Post fire macrofungal survival from temperate forests in northeastern Mexico

Sobrevivencia post incendio de macromicetos en bosque templado del noreste de México

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ABSTRACT. Temperate forests of Nuevo Leon have a high plant, animal and fungi diversity which form nutritional interaction networks and are affected by fires. Mycorrhizal fungi contribute to the nutritional functionality of forests, increasing roots uptake and translocation of minerals and water. The objective is to determine diversity of macromycetes in burned and unburned areas. Two sites (burned and not burned) in Iturbide, Nuevo León temperate forest were evaluated using 5 x 20 m plots. Results show 123 fungi species, 11 Ascomycetes and 112 Basidiomycetes in both study areas. The mycorrhizal species survived in the roots of the oak trees that regrew after the fire (*Quercus affinis, Q. canbyi, Q. cupreata, Q. graciliformis, Q. graciliramis Q. laeta* and *Q. polymorpha*). The burned site had 30 species, showing a 75.61% decrease in diversity as compared to the unburned site (118 species). Five of these fungi had not been registered in the last 38 years. They are *Jafnea semitosta, Sphaerosporella brunnea, Hypholoma lateritium, Climacocystis* sp. and *Oligoporus* sp. The last three are opportunistic; they established in stressed and weak trees. None pine species survived the fire. Results showed that richness and diversity of macromycetes were higher in unburned natural areas. Similarity between the two zones was low, since of the 123 species only 25 species were shared in both sites. Macromycetes were integrated in the Mycological Herbarium (CFNK) as reference and some strains with potential for cultivation are kept at the strain collection at the Faculty of Forest Sciences UANL.
Keywords: Regeneration, survived, parasitic fungi, nutrition, school forest.

RESUMEN. Los bosques templados de Nuevo León tienen una alta diversidad de plantas, animales y hongos formando redes de interacciones nutricionales que son afectados por incendios. Los hongos micorrízicos contribuyen a la nutrición aumentando la absorción y translocación de minerales y agua del suelo hacia los bosques. El objetivo es determinar la diversidad de macromicetos en áreas quemadas y no quemadas. Se evaluaron dos sitios (quemados y no quemados) del bosque templado de Iturbide, Nuevo León, utilizando parcelas de 5 x 20 m. Los resultados muestran 123 especies de hongos, 11 Ascomicetos y 112 Basidiomicetos en ambas áreas. Las especies micorrícicas sobrevivieron en raíces de encinos que rebrotaron tras el incendio (*Quercus affinis, Q. canbyi, Q. cupreata, Q. graciliformis, Q. graciliramis, Q. laeta y Q. polymorpha*). El área quemada tenía 30 especies, con disminución del 75,61% en comparación al sitio no quemado (118 especies). Cinco de estos hongos no habían sido registrados en los últimos 38 años. Son *Jafnea semitosta, Sphaerosporella brunnea, Hypholoma lateritium, Climacocystis* sp. y *Oligoporus* sp. Los últimos tres son oportunistas, se establecieron en árboles estresados y débiles. Ninguna especie de pino sobrevivió al incendio. Los resultados mostraron que la riqueza y diversidad de macromicetos fue mayor en áreas no quemadas. La similitud entre ambas áreas fue baja, de 123 especies solo 25 se compartieron. Los especimenes se depositaron en el Herbario Micológico (CFNK) y las cepas con potencial para cultivo están en la colección de cepas de la Facultad de Ciencias Forestales UANL.
Palabras clave: Regeneración, sobrevivencia, hongos parásitos, nutrición, bosque escuela.

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INTRODUCTION

Nuevo León temperate forests have many oaks and pines species, as well as madroño and manzanita trees, and they have a high macrofungal species diversity (Garza *et al.* 2023). This macrofungal diversity play an important role in the ecosystem forest recycling organic matter by means of enzymes used to degrade organic matter in their different nutritional ways e.g. mycorrhizal, saprophytic, parasitic, and pathogenic, in this way are functional for the growth and development of tree and shrub species in the forest (García *et al.* 1998, Zak and Willing 2004). Their cycle life involves the fleshy putrefying, woody and corky fruiting bodies production whose main function is to produce and release millions of spores via wind and rain, insects and other animals (e.g. mice, field rats, squirrels, birds, wild boars, deer, and bears) and play important roles for their distribution in the forest (García *et al.* 1998, Claridge *et al.* 2009, Garza *et al*. 2022, Rivera *et al.* 2023). The imbalances caused to the forest by immoderate logging, livestock, soil extraction and forest fires, among others, considerably reduces the richness and fungal species diversity thus affecting the forest functionality (Zak and Willig 2004, Hernández *et al*. 2013, Birkemore *et al.* 2018, García *et al.* 2021, Garza *et al.* 2022, Iordache *et al*. 2023).

Fires in the Sierra Madre Oriental of Mexico are important disruptors in arid montane and temperate forests, playing a crucial role in landscape ecology (Rodríguez-Trejo and Fulé 2003, González-Tagle *et al.* 2008). After a forest fire, the macromycetes species that were previously found were largely eradicated and after the first significant rain, the early stage fungi or pioneer species appear that develop just after the fire, their source is usually the spore bank present in the pre-fire soil (Claridge *et al.* 2009) and their fruiting is enhanced by the new conditions created by the fire (Hernández-Rodríguez *et al.* 2013). During succession, both early and late-stage fungi can establish mycorrhizal associations, but their nutritional requirements are different (Iordache *et al.* 2009, Savoie and Largeteau 2011). The present study of the functional richness of ectomycorrhizal macromycetes after a forest fire that occurred in the municipality of Iturbide in the state of Nuevo Leon is very important because the temperate forests in the state of Nuevo Leon have been seriously affected by forest fire in recent years (González-Tagle *et al.* 2008). With this research, we intend to generate scientific knowledge so far not existing for the state, such as locating the macro fungal species by means of their fruiting bodies in time and space on the forest floor after the occurrence of fire. Previous studies carried out in the proposed area have demonstrated a great diversity of ectomycorrhizal macromycetes species associated with the different types of vegetation in the municipality (Garza 1986, García *et al*. 2021, Garza *et al.* 2023). So far, macromycetes diversity species studies associated with the different vegetation types in the Nuevo León state showed that 1 300 species have been studied until now (Garza 1986). The results of this research focused on macrofungal species linked to the forest trees e.g. oaks and pines are of great importance for forest management and restoration purposes. With this research we want to confirm that forest fires affect macro fungal diversity of temperate forests of the Sierra Madre Oriental in the municipality of Iturbide, Nuevo Leon. The main objective is to determine the diversity of macromycetes with emphasis in ectomycorrhizal species present in areas affected by fire and to compare them with those growing in natural not burned areas.

MATERIALS AND METHODS

Study area description

The municipality of Iturbide is in the south of Nuevo Leon state at an altitude of 700 to 3 000 meters in the highest parts of the state (INEGI, 2009). This municipality is home to the "Bosque Escuela" originally founded by the Institute of Forestry and Natural Resource Management, now the Faculty of Forestry Sciences. The average temperature is 12 – 22 °C and the precipitation range from 500-800 mm, the climate is divided into: Semi-dry semi-warm (54%), Temperate sub-humid with summer rains, lower humidity (34%), Semi-warm sub-humid with summer rains, lower humidity (11%) and Temperate sub-humid with summer rains, medium humidity (1%) (Synnott and Marroquín 1987, INEGI 2009).

The vegetation types in the municipality are forest (67%), scrub (28%) and pasture (1%). Holm oak, mixed oak-pine and pine forests are the most characteristic and 4% of the municipality's territory is used for agriculture (INEGI, 2009; Salinas-Rodríguez *et al.* 2013). The main tree species form these temperate oak-pine and pine-oak forests are *Quercus canbyi* Trel., *Q. cupreata* Trel. & C.H. Mull., *Q. graciliformis* C.H. Mull., *Q. laceyi* Small, *Q. laeta* Liebm., *Q. polymorpha* Schltdl. & Cham. and *Q. rysophylla* Weath., as well as *Pinus teocote* Schltdl. & Cham. and *P. pseudostrobus* Lindl. (Synnott and Marroquín 1987, Alanis 2004, Salinas-Rodríguez *et al.* 2013).

Sampling methodology

Collections were made one year after the forest fire, during the rainy season when macromycetes produce fruiting bodies. 10 transects of 5 x 20 m aleatory established in every sampling site, burned and not burned (Figure 1), specimens were placed in paper bags labeled with the name site, habitat and any observation that help us with their identification (i.e. growing under a vascular plant, growing on the branch, leaf or dry trunk of some plant species). The identification was realized with the support of guides like Singer and Guzmán (1978), Ostry, Anderson and O'Brien (2011), Fergus and Fergus (2003) and websites like Index Fungorum (www.indexfungorum.org) and Mycobank database (Robert *et al.* 2005) to the species classification. Taxonomic identification of the species was carried out using traditional techniques and it was carried out by Dr. Fortunato Garza Ocañas, at the Faculty of Forest Sciences, Universidad Autónoma de Nuevo León (UANL). This study was carried out in the Department of Silviculture and Natural Resources Management of the Faculty of Forestry Sciences of the Universidad Autónoma de Nuevo León and in collaboration with the Center for Agricultural Research and Production (CIPA) of the UANL.

Diversity

Alpha diversity based on species richness was obtained using the (Past 4.03, 2020). To identify the species that contributed most to the differentiation between burned and natural conditions, the Jaccard Index was used to determine species similarity between the two communities, and the Wilson–Schmida Index was used to determine beta diversity, to measure species turnover. Complementarity was also calculated to determine the percentage of fungal species that are complementary between the burned and conserved forest. The range varies from 0 to 100% (Moreno 2001).

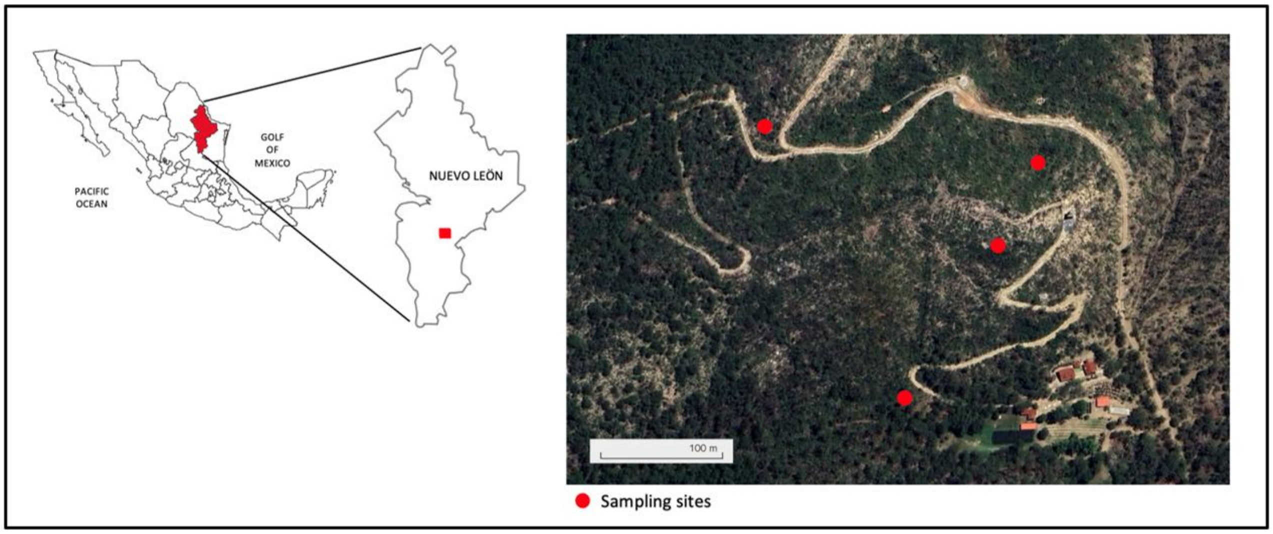

Figure 1. Location of sampling sites.

RESULTS

In this study the species of macromycetes and trees that survived the forest fire were determined, results showed the presence of 123 species, 11 Ascomycetes and 112 Basidiomycetes in both study areas (Table 1 Site 1), which corresponds to the burned area, has 30 species of which 15 are mycorrhizal, 13 saprophytic and 2 parasitic, corresponding to 24.39% of the total, compared to site 2, the area not affected by the fire, where 118 species were determined, of which 30 are mycorrhizal, 82 are saprophytic and 6 are parasitic (Figure 2). The following 25 species are present in both site conditions (burned and not burned): *Amanita vaginata* (Bull.) Lam., *Astraeus hygrometricus* (Pers.) Morgan, *Cantharellus* sp., *Coprinopsis atramentaria* (Bull.) Redhead, Vilgalys & Moncalvo, *Coprinopsis nivea* (Pers.) Redhead, Vilgalys & Moncalvo, *Coprinus comatus* (O.F. Müll.) Pers., *Cortinarius* sp. 1, *Deconica coprophila* (Bull.) P. Kumm., *Exidia glandulosa* (Bull.) Fr., *Helvella macropus* (Pers.) P. Karst., *Hortiboletus campestris* (A.H. Sm. & Thiers) Biketova & Wasser, *Inocybe geophylla* P. Kumm., *Inocybe* sp. 1, *Lentinus arcularius* (Batsch) Zmitr., *Lentinus tigrinus* (Bull.) Fr., *Pisolithus tinctorius* (Mont.) E. Fisch., *Russula cyanoxantha* (Schaeff.) Fr., *Schizophyllum commune* Fr., *Schizophyllum umbrinum* Berk., *Scleroderma verrucosa* Pers., *Stereum ostrea* (Blume & T. Nees) Fr., *Strobilomyces dryophilus* Cibula & N.S. Weber, *Suillus tomentosus* Singer, Snell & E.A. Dick, *Tapinella panuiodes* (Fr.) E.-J. Gilbert, *Xylaria hypoxylon* (L.) Grev. (Figures 3, 4). Original unburned and burned vegetation areas are shown respectively in (Figures 5, 6).

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Table 1. List of fungi species associated with burned and not burned sites in the temperate forest in Iturbide, Nuevo Leon. Classification based on Index Fungorum and Mycobank. The "x" indicates the species presence on the site. Site 1 = Burned; 30 species: 15 mycorrhizal; 13 saprophytic and 2 parasitic (24.39%). Site 2 = Not burned; 118 species: 30 mycorrhizal; 82 saprophytic and 6 parasitic (95.93%). Abbreviations: S = saprophytic, M = mycorrhizal, P = parasitic; E = edible; NE = not edible; M = medicinal; T = toxic.

Family	Species	Habit of growth	Edibility	Site	
				1	2
	Ascomycetes				
Helvellaceae	*Helvella macropus* (Pers.) P. Karst.	M	NE	x	x
Otideaceae	*Otidea* sp.	M	NE		x
Pyrenomataceae	*Sphaerosporella brunnea* (Alb. & Schwein.) Svrček & Kubička	M	NE	x	
Pyropyxidaceae	*Jafnea semitosta (Berk. & M.A. Curtis) Korf*	M	NE	x	
Hypoxlaceae	*Annulohypoxylon thouarsianum* (Lév.) Y.M. Ju, J.D. Rogers & H.M. Hsieh	S	NE		x
	Annulohypoxylon truncatum (Starbäck) Y.M. Ju, J.D. Rogers & H.M. Hsieh	S	NE		x
	Daldinia eschscholtzii (Ehrenb.) Rehm	S	NE		x
	Hypoxylon sp.	S	NE		x
Xylariaceae	*Kretzschmaria deusta* (Hoffm.) P.M.D. Martin	S	NE		x
	Xylaria hypoxylon (L.) Grev.	S	M	x	x
Hypocreaceae	*Hypomyces chrysospermus* (Bull.) Tul. & C. Tul.	P	NE		x
	Basidiomycetes				
Tremellaceae	*Tremella mesenterica* (Schaeff.) Pers.	S	E		x
Agaricaceae	*Coprinus comatus* (O.F. Müll.) Pers.	S	E	x	x
	Cyathus stercoreus (Schwein.) De Toni	S	NE		x
	Lepiota clypeolaria (Bull.) P. Kumm.	S	T		x
	Leucocoprinus rubrotinctus (Peck) Redhead	S	T		x
	Tulostoma sp.	M	NE		x
Amanitaceae	*Amanita afin caesarea* (Scop.) Pers.	M	E		x
	Amanita pantherina (DC.) Krombh.	M	T		x
	Amanita vaginata (Bull.) Lam.	M	T	x	x
	Amanita verna (Bull.) ex Lam.	M	T	x	x
	Zhuliangomyces illinitus (Fr.) Redhead	M	NE		x
Campanellaceae	*Campanella* sp.	S	NE		x
Clavariaceae	*Clavaria* sp.	S	NE		x
Cortinariaceae	*Cortinarius* sp.	M	T	x	x
	Cortinarius sp. 2	M	T		x
	Cortinarius sp. 3	M	T		x
Crepidotaceae	*Crepidotus* sp.	S	NE		x
Cyphellaceae	*Chondrostereum purpureum* (Pers.) Pouzar	S	NE		x
Entolomataceae	*Entoloma* sp.	S	T		x
Galeropsidaceae	*Panaeolus antillarum* (Fr.) Dennis	S	T		x
Hygrophoraceae	*Hygrocybe* sp.	S	T		x
	Neohygrocybe ovina (Bull.) Herink	S	T		x
Hymenogastraceae	*Phaeocollybia* sp.	M	NE		x
Incertae sedis	*Panaeolina foenisecii* (Pers.) Maire	S	NE		x
Inocybaceae	*Inocybe geophylla* P. Kumm.	M	T	x	x
	Inocybe sp.	M	T	x	x
Lycoperdaceae	*Apioperdon pyriforme* (Schaeff.) Vizzini	S	T		x
Lyophyllaceae	*Calocybe cyanea* Singer ex Redhead & Singer	S	NE		x
Marasmiaceae	*Tetrapyrgos nigripes* (Fr.) E. Horak	S	NE		x
Mycenaceae	*Mycena margarita* (Murrill) Murrill	S	T		x
	Panellus stipticus (Bull.) P. Karst.	S	NE		x
Omphalotaceae	*Gymnopus erythropus* (Pers.) Antonín, Halling & Noordel.	S	T		x
	Omphalotus subilludens (Murrill) H.E. Bigelow	S	T		x
Phyllotopsidaceae	*Phyllotopsis nidulans* (Pers.) Singer	S	NE		x

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Physalacriaceae	*Armillaria mellea* (Vahl) P. Kumm.	P	E		x
	Desarmillaria tabescens (Scop.) R.A. Koch & Aime	S	NE		x
	Oudemansiella melanotricha (Dörfelt) M.M. Moser	S	NE		x
Pleurotaceae	*Hohenbuehelia petaloides* (Bull.) Schulzer	S	NE		x
	Resupinatus alboniger (Pat.) Singer	S	NE		x
Pluteaceae	*Pluteus cervinus* (Schaeff.) P. Kumm.	S	T		x
	Pluteus longistriatus (Peck) Peck	S	T		x
	Pluteus sp.	S	T		x
	Pluteus sp. 2	S	T		x
Psathyrellaceae	*Candolleomyces candolleanus* (Fr.) D. Wächt. & A. Melzer	S	NE		x
	Coprinopsis atramentaria (Bull.) Redhead, Vilgalys & Moncalvo	S	E	x	x
	Coprinopsis lagopus (Fr.) Redhead, Vilgalys & Moncalvo	S	T		x
	Coprinopsis nivea (Pers.) Redhead, Vilgalys & Moncalvo	S	T	x	x
	Psathyrella sp.	S	NE		x
Schizophyllaceae	*Schizophyllum commune* Fr.	S	E	x	x
	Schizophyllum umbrinum Berk.	S	E	x	x
Strophariaceae	*Deconica coprophila* (Bull.) P. Kumm.	S	T	x	x
	Hypholoma lateritium (Schaeff.) P. Kumm.	S	T	x	
Auriculariaceae	*Auricularia auricula-judae (Bull.) Quél.*	S	E		x
	Exidia glandulosa (Bull.) Fr.	S	NE	x	x
Boletaceae	*Boletus* sp.	M	NE		x
	Hortiboletus campestris (A.H. Sm. & Thiers) Biketova & Wasser	M	NE	x	x
	Strobilomyces dryophilus Cibula & N.S. Weber	M	E	x	x
	Xerocomus subtomentosus (L.) Quél.	M	E		x
Diplocystidiaceae	*Astraeus hygrometricus* (Pers.) Morgan	M	T	x	x
	Astraeus pteridis (Shear) Zeller	S	NE		x
Sclerodermataceae	*Pisolithus tinctorius* (Mont.) E. Fisch.	M	E	x	x
	Scleroderma texense Berk.	M	E		x
	Scleroderma verrucosum (Bull) Pers.	M	T	x	x
Suillaceae	*Suillus tomentosus* Singer, Snell & E.A. Dick	M	E	x	x
Tapinellaceae	*Tapinella panuoides* (Fr.) E.-J. Gilbert	S	NE	x	x
Hydnaceae	*Cantharellus sp.*	M	E	x	x
Gloeophyllaceae	*Gloeophyllum sepiarium* (Wulfen) P. Karst.	S	NE		x
	Heliocybe sulcata (Berk.) Redhead & Ginns	S	E		x
Hirschioporaceae	*Pallidohirschioporus biformis (Fr.) Y.C. Dai, Yuan Yuan & M. Zhou*	S	NE		x
Hymenochaetaceae	*Fulvifomes* sp.	P	NE		x
	Fuscoporia gilva (Schwein.) T. Wagner & M. Fisch.	P	M		x
	Fuscoporia ferruginosa (Schrad.) Murrill	S	NE		x
	Hydnoporia olivacea (Schwein.) Teixeira	P	NE		x
	Inocutis sp.	S	NE		x
	Phellinus rimosus (Berk.) Pilát.	P	NE		x
Phallaceae	*Lysurus periphragmoides* (Klotzsch ex Hook.) Dring	S	NE		x
Cerrenaceae	*Cerrena hydnoides* (Sw.) Zmitr.	S	NE		x
Dacryobolaceae	*Oligoporus* sp.	P	NE	X	
Fomitopsidaceae	*Antrodia* sp.	S	NE		x
	Amyloporia xantha (Fr.) Bondartsev & Singer ex Bondartsev.	S	NE		x
Incertae sedis	*Climacocystis* sp.	P	NE	x	
Irpicaceae	*Byssomerulius corium* (Pers.) Parmasto	S	NE		x
	Irpex lacteus (Fr.) Fr.	S	NE		x
Laetiporaceae	*Laetiporus sulphureus* (Bull.) Murrill	S	E		x
Panaceae	*Panus neostrigosus* Drechsler-Santos & Wartchow	S	E		x
Polyporaceae	*Daedaleopsis confragosa (Bolton) J. Schröt.*	S	NE		x
	Fabisporus sanguineus (L.) Zmitr.	S	M		x
	Funalia hispida (Bagl.) M.M. Chen	S	NE		x
	Lentinus arcularius (Batsch) Zmitr.	S	NE	x	x
	Lentinus crinitus (L.) Fr.	S	E		x

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	Lentinus tigrinus (Bull.) Fr.	S	E	x	x
	Neofavolus alveolaris (DC.) Sotome & T. Hatt.	S	E		x
	Perenniporia ohiensis (Berk.) Ryvarden	S	NE		x
	Podofomes mollis (Sommerf.) Gorjón	S	NE		x
	Poria sp.	S	NE		x
	Pycnoporus sp.	S	M		x
	Trametes elegans (Spreng.) Fr.	S	NE		x
	Trametes hirsuta (Wulfen) Lloyd	S	NE		x
	Trametes hirta (P. Beauv.) Zmitr., Wasser & Ezhov	S	NE		x
	Trametes occidentalis Fr.	S	NE		x
	Trametes tenuis (Berk.) Justo	S	NE		x
	Trametes variegata (Berk.) Zmitr., Wasser & Ezhov	S	NE		x
Peniophoraceae	*Peniophora albobadia (Schwein.) Boidin*	S	NE		x
	Peniophora quercina (Pers.) Cooke	S	NE		x
Russulaceae	*Lactarius indigo* (Schwein.) Fr.	M	E		x
	Russula brevipes Peck	M	E		x
	Russula cyanoxantha (Schaeff.) Fr.	M	E	x	x
	Russula delica Fr.	M	E		x
	Russula mexicana Burl.	M	E		x
	Russula sp.	M	T		x
Stereaceae	*Stereum complicatum* (Fr.) Fr.	S	NE		x
	Stereum ostrea (Blume & T. Nees) Fr.	S	T	x	x

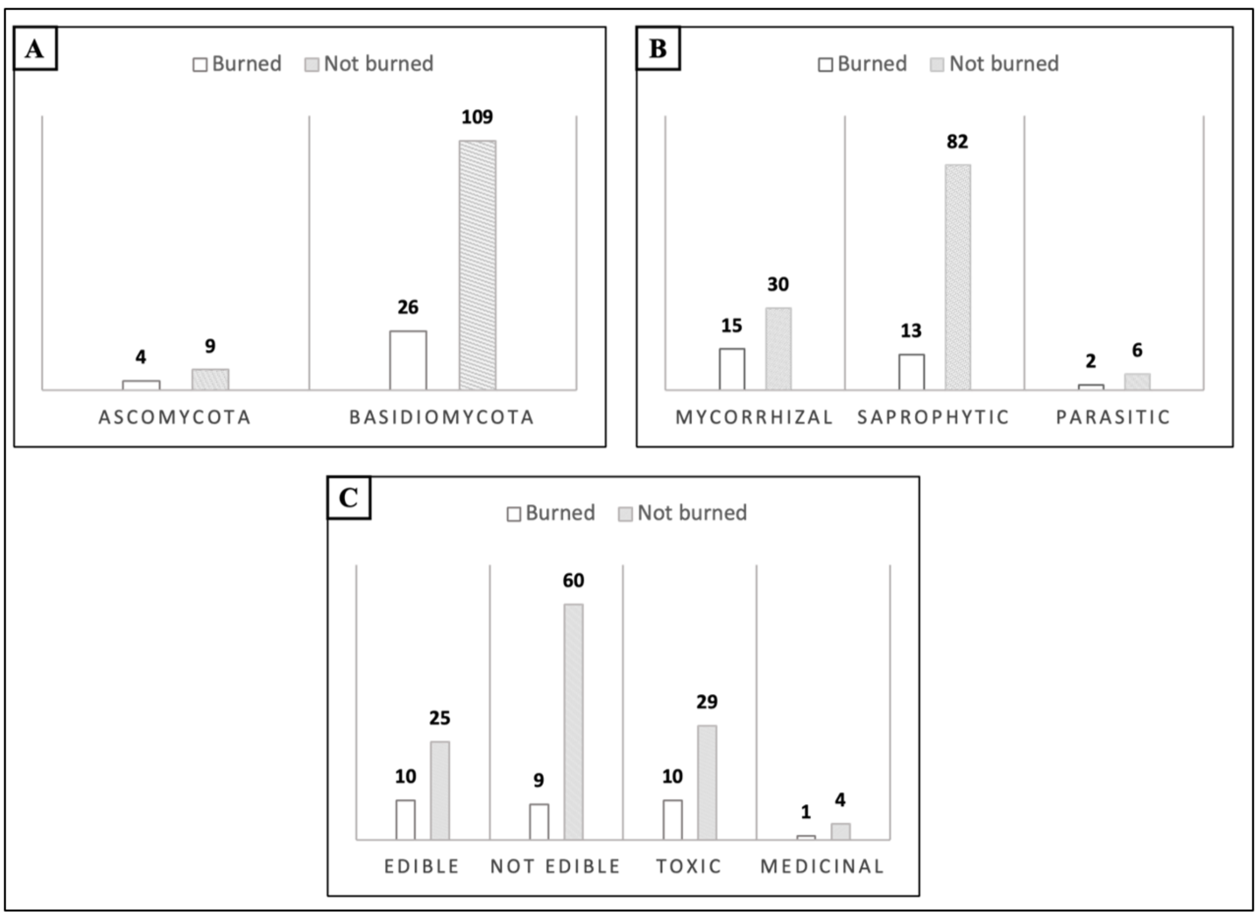

Figure 2. A. Ascomycota and Basidiomycota diversity species in the burned and unburned forest. B. Species growth habit. C. Species edibility.

Figure 3. Images of some of the species studied. A). *Helvella macropus* B). *Otidea* sp. C). *Jafnea semitosta* D). *Shaerosporella brunnea*. E) & F). *Daldinia eschscholtzii*. G). *Tremella mesenterica* H). *Lepiota clypeolaria.* I). *Leucocoprinus rubrotinctus*. J). *Clavaria* sp. K). *Inocybe* sp. L). *Gymnopus erythropus*.

Ascomycetes species *Helvella macropus* (Pers.) P. Karst., *Jafnea semitosta* (Berk. & M.A. Curtis) Korf, *Sphaerosporella brunnea* (Alb. & Schwein.) Svrček & Kubička and *Xylaria hypoxylon* (L.) Grev. grew in the burned area, *Jafnea semitosta* and *Sphaerosporella brunnea* had not been previously recorded from either of the 2 sites conditions (Figure 3). The Basidiomycetes *Amanita vaginata* (Bull.) Lam., *Astraeus hygrometricus* (Pers.) Morgan, *Cantharellus sp.*, *Cortinarius* sp. 1, *Hortiboletus campestris* (A.H. Sm. & Thiers) Biketova & Wasser, *Inocybe geophylla* P. Kumm., *Inocybe* sp. 1, *Pisolithus tinctorius* (Mont.) E. Fisch., *Russula cyanoxantha* (Schaeff.) Fr., *Scleroderma verrucosa* Pers., *Strobilomyces dryophilus* Cibula & N.S. Weber and *Suillus tomentosus* Singer, Snell & E.A. Dick are the species that survived the forest fire the rest of the mycorrhizal species occurred in the unburned area. *Hypholoma lateritium* (Schaeff.) P. Kumm., *Climacocystis* sp. and *Oligoporus* sp. are saprophytic or parasitic species not previously reported from either study site.

Figure 4. A). *Hohenbuehelia petaloides*. B). *Schyzophyllum commune*. C). *Schyzophyllum umbrinum*. D). *Hypholoma lateritium*. E). *Hortiboletus campestris*. F). *Strobilomyces dryophilus*. G). *Astraeus hygrometricus*. H). *Scleroderma texense*. I). *Suillus tomentosus*. J). *Cantharellus* sp. K). *Climacocystis* sp. L). *Oligoporus* sp.

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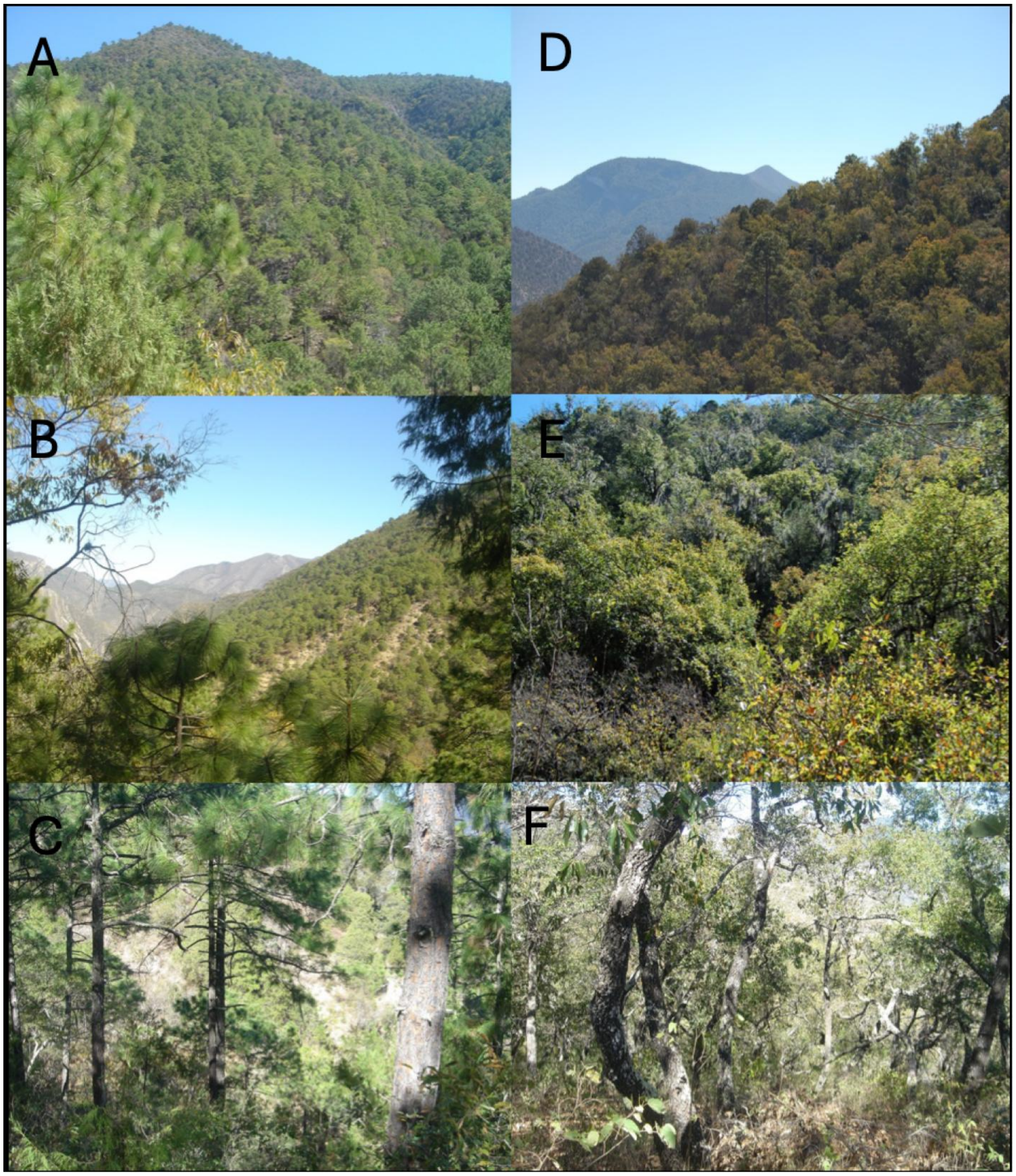

Figure 5. Forests before the fire, of conifers (A, B, C) and mixed of oaks and conifers (D, E, F).

Diversity

Alpha diversity in the burned area was 30 fungal species, whereas in the natural area it was 118, reflecting the effect of fire on the growth of ectomycorrhizal fungi in forest roots (Table 2). Similarity between the two zones was low, since of the 123 species recorded in total, only 25 were shared. The Jaccard Index showed only 20% similarity, which contrasts with the beta diversity and complementarity values, which were 66 and 79%, respectively—considered high given the range of 0–100% (Table 2). These results indicate high species turnover from natural to burned zones.

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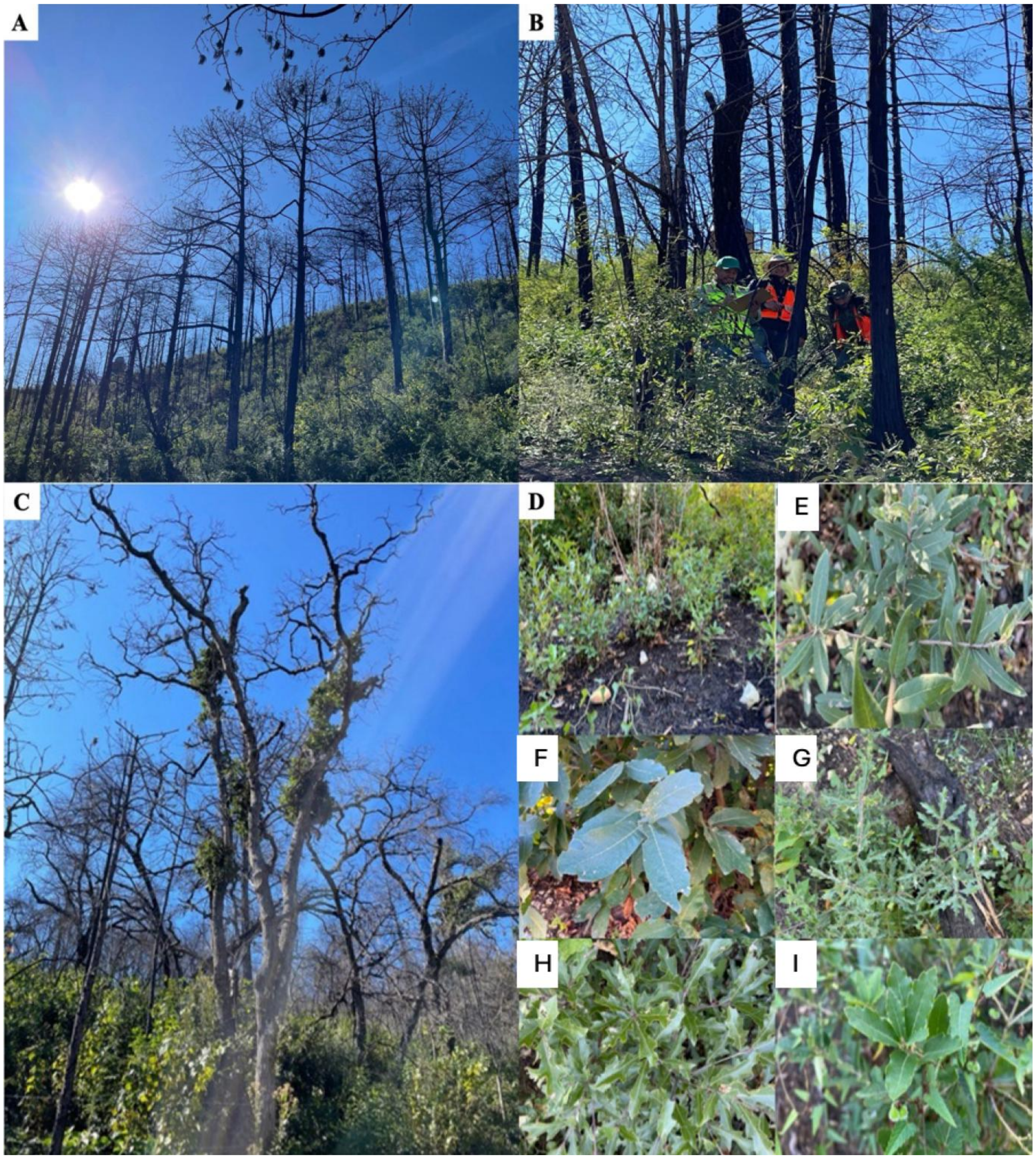

Figure 6. A). Panorama of the burned forest with regeneration of oaks and herbaceous species. B). Sampling of mushroom species. C) - I). Some Oak species that survived the fire: D) *Quercus canbyi, E) Q. affinis, F) Q. polymorpha, G) Q. graciliformis, H) Q. graciliramis* and *I) Q. laeta*

Table 2. Similarity Index and two Beta Diversity Index (%) and number of shared species between burned Forest and Unburned Forest.

Index	Value (%)
Jaccard index	20
Wilson-Schmida index	66
Complementarity index	79
Shared species	25

DISCUSSION

The results show 75.61% decrease in the number of macromycete species because of the forest fire. The mycorrhizal species might have survived living inside of the mycorrhizas of oaks that sprouted from burned stumps at the fire affected site. Some of the oak species that survived are *Quercus affinis, Q. canbyi, Q. cupreata, Q. graciliformis, Q. graciliramis Q. laeta* and *Q. polymorpha*. These oak species that survived and sprouted have living and functional mycorrhizas that are of great importance for the development of the regenerating oak forest, as suggested by López- Ráez and Pozo (2013) Apparently surviving ectomycorrhizal fungi in these forests have functioned as triggers to re sprouting mechanisms for the surviving of some oak species from burned stumps. These survival mechanisms both for ectomycorrhizal fungi and oak species are of high interest as for their management in these forests. It is also interesting to mention that some of the ECM fungal species that survived are reported as edible; also sporocarps produce spores that act as dispersion inoculants in the burned area giving rise to new mycelial colonies that might help to produce more mycorrhizas and when new acorns will be produced in the future they will find these inoculants in the forest floor. Rodents and other animals including insects coming from the nearby non-affected sites might act as spore dispersing agents which can also propitiate forest growth and development.

The life cycles of ectomycorrhizal fungi involve a part in which the fungi grow within the tissues of fine roots (Smith and Read 2008). Each year there is senescence of old rootlets which during autumn-winter detach from the root to which they are attached. In the active growing season, the fungal hyphae that remain attached to the root tissues from which the senescent roots were detached generate new hyphae that associate with the newly produced fine rootlets and form new mycorrhizas (Smith and Read 2008, Wang *et al.* 2017). Generally, this occurs at different levels of depth in the soil, but many occur in the most superficial part of the soil, in the case of the temperate forests of the municipality of Iturbide apparently some of the species of ectomycorrhizal fungi survived in this way lodged in the tissues of the fine roots in the deepest soil layers that were not affected by the superficial or crown fire that occurred in the forest and are of great importance for the development of the regenerating oak forest.

Of the 30 species found in the burned area, 5 had not been recorded in previous studies conducted for 38 years in these sites. They are: *Jafnea semitosta* (mycorrhizal); *Sphaerosporella brunnea* (mycorrhizal) and *Hypholoma lateritium, Climacocystis* sp. and *Oligoporus* sp. (saprophytic or parasitic). It is likely that the spores of these species benefited in their germination by the new conditions after fire forest.

There were no surviving pines in the burned area and there is a tendency to infection by *Hypholoma lateritium, Climacocystis* sp. and *Oligoporus* sp. these three fungal species are opportunistic, they establish themselves in stressed and weak trees, affecting the lumber at the base, rotting the wood and making them susceptible to falling due to rotting. Their presence after the fire is understood by the impact that the fire has on the diversity of vegetation. Some trees have two or three of these species growing at the same time. None of the pine species survived the fire.

During sampling in burned areas, there was no presence of squirrels, mice or birds of prey that might associate by mycophagy, which may indicate that the decrease in fungal species has an impact on the number of possible dispersers, such as rodents that consume them when they are available. The strategy that can help the development of the forest in the future is to continue reforestation with oaks and pines. Also, during the rainy season, mycorrhizal fungi fruits from unaffected areas can be introduced to the affected sites. This will help the vegetation to produce a greater number of mycorrhizal species associated with their root systems. It is also recommended not to thin the oak trees that are resprouting because these resprouts keep the soil free of heat from exposure to the sun's rays, which would dehydrate the soil and reduce the ability of the fungi to help the surviving oak species to better nourish themselves.

CONCLUSIONS

Results of this study confirm that forest fires affect macro fungal diversity in temperate forest of the Sierra Madre Oriental and analysis showed that both sites (burned and natural) shared 25 species in common. Fifty percent of the ectomycorrhizal fungi (ECM) species (i.e 15 species) survived the effects of fire and produced sporocarps a year after and during the rainy season. These results suggest that ECM fungi might propitiate new sprouting from oak burned stumps. Thus, ectomycorrhizal fungi might act as nutritional net mechanisms for oak survival and re colonization at the site affected by fire. The specimens found in the sites were placed in the herbarium (CFNL) to serve as reference as well as some isolates of selected species that have potential for their cultivation in the Mycological Herbarium of the Faculty of Forest Sciences UANL.

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CONFLICT OF INTERES

The authors declare that they have no competing interests.

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