

Effect of intensive mushroom harvesting on macromycete communities in the Mixteca region of Oaxaca, Mexico

Carolina Ruiz-Almenara^{Equal first author, 1}, Etelvina Gándara^{Equal first author, 2}, Marko Gómez-Hernández^{Corresp. 3}

¹ CIIDIR Oaxaca, Instituto Politécnico Nacional, Santa Cruz Xoxocotlán, Oaxaca, México

² Facultad de Ciencias Biológicas, Benemerita Universidad Autónoma de Puebla, Puebla, Mexico

³ CONACYT-CIIDIR Oaxaca, Instituto Politécnico Nacional, Santa Cruz Xoxocotlán, Oaxaca, México

Corresponding Author: Marko Gómez-Hernández

Email address: magomezhe@conacyt.mx

Wild edible mushrooms have been collected and consumed by people for centuries, and today represent a relevant source of food and income for many rural families worldwide. Preserving this non-timber forest product is of great interest, and there is concern about the damage caused by intensive mushroom harvesting on macromycete communities. The aim of this study was to evaluate the effect of intensive harvesting on the diversity and distribution of macromycete species in the Mixteca region of Oaxaca, Mexico. We selected four sites within the study area: two non-harvested sites, and two sites harvested for 5 and 9 years. In each site, 10 permanent plots of 10 m x 10 m were established, and fruit body sampling was carried out within each plot every week from June to October 2017. A total of 856 individuals corresponding to 138 macromycete species were recorded, and 23 of these were identified as edible. Overall macromycete diversity, edible macromycete diversity and species composition was similar in Sites 1(non-harvested) and 3 (harvested), and in Sites 2 (non-harvested) and 4 (harvested). Variation of diversity and species composition along the studied area was mainly related to microclimatic variables, while most environmental and vegetation structure variables homogeneously affected macromycete species in the four studied sites. Our results indicate that intensive harvesting of wild edible mushrooms is not affecting the diversity and distribution of macromycete species. Knowledge on this issue can allow improving regulatory frameworks in order to carry out a more sustainable management of this valuable non-timber forest product.

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Carolina Ruiz-Almenara¹, Etelvina Gándara¹, Marko Gómez-Hernández³

¹CIIDIR Unidad Oaxaca, Instituto Politécnico Nacional. Hornos 1003, Santa Cruz Xoxocotlán,
Oaxaca CP 71230, Mexico. E-mail: karoruizx@gmail.com

²Facultad de Ciencias Biológicas. Benemérita Universidad Autónoma de Puebla, Ciudad
Universitaria, Av. San Claudio s/n, Edificio Multi-laboratorios EMA-6, Laboratorio 301, Col.
San Manuel CP 72570, Puebla, Puebla. E-mail: etelvina.gandara@gmail.com

³CONACYT-CIIDIR Unidad Oaxaca, Instituto Politécnico Nacional. Hornos 1003, Santa Cruz
Xoxocotlán, Oaxaca CP 71230, Mexico.

Corresponding author:

³Marko Gómez-Hernández

E-mail address: mrk.gmz@gmail.com

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21 Abstract

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 23 represent a relevant source of food and income for many rural families worldwide. Preserving
 24 this non-timber forest product is of great interest, and there is concern about the damage caused
 25 by intensive mushroom harvesting on macromycete communities. The aim of this study was to
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 27 species in the Mixteca region of Oaxaca, Mexico. We selected four sites within the study area:
 28 two non-harvested sites, and two sites harvested for 5 and 9 years. In each site, 10 permanent
 29 plots of 10 m x 10 m were established, and fruit body sampling was carried out within each plot
 30 every week from June to October 2017. A total of 856 individuals corresponding to 138
 31 macromycete species were recorded, and 23 of these were identified as edible. Overall
 32 macromycete diversity, edible macromycete diversity and species composition was similar in
 33 Sites 1(non-harvested) and 3 (harvested), and in Sites 2 (non-harvested) and 4 (harvested).
 34 Variation of diversity and species composition along the studied area was mainly related to
 35 microclimatic variables, while most environmental and vegetation structure variables
 36 homogeneously affected macromycete species in the four studied sites. Our results indicate that
 37 intensive harvesting of wild edible mushrooms is not affecting the diversity and distribution of
 38 macromycete species. Knowledge on this issue can allow improving regulatory frameworks in
 39 order to carry out a more sustainable management of this valuable non-timber forest product.

40 Keywords: edible mushrooms, non-timber forest product, management, pine-oak forest,
 41 diversity, distribution

42

43 Introduction

44 Fungi are of great importance in forest ecosystems worldwide. As decomposers, they are the
 45 most important organisms for organic matter degradation, and play a key role in nutrient cycling
 46 (Lodge 1993; Deacon 2013). Mycorrhizal fungi form symbiotic associations with higher plants,
 47 facilitating plant uptake of water and nutrients such as phosphorus and nitrogen, in exchange for
 48 carbohydrates (Bever et al. 2001; Hall, Yun & Amicucci 2003). Plant and animal pathogenic
 49 fungi impact ecosystems mainly by influencing productivity and species diversity and
 50 composition, thereby acting as natural population regulators (Hansen & Stone 2005; Deacon
 51 2013).

52 In addition to their roles in ecosystem functioning, fungi are highly relevant for humans and
 53 human-related activities (Mueller & Bills 2004). Wild edible mushrooms have been collected
 54 and consumed by people for thousands of years and, given their nutritional value, some species
 55 are used as substitutes for meat in developing countries (Boa 2004). Wild edible macromycetes
 56 are also one of the most important non-timber forest products sold worldwide, generating ca.
 57 US\$2 billion each year (Arnolds 1995; Boa 2004). Information compiled from 10 countries
 58 revealed 2166 known species of wild edible mushrooms, but more than 80 countries are known
 59 to collect macromycetes for food and as sources of income (Boa 2004).

60 In Mexico, 371 macromycete species are traditionally consumed by people in rural areas, making
 61 it the second country with most species of wild mushrooms used as food, only after China (600
 62 species), and it is the sixth country in the world with the highest number of ethnic groups (Ruan-
 63 Soto, Garibay-Orijel & Cifuentes 2006; Garibay-Orijel & Ruan-Soto 2014). The state of Oaxaca

is one of the most biodiverse regions in the planet, and the most biologically and culturally diverse region in Mexico (Flores-Villela & Gerez 1994), but there is a lack of mycological information for this area (Garibay-Orijel et al. 2006). The few studies about macromycetes in Oaxaca include the diversity and traditional use of macromycetes in the Sierra Norte region (Villanueva-Jiménez, Villegas-Ríos & Cifuentes 2006; Garibay-Orijel et al. 2006, 2009), functional diversity of macrofungal communities in the Costa region (Caiafa et al. 2017), taxonomy and traditional use of *Psilocybe* species in different localities of Oaxaca (Guzmán et al. 2004; Ramírez-Cruz & Guzmán 2006), and traditional use of macrofungi in the Mixteca region (Santiago et al. 2016). The Sierra Norte region has the most complete inventory of useful macromycetes in Mexico, comprising a total of 159 taxa (Garibay-Orijel et al. 2009), but it is widely known that many communities throughout Oaxaca traditionally use wild mushrooms. However, mushroom harvesting has been suggested to affect macromycete communities and fruit body production in subsequent years by lowering the spore-release, damaging mycelia, and disrupting biotic interaction with other species (Arnolds 1995; Leonard 1997; Money 2005). Due to the role of macromycetes in ecosystem processes, and their nutritional and economic importance, concern about harvesting effects has grown among mycologists, conservation planners, forest managers, landowners, and mushroom traders (Boa 2004; Leonard 1997; Pilz et al. 2007; Pilz & Molina 2002). Nevertheless, results from experimental and long-term research have stated that over-harvesting causes no damage to the macromycete communities since only the fruit bodies are removed and the mycelium is untouched, but soil compaction associated with mushroom collecting can reduce the number of fruit bodies per year (Egli, Ayer & Chatelain 1990, Norvell 1995; Egli et al 2006).

Researchers have recommended that collection of wild edible mushrooms should be legally regulated, and that rare/endangered species must be identified and protected from harvesting (Leonard 1997; Money 2005). In Mexico, despite the social, economic, and cultural relevance of wild mushroom harvesting, the scant information such as official statistics and scientific knowledge on this activity has caused the regulatory framework to be ambiguous, inconsistent, and difficult to comply with. For example, the Wildlife Act considers the use of wild macromycetes, but only on the basis of a management plan with evidence showing that the extraction rate is less than that of natural renewal, which makes nearly impossible to obtain an official permission to harvest (Badillo et al. 2013). In most rural communities of Oaxaca, people from the same community share their lands and make decisions about forest management regulations (including wild mushrooms), usually with the support of government institutions, academics, and social organizations. However, wild mushroom harvesting is frequently excluded from management plans due to the scarce information about the relevance and implications of this activity.

The present study was carried out in a community located in the highlands of the Mixteca region of Oaxaca, where people have been intensively harvesting wild edible macromycetes in the same places for many years. The aim of this study was to assess the effects of local harvesting of wild edible mushrooms on the diversity and distribution of macromycete species. Since macromycete communities are susceptible to mycelium damage, reduction of spore release, and microclimate/environmental variation, we predicted that 1) the diversity of macrofungi is likely to be similar in harvesting sites, but different to the diversity in sites where this activity is not performed, 2) the turnover of species composition between harvested and non-harvested sites can be conspicuous, and 3) the likely changes of diversity and distribution of macromycetes along

the study area can be due to the variation of microclimatic/environmental factors rather than the effect of mushroom harvesting.

Material & Methods

Study area and sites

The study area is located in the village of Independencia (17°05'43" N, 97°39'35" W), which is part of the municipality of San Esteban Atlatlahuca, district of Tlaxiaco, in the Mixteca region of Oaxaca, Mexico. Independencia is found in the Sierra Madre del Sur mountain range at 2670 m.a.s.l., characterized by *Pinus-Quercus* forests. The climate is subhumid temperate with summer rains. Temperature ranges from 10 to 16 °C, and annual precipitation from 800 to 1500 mm (INEGI 2008).

With the assistance of local mushroom collectors, four study sites were established in forests surrounding Independencia: two sites in areas where locals harvest wild edible mushrooms for ca. 7 months every year, and two where they do not carry out this activity. Sites 1 and 2 are non-harvesting areas, and Sites 3 and 4 have been harvested for 9 and 5 years, respectively. The characteristics of the selected sites were as similar as possible to avoid conspicuous differences that could mask the effect of harvesting on relevant variables related to the macromycete communities. The similarity of the sites was based on the altitude, tree composition, vegetation structure, topography of the terrain, and understory coverage. In each site we established 10 permanent plots of 10 m x 10 m located at least 10 m apart from each other, totaling 0.1 ha per site.

Macromycete sampling

After obtaining permission to collect macromycete samples from the municipal authorities of San Esteban Atatlahuca, samplings were carried out in the rainy season (June-October) of 2017. Since mushrooms are ephemeral, samplings consisted in continuously collecting macromycete fruit bodies in each plot within the four study sites every week. To prevent affecting fruit body production caused by the samplings, mainly in the non-harvesting areas, both in the harvesting and non-harvesting areas only 1 or 2 fruiting bodies per species were collected for identification when necessary. Fruiting bodies of the same species within a diameter < 50 cm were recorded as a single individual. To avoid soil compaction and raking leaf litter, samplings and data recording within the plots were carefully carried out by one single person. Samples were identified based on their micro and macromorphological traits. When specimens could not be identified at the species level, they were classified as morphospecies using a higher taxonomic level approach. Species were identified as edible or not based on a literature review (Garibay-Orijel et al. 2009; Karun & Sridhar 2017).

Explanatory variables

The microclimatic variables recorded in each plot every sampling day were: air and soil temperature, relative air humidity, percentage of soil water content, soil pH, and soil compaction. Soil texture for all sites was classified as sandy clay loam to clay loam, and the ideal bulk density for plant growth on this type of soils is < 1.40 and when it reaches 1.60 it begins affecting root growth, restricting it when it is > 1.75 . Other environmental variables recorded per plot included: slope, aspect, canopy openness, percentage of moss, rockiness, and soil coverage. Litter depth was measured at the beginning, middle, and the end of the sampling season. In each plot, trees with diameter > 10 cm at 1.3 m above ground were counted, also measuring their diameter and

height. Vegetation structure was characterized using the basal area ($\text{m}^2 \text{ ha}^{-1}$), density (individuals ha^{-1}), and mean and maximum height (m) of the trees counted.

Data analysis

The number of macrofungal species in each site was recorded, and the observed species richness between sites was compared by means of rarefaction curves standardizing the samples to the minimum number of individuals recorded in one site. Species accumulation curves were constructed to determine the effectiveness of the sampling effort (i.e. number of plots).

Macrofungal diversity was calculated with the Shannon index, and true diversity of first order (qD) using the multiplicative diversity decompositions of the effective numbers of species (Jost 2006, 2007). A single linkage hierarchical cluster analysis was performed based on composition and abundance of species. These analyses were conducted in R version 3.4.2 (R Core Team 2017). The completeness of the macromycete inventories was estimated using the richness estimator Chao 2, and the turnover of species composition was assessed with the Chao-Jaccard similarity index, both of them calculated in EstimateS 9.1.0 (Colwell 2013).

The Spearman correlation coefficient was calculated to determine the relationship between the explanatory variables and macrofungal richness. To understand the distribution of macromycete species with respect to the set of environmental, microclimatic, and vegetation structure variables, canonical correlation analyses (CCA) were performed. A lineal regression analysis was carried out to determine the relation between species similarity and geographic distance between sites. The *t*-test proposed by Hutchenson (Zar 1999) was used to determine differences in Shannon diversity values between sites. Unless stated otherwise, statistical analyses were performed in R version 3.4.2. (R Core Team 2017).

175

176 **Results**

177 **Macromycete species richness and taxonomic groups**

178 A total of 856 individuals corresponding to 138 species were recorded, and 23 of these were
 179 identified as edible species. The phylum Basidiomycota was represented by 10 orders and 33
 180 families, and Ascomycota by 4 orders and 4 families (Appendices A, B). Site 4 had the highest
 181 macromycete species richness (72), while Site 1 showed the lowest number of species (34).
 182 Similarly, the highest richness of edible species was found in Site 4 (14), and the lowest in Site 1
 183 (9) (Table 1). The Chao 2 estimator suggested that the species inventories were over 50%
 184 complete for all sites (Table 1).

185 Similarly, the number of species estimated with the rarefaction curves (using a standardized
 186 abundance of 115 individuals) indicated that Sites 2 and 4 had the highest richness (42 and 38
 187 species, respectively) compared to Sites 1 and 3 (33 and 35 species, respectively) (Figure 1A).
 188 The species accumulation curves using the 10 plots as the sampling effort for each site did not
 189 reach the asymptote, suggesting that our inventories were not complete, as indicated by the Chao
 190 2 estimator (Figure 1B).

191 **Macromycete diversity and distribution**

192 Both the Shannon and true diversity indices (Table 1) indicated that Site 2 had the highest
 193 diversity of macromycetes (1.54 and 35, respectively), and Site 1 had the lowest (1.17 and 14.83,
 194 respectively). The *t* test did not show significant differences in Shannon values between Sites 2
 195 and 4. The same pattern of Shannon and true diversity values was observed for the edible species
 196 (Table 1), with Site 2 being the most diverse (0.96 and 9.08, respectively), and Site 1 being the

least diverse (0.57 and 3.7, respectively). There were no statistical differences in Shannon diversity between Sites 1 (non-harvested area) and 3 (harvested area), and between Sites 2 (non-harvested area) and 4 (harvested area). The proportion of edible species with respect to the total of species recorded in each site was 26.5% for Site 1, 18.8% for Site 2, 20.8% for Site 3, and 19.4% for Site 4.

The microclimatic variables recorded along the sampling season showed that air and soil temperature were higher in Sites 1 and 3, air relative humidity was higher in Sites 2 and 4, and soil water content was higher in Site 2 (Figure 2). Spearman's correlation coefficient indicated that macromycete richness was positively correlated with air relative humidity, herbaceous plant coverage, slope, maximum tree height and tree basal area; and negatively correlated with air and soil temperature (Table 2).

The cluster analysis indicated that Sites 1 and 3 were similar in species composition, and Site 2 was similar to Site 4 (Figure 3). Correspondingly, the Chao-Jaccard showed that for both the total macromycetes species and the edible species, Sites 1 (non-harvested area) and 3 (harvested area) were the most similar, followed by Sites 2 (non-harvested area) and 4 (harvested area). Sites 1 and 4 were the most dissimilar in terms of total macromycete species, and for edible species they were Sites 1 and 2 (Table 3). Geographic distance between sites and values of the Chao-Jaccard index were not significantly related ($p = 0.6$).

The CCA for microclimatic explanatory variables was carried out for 138 macromycete species considering air temperature, air relative humidity, soil temperature and percentage of water in the soil. The model only retained air and soil temperature, but the other variables were included to better explain the ordination. Axis 1 (eigenvalue = 0.4926) and axis 2 (eigenvalue = 0.3226) accounted for 37% and 24% of the species-microclimate relationship, respectively. CCA results

showed that Sites 1 and 3 were clearly separated from Sites 2 and 4 along the first canonical axis (Figure 4).

The CCA for environmental variables was also carried out for the 138 macromycete species considering litterfall, canopy openness, slope, aspect, rockiness, moss and herbaceous coverage, bulk density, soil porosity and soil water filled pore space. The model only retained moss coverage, but the other variables contributed to explain the ordination. Axis 1 (eigenvalue = 0.4213) and axis 2 (eigenvalue = 0.3545) accounted for 17% and 14% of the explained species-environmental relationship, respectively (Figure 5).

The CCA for vegetation structure also considered 138 species and used mean tree height, maximum tree height, tree basal area and tree density. The model only retained maximum tree height, but the other variables were included to explain the ordination. Axis 1 (eigenvalue = 0.4509) and axis 2 (eigenvalue = 0.3049) accounted for 38% and 25% of the explained species-vegetation structure relationship, respectively. CCA results showed that Sites 1 and 3 were separated from Sites 2 and 4 along the first canonical axis (Figure 6).

Discussion

Mexico is one of the main consumers of wild edible mushrooms in the world, and several studies have shown the high diversity of these organisms in the country and their importance as sources of food and income for people in rural areas. For instance, in a forest of La Malinche National Park in Tlaxcala, 93 macrofungal species were recorded, 91 of them reported in the literature as edible, and 74 species were found to be used by the local people (Montoya et al. 2004). In Ixtlan, Oaxaca, 159 macromycete taxa were reported as having a use, including 113 edible species

(Garibay-Orijel et al. 2009). In the Sierra del Ajusco, in Mexico City, 29 wild edible species were found in just 800 m² (Zamora-Martinez & Pascual-Pola 1994). In Cerro El Zamora, located between Guanajuato and Queretaro, a study identified 130 macromycete species, 55 of which were recognized as edible based on a literature review (Landeros et al. 2006). In our study area, a total of 138 macromycete taxa were recorded, and 23 were recognized as edible according to a literature review. Interviews with local people, performed as part of an ethnomycological study conducted simultaneously to this one, showed that they consume at least 45 species, but only 9 of these were represented in our samples. In spite of having marked our permanent plots in the harvesting sites with barricade tape and having agreed with the local population that they would not collect mushrooms within the plots during the sampling season, traces of harvesting were often found which could explain the low recorded richness of locally used edible macromycetes.

The diversity of macromycetes did not differ between the non-harvested (Sites 1 and 2) and harvested (Sites 3 and 4) areas. Both for all macrofungi and for the edible species, Sites 2 and 4 showed a similar diversity and were the most diverse, while Sites 1 and 3 were similar and less diverse. It is broadly known that macromycete communities are strongly influenced by habitat heterogeneity and microclimate variation, and our results on diversity can be clearly explained by the observed microclimatic conditions. In spite of the environment and vegetation structure were similar in the four studied sites, microclimate was not homogeneous between sites and the differences resembled the observed patterns of diversity where Sites 2 and 4 on the one hand, and Sites 1 and 3 on the other, shared most microclimatic similarities. Several studies have suggested that humidity, precipitation and temperature are the main factors affecting macromycete fruiting and diversity in both temperate and tropical forests (e. g. O'Dell, Ammirati & Schreiner 2000; Ohenoja 1995; Lodge et al. 2004; Brown, Bhagwat & Watkinson 2006;

Durall et al. 2006; Gomez et al. 2012), and that temperature and humidity are the best predictors of fungal richness (Talley 2002). Our results showed that air and soil temperatures were higher in Sites 1 and 3, and negatively correlated with macromycete species richness. Likewise, air humidity was higher in Sites 2 and 4, and positively correlated with species richness. The observed differences in richness and diversity between sites therefore did not correspond with the harvesting activity and were related to microclimatic differences along the study area. These results suggest that mushroom harvesting is not likely affecting the assemblages of edible macromycetes, nor disturbing environmental factors of relevance for macrofungal communities. This is consistent with different long term studies evaluating the effect of mushroom harvesting on the number of macromycete species and fruit body production. In a 29-year study carried out within two fungus reserves in southwestern Switzerland, systematic harvesting was applied using picking and cutting techniques and the results indicated that regardless of the harvesting technique, neither macromycete species richness nor fruiting were affected (Egli et al. 2006). Similarly, 13- and 40-year studies conducted in the United States and Sweden, respectively, revealed that intensive collecting of wild mushrooms did not reduce annual production of fruit bodies (Jahn & Jahn 1986; Norvell 1995). It has been suggested that stability in the number of macromycete species and fruiting in areas under harvesting pressure may be explained by the hundreds of spores released from each fruit body before and during mushroom collection, or because enough spores disperse from adjacent areas (Money 2005; Egli et al. 2006).

Apart from microclimatic conditions, numerous environmental variables have been related to macrofungal diversity and fruit body production, e.g. slope, aspect, basal area, presence of rocks, and density of trees (O'Dell, Ammirati & Schreiner 1999; Ferris, Peace & Newton 2000; Cavender-Bares et al. 2009; Egli et al. 2010; Gomez et al. 2012). Our results showed a positive

288 correlation between slope and the number of macromycete species, agreeing with findings by
 289 Caiafa et al. (2017) in the Costa region of Oaxaca. But understanding how the slope influences
 290 macromycete richness can be a difficult task due to the variety of biotic and abiotic factors
 291 related to the soil environment. Findings have suggested that the slope effect on macromycetes is
 292 related to vegetation type, as well as to the moisture and temperature gradient along the slope.
 293 However, there are discrepancies between studies since some of them report a positive relation
 294 between slope and species richness, and others report it to be negative (Nantel & Neumann 1992;
 295 Rubino & McCarthy 2003; Gómez-Hernández et al. 2012). In this study, basal area and
 296 maximum height of trees were positively correlated with species richness, and a greater amount
 297 of fruit bodies were recorded in areas with wider and taller trees. Correspondingly, the highest
 298 basal area, maximum height of trees, and macromycete richness and abundance were recorded in
 299 Site 4. Related studies have proposed that the composition and structure of host tree communities
 300 can influence macromycete richness and fruit by affecting fungal specialization and providing
 301 different habitats and resource quality and quantity (Villeneuve, Grandtner & Fortin 1989; Gabel
 302 & Gabel 2007; Richard et al. 2004; Brown, Bhagwat & Watkinson 2006; Zhang et al. 2010). The
 303 herbaceous coverage in our study area was positively correlated with macromycete species
 304 richness, agreeing with results that suggest a trend towards increasing the number of
 305 macromycete fruit bodies with increased herbaceous coverage, and a positive relation between
 306 the number of macromycete species and fruit body production (Mehus 1986; Toledo,
 307 Barroetaveña & Rajchenberg 2014). The observed trend can be explained by the fact that the
 308 herbaceous layer provides up to 16% of annual litter fall and influences the cycling rates of N, P,
 309 K and Mg, which are important nutrients for fungal growth and health (Gilliam 2007). Soil
 310 compaction by trampling has been proposed as one of the consequences from harvesting that can

trigger a decrease in macromycete diversity and fruit body production by causing mycelium smashing (Arnolds 1995; Watling 2003). Egli, Ayer & Chatelain (1990) intensively trampled a plot every 2 days during summer and autumn in 1 year, and observed a strong decrease in fruit body production. Local people in our study area harvest mushrooms every 2 days for 7 months every year, however, the soil water content (which is directly related to soil compaction) was similar between non-harvesting and harvesting sites, and macromycete abundance was higher in the harvesting sites. These results suggest that trampling during mushroom collecting has not caused a severe soil compaction and damage to the macrofungal communities despite many years of intensive harvesting.

Vegetation type in the assessed sites was pine-oak forest with a marked dominance of pines, and the composition of tree species was similar in all sites. In forests with low diversity of tree species, as in our study, the opportunity for macromycete specialization increases due to the high abundance of few tree species, and the composition of specialist fungi has been observed to change across the distribution of a vegetation type (Nantel & Neumann 1992; Ferrer & Gilbert 2003; Lodge et al. 2008). The turnover of macromycete species between our four study sites was not as conspicuous as expected. The similarity in species composition ranged from 55 to 79%, and resembled the trend observed for microclimate since it was similar between Sites 2 (non-harvesting) and 4 (harvesting), and between Sites 1 (non-harvesting) and 3 (harvesting).

Corresponding with our results, other studies have reported that variation of macrofungal species composition between sites, within the same vegetation type, was more related to precipitation and temperature than to the composition of tree assemblages (Marmolejo & Méndez-Cortés 2007; Cavender-Bares et al. 2009; Gómez & Williams-Linera 2011). Furthermore, the ordination analyses indicated that air and soil temperature, air relative humidity, and the humidity-related

variables of moss coverage and maximum tree height are the main factors involved in the distribution of macromycetes through our studied area. The other vegetation structure and environmental variables were homogeneous in the four studied sites and equally related to macromycete distribution, thus were not playing a key role on the observed changes in species composition between study sites. In accordance with our results on diversity and species richness, our findings regarding distribution suggest that microclimate differences between sites have the main influence on macromycete distribution along the studied area.

Conclusions

This study has shown that harvesting wild edible mushrooms for several years within a specific area may not represent a threat to macrofungal communities, and it can be a sustainable activity. Patterns of diversity and distribution of macromycetes along harvesting/non-harvesting areas are mainly determined by the intrinsic microclimatic variation among sites. The present study included only one season of data, which could be a limitation, thus carrying out long term studies on different ecosystems and evaluating harvesting technics is of great interest to elucidate the most suitable methods to accurately manage this valuable non-timber forest product. Surveys along disturbance gradients are also desirable to clearly determine whether harvesting wild mushrooms is an innocuous activity as long as the environment and macromycete habitat are not disturbed. Generating more information on this activity will allow improving regulatory frameworks and not to exclude mushroom harvesting from management and conservation plans.

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Figure 1(on next page)

A) Rarefaction and B) accumulation curves for species richness in the four studied sites based on a standardized number of individuals and plots as sampling effort, respectively.

Vertical dotted line in rarefaction curves indicates species richness for the minimum number of individuals recorded in a study site.

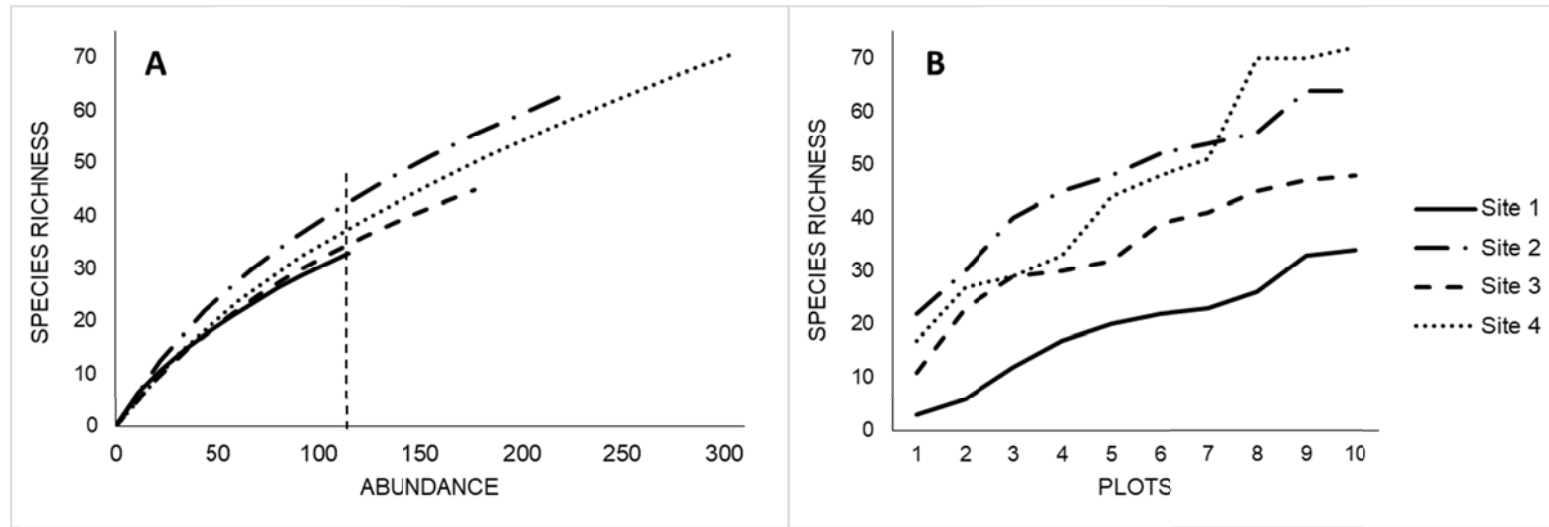


Figure 2(on next page)

Monthly variation of A) soil water content, B) air temperature, C) air relative humidity, and D) soil temperature in the studied sites through the sampling season.

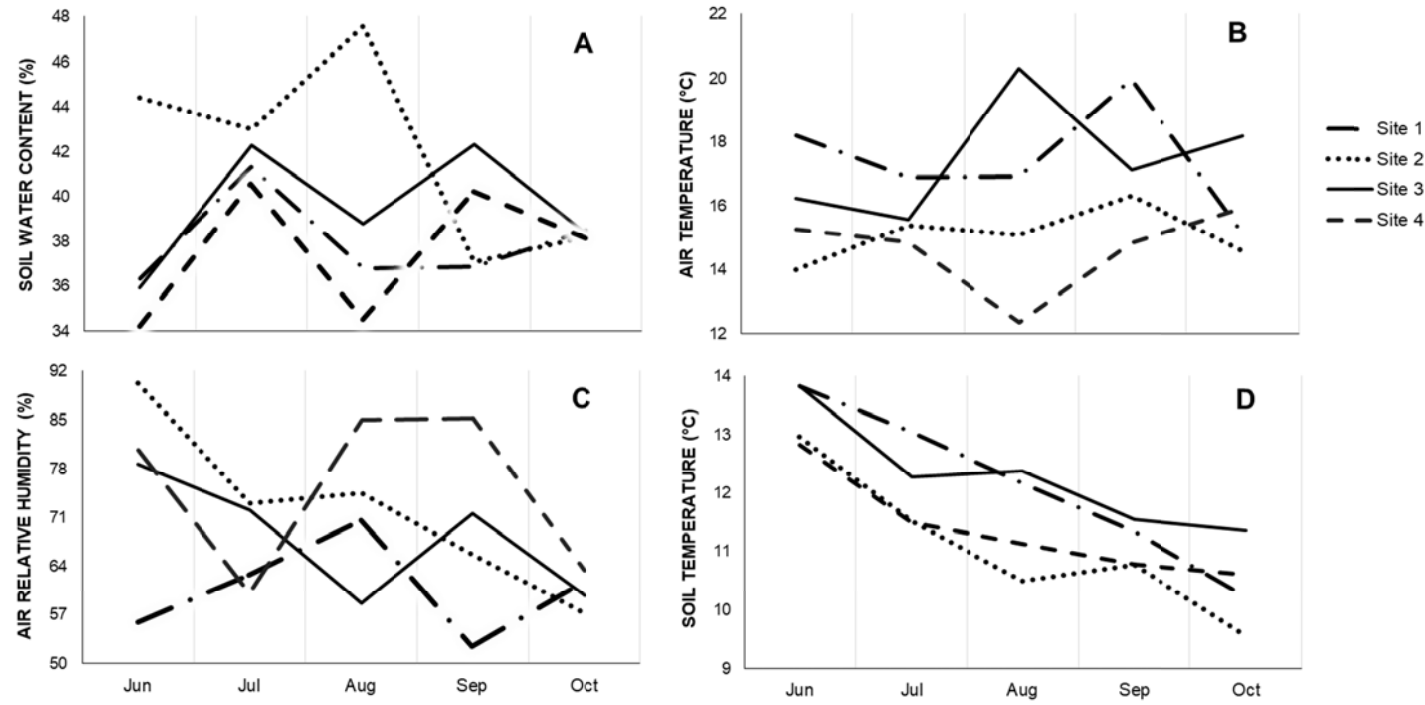


Figure 3(on next page)

Cluster analysis for the four studied sites, based on composition of species and abundance.

Euclidian distance is indicated by height values.

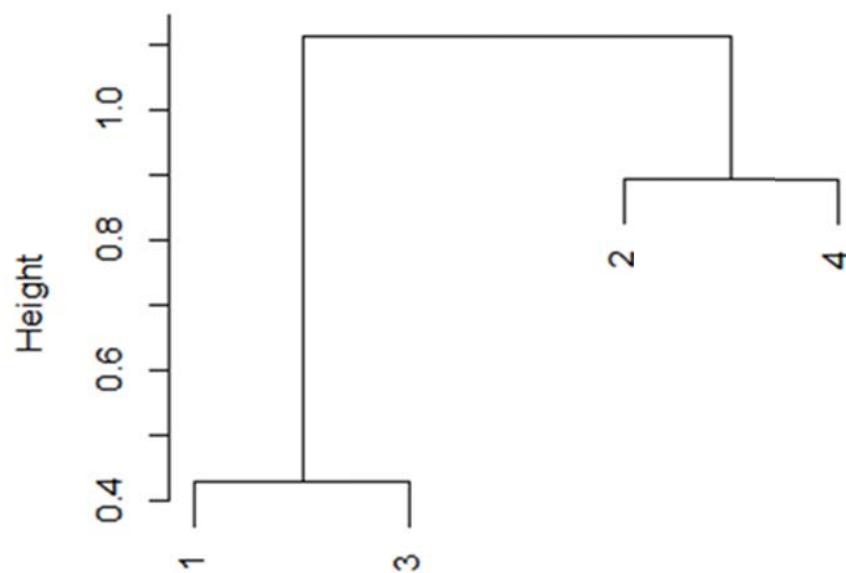


Figure 4(on next page)

CCA for all the recorded macromycetes in the four study sites.

Vectors are microclimatic explanatory variables: soil temperature (soilT), soil water content (soilW), air relative humidity (airH), and air temperature (airT).

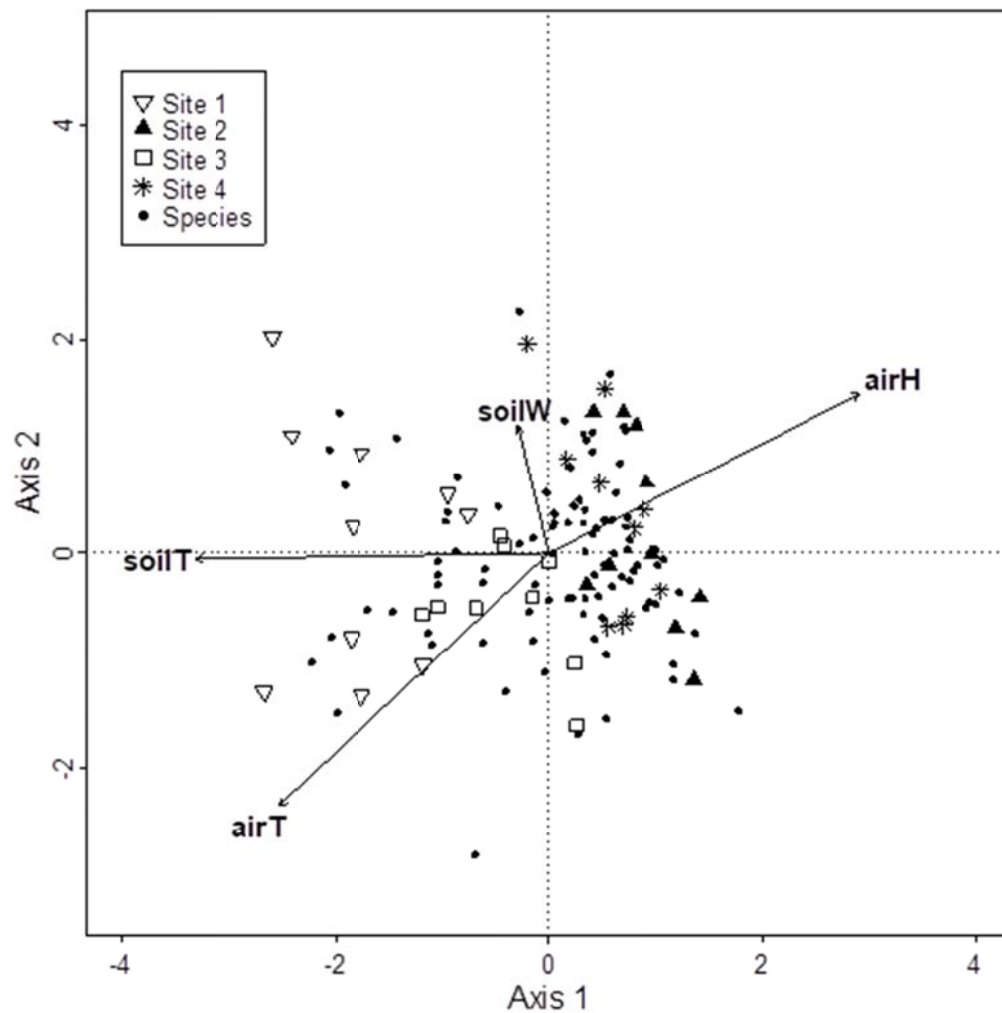


Figure 5(on next page)

CCA for all the recorded macromycetes in the four study sites.

Vectors are environmental explanatory variables: bulk density (bulkD), herbaceous coverage (herbs), rockiness coverage (rock), slope, canopy, moss coverage (moss), litterfall, aspect, and soil pore space filled with water (waterFPS).

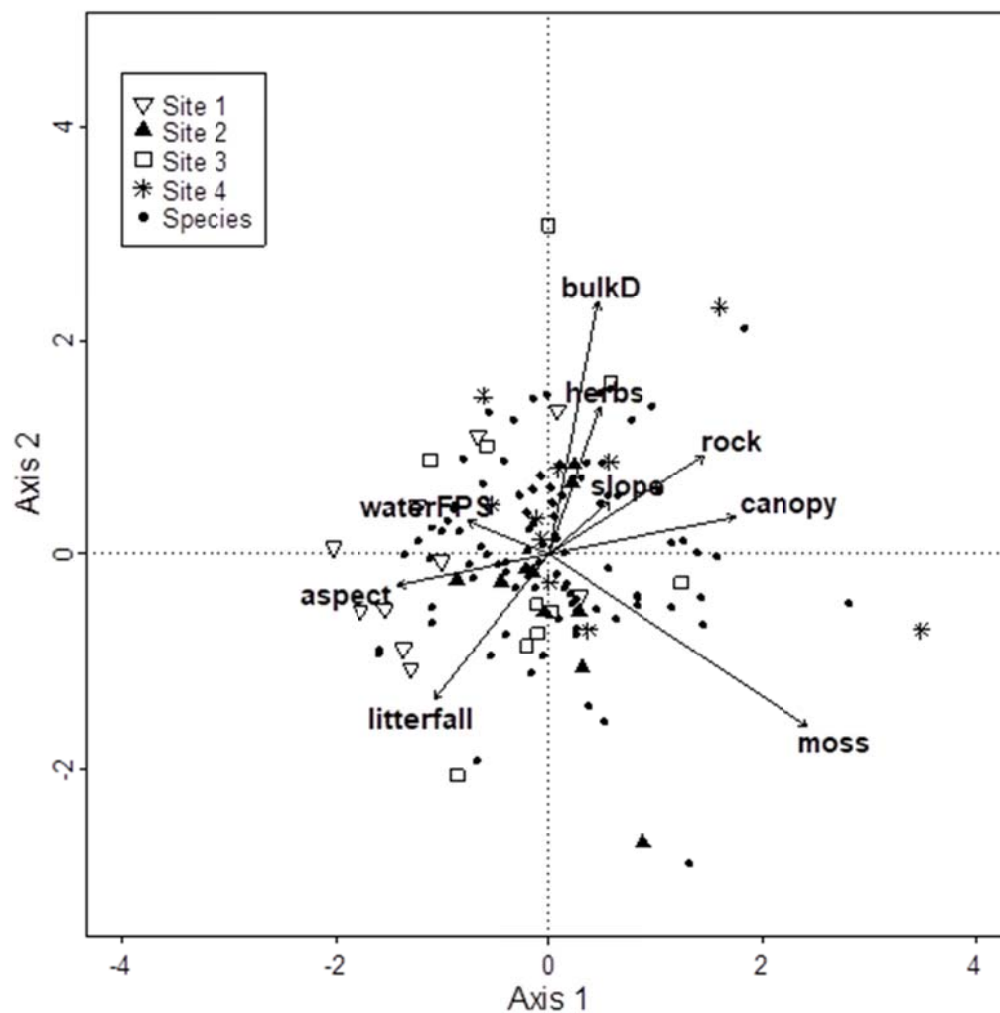


Figure 6(on next page)

CCA for all the recorded macromycetes in the four study sites.

Vectors are vegetation structure explanatory variables: tree maximum height (treemaxH), tree average height (treeavH), tree basal area (treeBA), and tree density (treeDen).

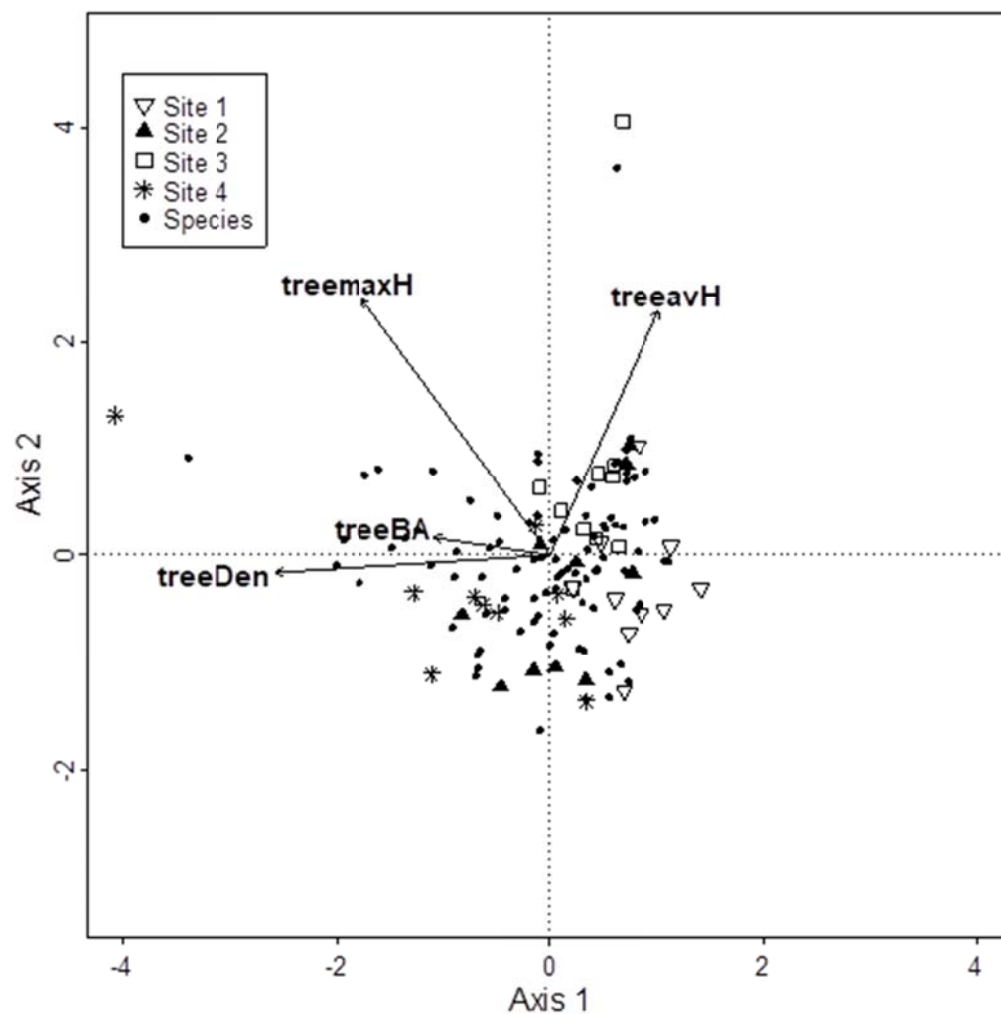


Table 1 (on next page)

Macromycete species richness, diversity and abundance in each studied site of the Mixteca region of Oaxaca, Mexico.

1 Table 1. Macromycete species richness, diversity and abundance in each studied site of the Mixteca region of Oaxaca, Mexico.

| 2 | | Site 1 | Site 2 | Site 3 | Site 4 |
|----|---------------------|---------------|---------------|-----------|-----------|
| 3 | SITE STATUS | Non-harvested | Non-harvested | Harvested | Harvested |
| 4 | ALL MACROMYCETES | | | | |
| 5 | Richness | 34 | 64 | 48 | 72 |
| 6 | Shannon diversity | 1.17 | 1.54 | 1.33 | 1.53 |
| 7 | True diversity | 14.83 | 35 | 21.28 | 34.01 |
| 8 | Abundance | 115 | 221 | 177 | 306 |
| 9 | EDIBLE MACROMYCETES | | | | |
| 10 | Richness | 9 | 12 | 10 | 14 |
| 11 | Shannon diversity | 0.57 | 0.96 | 0.6 | 0.87 |
| 12 | True diversity | 3.7 | 9.08 | 4.02 | 7.47 |
| 13 | Abundance | 66 | 36 | 84 | 86 |
| 14 | | | | | |

Table 2(on next page)

Chao-Jaccard similarity index between pairs of sites based on the composition of macromycete species.

Table 2. Chao-Jaccard similarity index between pairs of sites based on the composition of macromycete species.

| Pairs of sites | All macromycetes | Edible macromycetes |
|----------------|------------------|---------------------|
| 1-2 | 0.7 | 0.17 |
| 1-3 | 0.79 | 0.88 |
| 1-4 | 0.55 | 0.53 |
| 2-3 | 0.69 | 0.33 |
| 2-4 | 0.73 | 0.74 |
| 3-4 | 0.64 | 0.65 |

Table 3(on next page)

Spearman correlation coefficients (ρ) between the species richness of macromycetes recorded in the studied area and the explanatory variables.

Table 3. Spearman correlation coefficients (ρ) between the species richness of macromycetes recorded in the studied area and the explanatory variables.

| Variable | ρ | p-value |
|-----------------------------------|--------|---------|
| Air temperature*** | -0.58 | 0.00008 |
| Air relative humidity*** | 0.634 | 0.00001 |
| Soil temperature** | -0.414 | 0.007 |
| Soil water content | 0.098 | 0.545 |
| Soil porosity | -0.004 | 0.977 |
| Soil pore space filled with water | 0.03 | 0.854 |
| Bulk density | 0.004 | 0.977 |
| pH | 0.14 | 0.388 |
| Litterfall | -0.068 | 0.676 |
| Rockiness | 0.169 | 0.294 |
| Moss cover | 0.214 | 0.184 |
| Herbaceous* | 0.336 | 0.033 |
| Slope* | 0.36 | 0.022 |
| Aspect | -0.099 | 0.541 |
| Canopy | 0.075 | 0.642 |
| Tree average height | 0.158 | 0.327 |
| Tree maximum height* | 0.372 | 0.017 |
| Tree basal area* | 0.329 | 0.038 |
| Tree density | 0.172 | 0.285 |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$