interestingly, 52% of Hondurans had never consumed mushrooms versus only 25% of Costa Ricans. These results were interesting considering that Costa Rica was thought to be more mycophobic than Honduras, but they may point to the documented high level of self-perceived green mentality in Costa Rica that actually represents a double discourse in practice (Courvisanos and Jain, 2006), which may have biased the answers.

When participants were asked to mentally associate fungi and one aspect of their lifestyle, some differences were recorded by gender. The most common answers provided by female participants were related to venomous and hallucinogenic aspects of fungal use, whereas males' answers were more commonly related to characteristics of fungi's edibility and their capacity to be used as food. Interestingly, responses related to hallucinogenic uses increased with the age of the participants. When asked about their preference for either animals, plants or fungi, results showed that about 62% of all participants mentioned preferring animals and about 43% preferred plants, leaving only 5% of answers for fungal preference over the other two groups of organisms.

Even though some response distributions were different between the two countries, and some differences were found at the gender level, it was interesting to observe that response associations with video games (i.e., Mario Bros), television shows (i.e., The Smurfs), and world events (i.e., nuclear bomb cloud shape) were recorded equally in both studied groups. For the majority of the participants surveyed, such aspects may be part of their daily life considering that cable television and video game consoles are common among individuals attending college worldwide (Jacobsen and Forste, 2011).

Results from that study suggested that exposure to formal education or previous cultural background in the studied groups may not have played such an important role in shaping perceptual views about fungi as social aspects have. Even though both studied groups have different historical heritage and levels of emotional proximity with natural resources, these results showed no significant differences in their perceptual patterns toward fungi. As such, it seemed that homogeneity within urban areas due to common globalized stimuli might have played a more prominent role in determining natural interactions. This is a very important argument to consider since the development of management strategies in relation with natural resources should respect particular socioeconomic and historical differences.

For Costa Rica, an unpublished study, carried out with more detail in 11 population centers across the country, also showed that regional differences exist within a small territory. In this case, when participants were asked if they knew what fungi were, most surveyed people across the country responded positively, but the lowest percentages (79% and 76%) of positive responses



were found in the only part of Costa Rica with a Mesoamerican cultural background. The corresponding area associated with those responses is located in the lowlands of the dry forest region of Costa Rica, which is similar in biological context to some areas of the Mexican state of Oaxaca, but dramatically different in the social perception on fungi, for example. Such type of differences has been documented, however, around deep social issues within mycophilic regions, between low and high elevation areas, with different forest ecosystems as well (see [Thompson 1970](#)). Similarly, when participants were asked if fungi were important for ecosystem functions, a vast majority answered positively. However, communities located along the north and central Pacific coast, where seasonally dry forests occur, showed the lowest percentages of positive responses (63% in average versus 82% for highly educated communities in the center of the country). Ironically, when participants were given four real ecological roles of fungi in forests, 45% failed to recognize at least two of those roles, and the largest percentage of participants correctly associating three or four roles (33% in average) were found in highly educated regions. Despite the latter, no correlations were found between the human development index of the population centers and the answer distribution found in the study, suggesting that responses have a cultural background more than a socio-economic one.

When participants were asked about the most important use of fungi for human lifestyles, their value as a source of food and medicines was provided by 44% and 23% of all participants. Interestingly, Caribbean centers with tropical rainforest showed the highest values (an average of 55% of all answers in their respective town), and lo-

cations along the dryer Pacific showed the smallest percentages (average of 34% of answers). At the same time, locations on the Caribbean coast were associated with the highest percentage of respondents consuming fungi at least once a month (average of 41% of answers), and respondents in towns located on the Pacific side of Costa Rica showed the lowest values of monthly fungal consumption (average of 32% of answers). The significant correlation between reported consumption of fungi and perceptual value of fungi as a source of food was moderately high ($r=0.71$), suggesting that, in this particular aspect, the Costa Rican society might have learned the value of fungi as a source of food by ingesting the source itself. The latter seems to be more prevalent in population centers with wet and rain forests than in those with dry forests.

The examples provided herein are simple demonstrations that surveys could be useful to determine guidelines for natural resource management (see [Brown, 2004](#)) and public interaction with fungi. In the case of this group of organisms, this exercise has been conducted in Costa Rica for the first time in recent years, and the complete analyses have not been published yet. However, some of the information contained in these public opinion assessments is important to understand sociocultural, economic, and historical links of particular sectors of the population with a number of natural resources. Such a task of understanding the human-nature interaction is easier to implement for widely valued resources such as water and air ([Bergstrom and Randall, 2016](#)), and harder for poorly known biological groups such as the fungi. However, those constraints have shown that in the Costa Rican case, there are opportunities of mycoliteracy in most areas of the country



and formal biological research could also be reinterpreted to reach those populations (see [Stone, 2017](#)).

Lessons from Fungal Research in the Context of Development and Conservation of Natural Resources

In 2011, Costa Rica held the Latin American Mycological Congress organized by the Latin American Mycological Association. This is the most important international event on mycology in the region, and it was an accomplishment to organize such event in this country at that time. An executive decree from the President of Costa Rica declared this an event of public interest ([Decreto ejecutivo 36573-MICIT, 2011](#)). Such meeting was possible thanks to academic and government support, a critical number of internal researchers working on mycological issues, and the fact that, within the Mesoamerican biodiversity region, Costa Rica was recognized as one of the growing centers of fungal studies. The most important aspect brought into the country by this event, however, was the promotion of mycology among the younger generation of Costa Ricans that had not been exposed to the topic.

This exposure to fungi during the 21st century, particularly with online resources, should be carried out with multimodal techniques (see [Jewitt, 2012](#)). The availability of information on the internet is an important aspect to consider in the development of longterm scientific programs, given the increased dependence on internet resources ([Sheenan and Young, 2012](#)). The advantage of fungi is that they are appealing and interesting for many people, and the opportunity to develop these multimodal approaches to communicate mycology should not

be missed these days. For instance, from a series of informative videos produced by the authors of this chapter and uploaded to a popular online platform, one specific video on the biology of *Amanita muscaria* sensu lato has received 100 times more visits (between 2014 and 2017) than other 30 videos produced on other topics. In the end, the importance of active research in a field of study for the development of local societies, as mentioned earlier, is the translation of scientific information into products that those societies can use for purposes ranging in all disciplines of human knowledge.

For Costa Rica, this translation of active research into tangible products, publicly available online, seems to have been successful in the last years. As a proxy to evaluate such availability of information, when a search (in Spanish) was performed on Google Scholar looking for resources dealing with fungi in association with the different countries in Central America and Mexico, it was evident that Costa Rica had carried out this work more efficiently than the average for the other regional countries (Figure 2). As a comparison, Mexico is very rich in fungal resources and human-fungi interactions, and mycological studies are usually more publicized than in other parts of Latin America due to the mycophilic character of the Mexican population. Even though there are obvious limitations to the analysis of results from this type of public platforms on the internet, they can also provide interesting data for comparison purposes with more professional and specialized databases ([Falagas et al., 2008](#)). However, in the end, the availability of fungal information in public and easy-to-use platforms has a higher potential of reaching non-specialized public (non-mycologists), and it is very important for educational purposes.



Despite the latter, someone still must generate such information and resources and it seems that established groups (professional and non-professional) are more productive for the communication of science, including mycology, when they become the active participants of the process (see [Pagani and Malacarne, 2017](#)). However, for these approaches to take place effectively, in an equilibrated manner, non-professional groups should also exist to counterbalance the academic-based (and academically-biased) delivery of information from fungal researchers. In this sense, the promotion of mycology should reach all strata of societies with differential approaches, so collective efforts compensate specific biases.

In Costa Rica, one limitation of this active process of mycological communication has been the reserved role of nonprofessionals and the reduced promotion of citizen science for the generation of information. These two types of contribution are acknowledged to be important factors promoting science in societies ([Bonney et al., 2014](#); [Bonney et al., 2015](#)). Even though the field guides on fungi produced by the National Institute of Biodiversity (INBio) ([Mata, 1999](#); [Mata et al., 2003](#), [Chaverri et al., 2010](#)), and several websites produced in recent decades have been important contributors to disseminate information on fungi in the country, public empowerment and “ownership” of mycological information by nonprofessionals have not been well stimulated in this territory. Unfortunately, public offices in charge of natural resources (including fungi) integration with social stakeholders have placed their interest in the dissemination of information on the cultivation of introduced fungal species rather than on the rescue of local knowledge in relation to

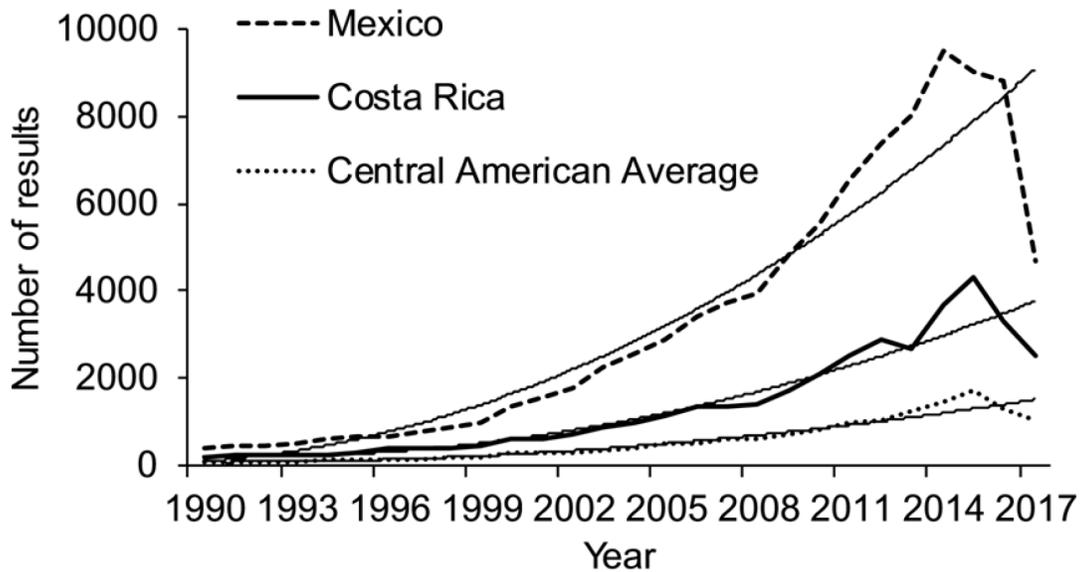
the use and value of regional fungi by autochthonous populations.

Using information from the University of Costa Rica’s Research Office, which records thematic research in Costa Rica since 1975 (www.vinv.ucr.ac.cr), it seems clear that fungal studies in this country, during the last 40 years, have not been designed to reach the public. For example, only 15% of proposed projects on fungi have had a social application component and none of the projects during that time have included citizen science promotion of some kind. As such, the connectivity between mycology and the triple helix, a socioeconomic approach proposed for developing countries that seeks to link academia, productive sector and governments (see [Molina-Murillo and Rojas, 2015](#)), has been very limited in Costa Rica.

Overall, mycology in Costa Rica has focused on the primary basic biological aspects. In this sense, local and foreign researchers in the country have generated important information to understand taxonomic and distributional patterns of fungi. Even though fungal studies in the country have had a multidisciplinary approach in the present century, they still lack real applicability and connectivity with Costa Rica’s development strategy. However, in terms of fungal conservation and administration of fungal resources, this country has established a series of public measurements to include fungi in non-academic agendas. The latter has positioned Costa Rica slightly ahead of other countries in the same region in terms of integrating fungi in the management of nature. For this and other initiatives, from a global perspective including other taxonomic groups, Costa Rica has been used as a case study in Latin America ([Zimmerer, 2011](#)).



Figure 2. Availability of results in response to a search for fungi in Google Scholar during the period 1990-2017 for Mexico, Costa Rica and the average of Central American countries excluding Costa Rica. All trend lines are shown and correspond to quadratic functions with parametric correlation values higher than 0.90. Note: the present study is the source for the construction of this figure.



Recent ecological studies carried out in the country have generated important information to understand fungal dynamics in the context of ecosystem services and climate change. Also, opinion studies carried out in Costa Rica have been useful to analyze socioeconomic, cultural, and gender-based perceptual views in the different regions of the country. The interaction of these two research lines is imperative for an effective and modern approach to manage fungal resources in such territory. However, inequalities in mycoliteracy across Costa Rica should be addressed with multiapproach channels, among which the internet is prominent. With a future promotion of citizen science-based research and community-based projects involving fungi, maybe social proximity to this group of organisms would allow more effective interaction with them. Potential entrepreneurs setting up initiatives using fungi as a source of

food or as part of industrial applications could be interesting to identify in Costa Rica for the development of future applications. Interestingly, the issues exposed herein, focused on the Costa Rican case, are examples of similar matters taking place in other parts of the world. Hopefully, shared lessons can lead to important accomplishments beyond political borders for the benefit of everyone someday.

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