Forest Systems
31 (3), eR01, 11 pages (2022)
eISSN: 2171-9845
https://doi.org/10.5424/fs/2022313-19288
INIA-CSIC

REVIEW ARTICLE

OPEN ACCESS

Edible fungi for local and sustainable development in the Patagonian Andes forests of Argentina: A review

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Abstract

Wild fungi are one of the most characteristic and diverse non-wood forest products from native and planted forest environments and grasslands in the Patagonian Andes. Through the technological and scientific platform "Patagonia Fungi, trails and tastes®", we work to promote mycotourism and mycogastronomy as sustainable identity and inclusive economic and educational activities that promote local development, taking advantage of the outstanding regional tourist profile. We also work on the development of functional foods and promote the cultivation of edible and medicinal fungi. The main objectives of this research were to define novel edible species and evaluate them for sustainable uses, including: environmental characterizations of their fruiting niches and 'mycosilvicultural' managements to increase their productivity; documentation and analysis of the ancestral uses and their processes of change; determination of the nutritional and nutraceutical profiles; studies of molecular genetic diversity of various genera; protocols for the domestication of wild species; evaluation and selection of lignocellulosic substrates for cultivation from available residues in Patagonian Andes; economic aspects related to the marketing and use in local gastronomy; evaluation of postharvest preservation techniques. Most relevant actions include the design and implementation of mycotourism trails, the promotion of an identity mycogastronomy; the inter-institutional management of protocols for sustainable harvesting and food safety practices; the incorporation of 21 new species in the Argentinean Food Code. We also work for food sovereignty through a spawn production laboratory fostering edible and medicinal fungi cultivation through courses and assistance to producers from family to productive scales.

Additional key words: wild edible mushrooms; mushroom cultivation; non-wood forest products; food sovereignty; *Nothofagus* forest; mycotourism; mycogastronomy.

Abbreviations used: GIS (Geographic Information System); NWFPs (non-wood forest products); R&D (Research and Development).

Citation: Barroetaveña, C; Pildain, MB (2022). Edible fungi for local and sustainable development in the Patagonian Andes of Argentina: A review. Forest Systems, Volume 31, Issue 3, eR01. https://doi.org/10.5424/fs/2022313-19288

Supplementary material (Fig. S1) accompanies the paper on Forest System´s website.

Received: 10 Feb 2022. **Accepted:** 07 Oct 2022.

Funding agencies/institutions	Project / Grant
CONICET	PIP 11220170100982C
MINCyT	PICT 2018-3234

Competing interests: The authors have declared that no competing interests exist.

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This article belongs to the Special Issue "Forests: Reservoirs of Global Mycocultural Heritage and Mycological Resources". https://revistas.inia.es/index.php/fs/si1

Introduction

Patagonia constitutes a huge piece of land, comprising five provinces with an area of one million square kilometers that represents half of Argentina (https://www.ign.gob.ar/). It has diverse and abundant natural resources, although it is the region with the lowest population density in the country: just two and a half people per square kilometer (Cámara Argentina de Comercio y Servicios, 2019). This situation coexists with the need to support and strengthen rural populations and generate jobs, to avoid internal migration to big cities, while preserving the environmental value and ecological functions of Patagonia. In this scenario, improving agroforestry systems, making environmentally sustainable economic use of native forests and tree plantations, constitutes a promising opportunity.

The subantarctic forests of Argentine and Chilean Patagonia have been inhabited since pre-Hispanic times by native communities, constituting humanized landscapes with different degrees of domestication as a result of their particular management logics and relationship with their constituent elements (Aigo *et al*., 2020). Most of the rural population is composed by "criollos" and "mapuches" who maintain subsistence economies, strongly depending on the knowledge transmitted from generation to generation about useful species and their natural rhythms (Molares & Ladio, 2014). The environmental knowledge that sustains this type of economy is part of the cultural and cumulative heritage of native people, conceptually called traditional ecological knowledge (Laudari, 2010). This physical landscape is characterized by being a complex and heterogeneous ecosystem matrix, with patches of *Nothofagus* spp. primary and secondary, grazing sites, introduced conifer plantations, fruit, shelter and ornamental plantations, interrelated through roads, bodies of water and by rural activities that involve the movement of residents and livestock throughout the year (Molares *et al*., 2019). The inhabitants have a profile of small "criancero", or "smallholder or subsistence producer", or "campesinos", involving the breeding of cattle and sheep, in many cases, their main income item. Another traditional activity is the extraction of firewood from ñire (*Nothofagus antarctica*) and small forest exploitation of lenga (*Nothofagus pumilio*) forests, through private and state sawmills.

With a narrow although long area of native forest on the west close to Andes, several tree plantations, wet meadows, and protective forest curtains going east, the native and planted forests and the grasslands of the Andean Patagonian region have a great wealth of fungi with enormous scientific and cultural interest and with potential uses linked to local development. Many of them are unique to our region, more than 30 species are edible (Barroetaveña & Toledo 2020), but only *Morchella* species (morels) are of commercial relevance at a national and international level, while "pine boletes", exotic ectomycorrhizal mushrooms associated with *Pinus* spp. (mainly *Suillus luteus* eventually mixed with *Suillus granulatus* or *Suillus lakei* in less proportion), have regional and national circulation (Fernández *et al*., 2012; Valtriani *et al*., 2017). The other species, many of them with records of ancestral consumption (*e.g.* Molares *et al.*, 2019) are not being used (or only very marginally) for self-consumption or trading.

The non-wood forest products (NWFPs) of Andean Patagonia have played a crucial role in the indigenous diet since prehistoric times (Ciampagna & Capparelli, 2012), as well as in present populations (Molares & Ladio, 2012; Chamorro *et al*., 2018; Ochoa, 2019). In particular, wild edible fruits and fungi have gained special interest in recent decades, due to their value as functional foods and their potential for the development of local economies (Tacón Clavaín *et al*., 2004; Barroetaveña & Toledo, 2016; Chamorro *et al*., 2018; Ochoa, 2019). However, to date there is no documented information on the marketing for these products, nor on the players involved, nor on their contribution to the domestic economy (Valtriani *et al.,* 2017; Ochoa*,* 2019).

Society in general demands natural foods, with better nutritional and nutraceutical quality. Edible fungi are nutritious and certifiable organic foods given their origin from pristine ecosystems in Patagonia. Knowing them will allow to strengthen a mycological culture in the region, developing an identity and sovereign gastronomy based on valuing and using natural resources in a sustainable way. Likewise, the fungal diversity of the region offers the opportunity to incorporate them in ecotourism developments, through the implementation of mycotrails, which also constitute interactive educational spaces for everyone but especially children and young people. As many populations in Patagonia are still isolated, and the arrival of fresh food is difficult and expensive, diversifying the production of family or community gardens with cultivated edible fungi is a way to ensure food sovereignty.

Given the growing questioning of the extractivist and hegemonic productive paradigm, projects that propose the integration of the traditional ecological knowledge and scientific knowledge are increasingly valued, to build more successful paths towards solving problems of biocultural conservation and sustainable socioeconomic development (Morales *et al*., 2017).

Wild edible fungi as NWFPs worldwide and in Patagonia

Edible fungi are a highly appreciated food in different parts of the world whose consumption has increased in recent years (Royse & Sanchez, 2017; Pérez-Moreno *et al*., 2021a). Also, some species have important ecological roles associated with natural forests conservation; ectomycorrhizal fungi comprise the most lucrative wild edible fungi group in the world and are key players in forest conservation related with ecosystem health maintenance and nutrient cycling (Pérez-Moreno *et al.*, 2021a).

Their culinary and commercial value is due to the fact that, in addition to having particular aromas, flavors, colors, shapes and textures, they contain numerous nutritional compounds and others that can be beneficial to health (Pérez-Moreno & Martínez-Reyes, 2014; Barroetaveña & Toledo, 2017). However, Argentina is in general a mycophobic country; the average consumption of edible fungi per capita is just 100 g/person/year, 40 times less than in Europe (Abeyá *et al*., 2007). Mycophobia or fungophobia, due to fear of the unknown, is dominant although there is a long-standing mycological school in the country. Carlos Spegazzini started the lines of mycological research in the country after his travels since 1881, and from there several research groups in universities and science and technology institutes have described several new species of fungi per year, and isolated new antibiotics and other interesting bioactive principles. However, fungi and their potential remain unknown to the vast majority of Argentinian society (Gamundí *et al*., 2017). This contradiction, further accentuated by the extensive immigration of citizens from mycophilic countries such as Spain and Italy (Pérez-Moreno *et al.*, 2021b), and with a register of ancestral uses of edible mushrooms by original populations (Molares *et al.*, 2019) could be explained by different convergent historical processes. Immigrants came to a new continent with different and unknown species, so had to be precocious; moreover, intensive livestock raising has been a main activity that provided a rich food source; also, the majority of the current population is settled in cities (INDEC, 2010), with scarce contact with wild environment. Regarding Mapuche-Tehuelche people, after the 16th century, in coincidence with the conquest and colonization by Europeans and then the constitution of the states of Chile and Argentina, they were forced to migrate toward the south and east, restricted to the driest areas of Argentina (Zabala, 2000), that favors a process of cultural erosion (Barthel *et al.*, 2013).

The environmental, biological, and recreational role of forests has increased during the last decades (Latorre *et al.*, 2021). In this sense, Mycotourism has emerged as an option to diversify economic activities in rural areas within the multiple use of forest environments, increasing its value, creating wealth for their local communities and potential for future developments (De Frutos *et al.*, 2012; Moisan-De Serres *et al.*, 2017). Forest environments host a population with very particular cultural and productive characteristics that are facing processes of change. New strategies arise to reinterpret their productive potential in the contemporary world. Among these new developments, tourism in rural areas stands out as an activity based on the biocultural heritage that the forest boasts compared to the cities. Despite the existing mycodiversity in forests worldwide, fungi harvesting is associated with marginalization and poverty, which arises from the inability to add value locally; however, activities such as mycogastronomy and mycotourism have proven effective in enhancing these products in some instances (Thome-Ortiz, 2015; Pérez-Moreno *et al*., 2021a,b). Mycotourism development started about 20 years ago in Spain, with the Spanish mycological program of Castilla and Leon (http://www.micocyl.es), and rapidly gained attention in other countries as Canada, Scotland (Buntgen *et al.,* 2017), and more recently in central America (Pérez-Moreno *et al*., 2021a) and Argentina (Barroetaveña & Toledo, 2020).

Edible fungi favor food diversification, since they constitute a resource of high nutritional value for family consumption and can also be used in the development of a Patagonian mycogastronomy as a key axis: they are differentiated, and identity products given the great variety of endemic sub-Antarctic species that allow their incorporation into the local gastronomic circuit linked to tourism and the development of higher value-added products (Table 1; Fig. 1). Mycotourism with a local development perspective also requires ethno-knowledge about wild edible fungi, which represent a heritage that can be appropriated by local communities (Molares *et al*., 2019). Many of these species are part of the cultural knowledge of the native locals, since the Mapuche and Creole communities are the ones who know the timing and sites of good species fruiting, which is strictly seasonal during the fall (April-May) or spring (October-November) and provide an opportunity to develop new attractions for the low-season months.

Tourism is one of the activities that has grown the most in recent years in Patagonia, both for national and international tourists seeking experiences that allow visitors to approach and understand the unique natural beauty of the subantarctic forests. In this sense, rural tourism and ecotourism appear as very interesting alternatives for passing tourists, which in turn allow the development of new offers linked to activities that keep local people in particular places. In addition, the area is very significant for fishermen, since its rivers are home to Pacific salmon and trout, attracting fans of this recreational-sport activity in out-of-date seasons. All this represents a promising scenario to develop offers of new activities for these audiences (Porto & García, 2020).

In conclusion, the development of mycotourism integrated with mycogastronomy and product development is a complex task that requires a multidisciplinary approach involving social, economic, ecological, cultural, biological, technological, and political issues.

Patagonia fungi: research, development and knowledge transfer - Current achievements

Through the scientific-technological platform "Patagonia Fungi, trails and tastes®", we are working to promote mycotourism (observation, interpretation, photography, and controlled collection of edible wild fungi fructifications), mycogastronomy (gastronomy with edible fungi) and the development of fungi-based functional foods. Taking advantage of the existing outstanding tourist profile of Patagonia and mushroom provenance from these non-pol-

Table 1. Edible fungi registered in Patagonia Argentina.

Associated forest	Ecology	Mushroom species	Native/ exotic[a]	Edibility	Fruiting season	Inclusion in the Argentinian Food Code
Native forest	Mycorrhizal	*Cortinarius magellanicus*	native	cooked	autumn	In process
		Cortinarius xiphidipus	native	cooked	autumn	In process
		Ramaria patagonica	native	cooked	autumn	In process
		Ramaria botrytis	cosmopolitan	cooked	autumn	In process
	Parasitic	*Cyttaria darwinii*	native	Raw or cooked	autumn - spring	Included
		Cyttaria hariotii	native	Raw or cooked	autumn - spring	Included
	Wood rotting	*Aleurodiscus vitellinus*	native	cooked	autumn	In process
		Grifola gargal	native	cooked	autumn	In process
		Hydropus dusenii	native	cooked	autumn	In process
		Fistulina anctartica	native	cooked	autumn	In process
		Fistulina endoxantha	native	cooked	autumn	In process
		Fistulina patagonica	native	cooked	autumn	In process
		Pleurotus ostreatus	exotic	cooked	autumn	Included
	Saprophytic	*Aleuria aurantia*	exotic	Raw or cooked	autumn	In process
		Lepista nuda	cosmopolitan	Raw or cooked	autumn	Included
		Lycoperdon perlatum	cosmopolitan	Raw or cooked	autumn	In process
		Macrolepiota procera	cosmopolitan	cooked	autumn	In process
		Morchella eximia	cosmopolitan	cooked	spring	Included
		Morchella andinensis	native	cooked	spring	Included
		Morchella tridentina	cosmopolitan	cooked	spring	Included
Plantations	Mycorrhizal	*Lactarius deliciosus*	exotic	with cooking	autumn	Included
		Tuber melanosporum	exotic	raw	autumn	Included
		Rhizopogon roseolus	exotic	with cooking	autumn - spring	In process
		Suillus granulatus	exotic	with cooking	autumn	Included
		Suillus lakei	exotic	with cooking	autumn	In process
		Suillus luteus	exotic	with cooking	autumn	Included
		Tuber borchii	exotic	raw	autumn	In process
	Saprophytic	*Macrolepiota procera*	cosmopolitan	with cooking	autumn	In process
Meadows	Saprophytic	*Agaricus arvensis*	cosmopolitan	With cooking	spring/autumn	In process
		Agaricus augustus	cosmopolitan	With cooking	spring/autumn	In process
		Agaricus campestris	cosmopolitan	With cooking	spring/autumn	Included
		Calvatia gigantea	cosmopolitan	With cooking	spring/autumn	In process
		Coprinus comatus	cosmopolitan	With cooking	autumn	In process

[a] Exotic is used to point out those mushroom species that are known to be introduced with their tree partner; instead, species fruiting in anthropized natural forests and meadows, with broad distributions worldwide but with no available phylogenetic studies for Patagonia, are classified as cosmopolitan. Table sources: Toledo *et al.,* 2016; Barroetaveña *et al.,* 2020.

luted environments, identity-based, sustainable economic and cultural activities that lead to local development are promising (Fig. S1 [suppl]). Likewise, we promote the cultivation of edible and medicinal mushrooms (mainly strains of *Pleurotus* spp., *Lentinula edodes*, *Hericium erinaceus*, *Flammulina velutipes*, *Ganoderma lucidum*, *Grifola frondosa* and *Agrocybe aegerita*). From the institutional Spawn Production Laboratory belonging to Centro de Investigación y Extensión Forestal Andino Patagonia (CIEFAP), we provide services, supplies and training along with the progress of applied research.

We use the name 'scientific-technological platform' in the meaning of an institutional organization, created on the basis of scientific and traditional knowledge with innovative potential, arising from Research and Development (R&D) activities that contribute to solving problems (or taking advantage of opportunities) within a strategy of diversification and generation of new products.

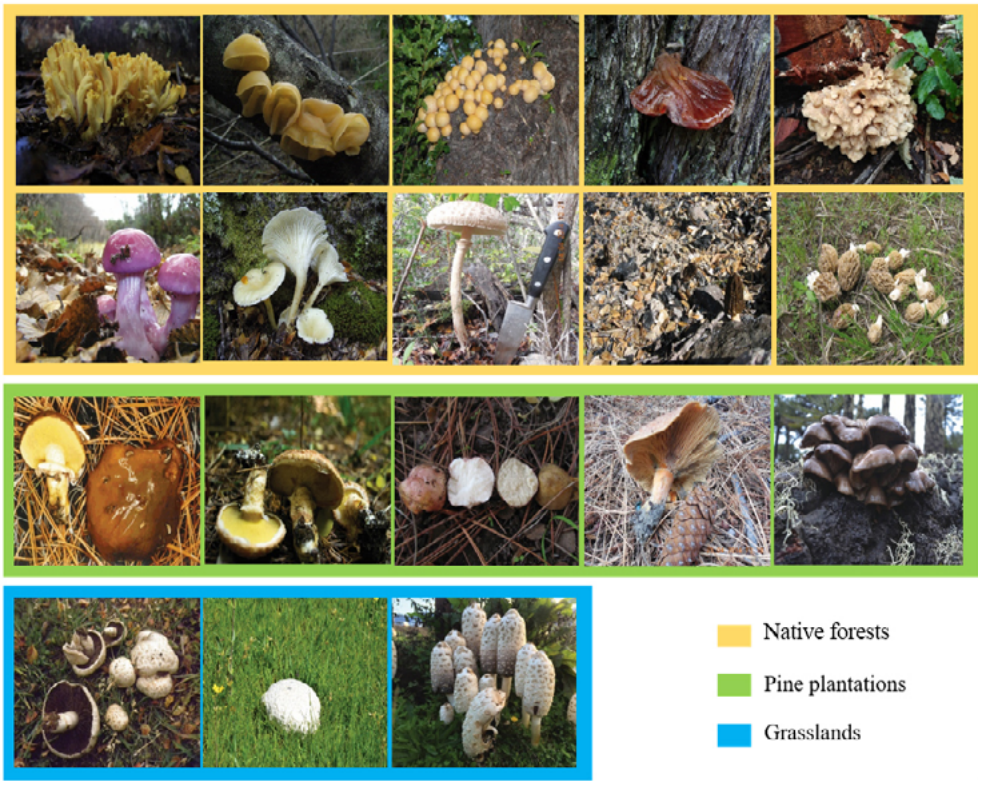

Figure 1. Most prominent endemic and introduced wild edible species from Patagonia native forests: *Ramaria patagonica* (Changle), *Aleurodiscus vitellinus* (Jelly Ear), *Cyttaria hariotii* (Llao llao), *Fistulina antarctica* (Cow Tonge), *Grifola gargal* (Gargal), *Cortinarius magellanicus* (Purple Hat Mushroom), *Hydropus dusenii* (White Trumpet), *Macrolepiota aff procera* (Parasol Mushroom), *Morchella eximia* (Black Morel) and *M. tridentina* (Blonde Morel); from plantations: *Suillus luteus* (Slippery Jack), *S. lakei* (Matte Jack), *Rhizopogon roseolus* sensu Trappe (False Truffle), *Lactarius deliciosus* (Saffron Milk Cap), *Pleurotus ostreatus* (Oyster Mushroom) (Photo: Mario Rajchenberg); and grasslands: *Agaricus campestris* (Field Mushroom), *Calvatia gigantea* (Giant Puffball) (Photo: Maximiliano Rugolo), *Coprinus comatus* (Shaggy Mane) (Photo: Giuliana Furci). Complete list at www.ciefap.org.ar. (Photos from the authors except those indicated).

"Patagonia Fungi, trails and tastes®", works jointly throughout the region in applied research, which supports transfer of knowledge and development of actions. When we refer to the transfer of knowledge or R&D results, we mean actions that try to facilitate the use, application and social and economic innovation of the new knowledge and technological development derived from research. Investigations undertaken with wild fungi include the identification of more than 30 edible species from native forests, grasslands and forest plantations, describing their organoleptic properties (Barroetaveña *et al.,* 2016, 2020; Toledo *et al.,* 2016a; Barroetaveña & Toledo, 2020), analyzing their taxonomy and phylogeny (Rajchenberg, 2006; Pildain *et al*., 2014; Salgado Salomón *et al.,* 2018, 2021; Pildain *et al*., 2019; González *et al*., 2021; Rajchenberg *et al*., 2021), their phenology, ecology and productivity (Barroetaveña *et al*., 2010; Toledo *et al.,* 2014; Barroetaveña & Toledo, 2020; Pildain *et al*., 2021), their nutritional and nutraceutical values (Toledo *et al.,* 2016b; Barroetaveña & Toledo, 2017; Barroetaveña *et al*., 2020), features related to the domestication of cultivable species and "mycosilvicultural" management to increase their productivity (Solans *et al*., 2010; Toledo & Barroetaveña, 2017), the economy of trading and demand in local gastronomy (Fernández *et al*., 2012, 2020), and finally the sociocultural features of harvesters and the documentation of ancestral uses considering the associated processes of change (Valtriani *et al*., 2017; Molares *et al.,* 2019). Investigations with cultivated mushrooms included the evaluation and selection of lignocellulosic substrates from waste available in Andean Patagonia (Roggero Luque *et al*., 2021, 2022), testing preservation techniques in order to extend their fresh commercialization window (Ohaco & Barroetaveña, 2018), and the enriching of the culture collection with strains of native, wood degraders species (*Fistulina antarctica*, *Fistulina endoxantha*, *Grifola gargal*, *Ganoderma australe* and *Aleurodiscus vitellinus*) to develop their cultivation protocols.

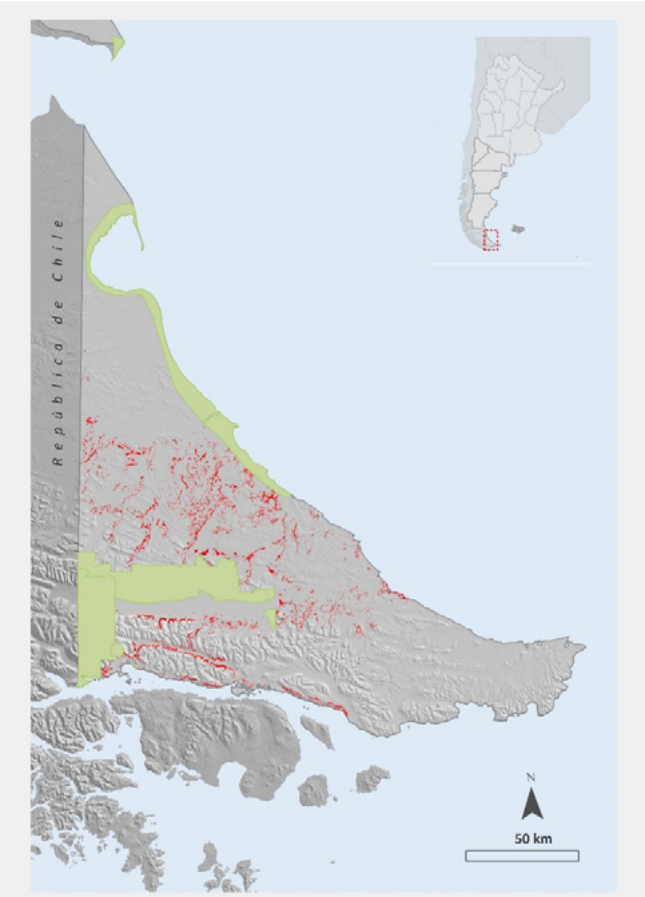

Figure 2. Map of the Tierra del Fuego province with the potential harvest areas (red dots) and protected areas (green) for *Cyttaria darwinii*.

The main products for the food industry and gastronomy were the design of functional foods with both wild and cultivated species (soups, rice, noodles, salts) and the creation of identity recipes with chefs (Barroetaveña *et al.*, 2021b). While for the policyholders that deal with regulations of natural resources uses, the estimation of areas suitable for harvesting is outstanding and presented below.

Determination of potential wild fungi harvesting areas in Patagonia

The collection and use of wild fungi in Patagonia have been carried out without reliable spatial information or an inventory of species distribution. The prediction of their fruiting is linked to the distribution of forest species, forest site quality and stands characteristics, being Geographic Information Systems (GIS) the most widely used tools for that goal (Tsiaras & Domakinis, 2015).

To model the distribution and availability of wild edible fungi in the five Patagonian provinces, a GIS has been developed using different layers of information: classification of forest types and land cover; map of routes, paths, and trails; protected areas and reserves (not available for harvesting); water bodies; cadastral data; digital elevation models and climate data. Forest surfaces were calculated for each fungal species using the following criteria: i) surface within protected areas and reserves; ii) surface accessible by roads and lakes; iii) surface accessible by roads and lakes that are within protected areas; iv) surface including all previous groups according to slope. Finally, three final categories of accessibility have been defined: easy, moderate, and difficult (unpublished). The GIS makes it possible to analyze by province the area in hectares for each group of fungi (mushroom species defined by tree host species) and different categories of accessibility and location. In total, more than 520,000 ha of potential fungi harvesting areas were determined for the five provinces. Among them, the group of species with the greatest potential for total accessibility is the *Cyttaria* group, present in native forests and with species associated with all *Nothofagus* species within the five Patagonian provinces. Figure 2 shows potential harvest areas in Tierra del Fuego for *Cyttaria darwinii.*

The model was preliminarily validated with species collection records. Having this tool, which should continue to be enriched with check-ups in the territory, restricted inventories, and evaluations of productivity by species, will make it possible to plan the proper use of the resource, delimit areas subjected to harvest, and estimate the expected harvest volumes (Kucuker & Baskent, 2015). Policy makers need this background information when establishing prices and areas to develop harvesting permits (De Frutos *et al.,* 2016).

Transfer actions

Since the use of fungi as a tourism and food resource is new in the region, it is necessary to strengthen their supply and to encourage consumers to search and request them. The strategy aims to address both aspects in parallel, seeking to encourage harmonious and sustainable growth. For that, target groups to work with have been classified in two groups: those that "offer" and those that "demand" products and services related to edible and medicinal fungi. The first group includes the primary providers of products and services: mycologists, harvesters, mycotourism guides, mushroom producers, and gastronomic service providers (restaurants, tourism entrepreneurs, owners of forested land, greengrocers- dietary food stores). The second group includes the public, local and international lovers of gourmet gastronomy, healthy eating enthusiasts, ecotourism enthusiasts, children, and young people in formal education.

The main actions directed to the offering group include training in mycogastronomy and mycotourism for collectors and guides, fungi flavor laboratories with chefs from the region, the preparation of preserves and delicatessen products with high nutritional value, joint organization of

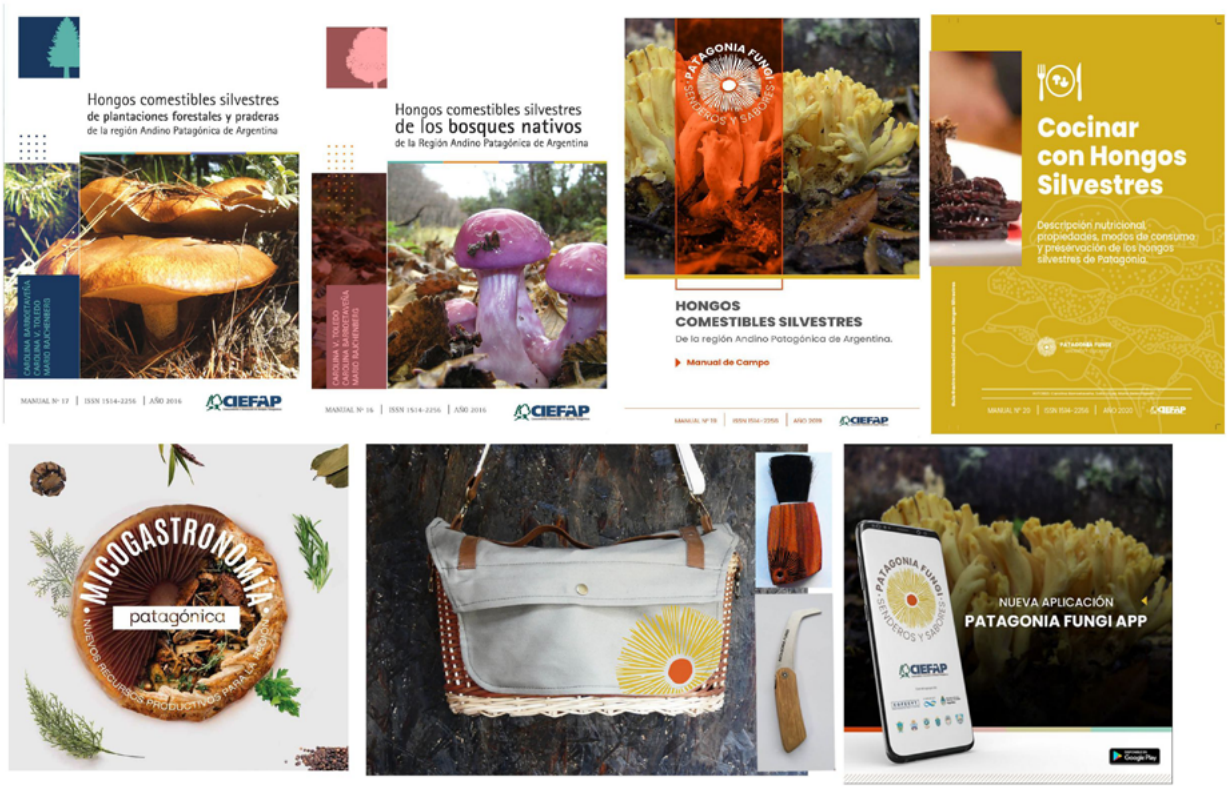

Figure 3. Products and tools for knowledge transfer developed by Patagonia Fungi. Freely available (except the harvest kit) at www.ciefap.org.ar.

innovative fungi tasting dinners with restaurants, the layout and implementation of mycotouristic paths and training courses for mushroom cultivators. Actions related with the demand group comprise participation in gastronomic fairs, fungi identification training, community attendance to talks and participation in the Media promoting identity mycogastronomy and the opportunity that wild fungi fruiting offer to novel tourist developments for the low seasons.

The promotion of inter-institutional work and articulation with private and provincial and municipal officials linked to tourism and food safety has been a key stone to accomplish several actions: the assembly of an inter-institutional board to develop regional protocols for good harvest practices and food safety; the application for inclusion of 21 species in the Argentine food code (Table 1); the elaboration of agreements for the use of mycotourism paths. The training and transfer actions in the territory were articulated with technicians from each provincial Forestry Secretariat, and with family farming agents. Two shared-use agri-food plants were strengthened in two locations in Neuquén province, based on national financing requested from the platform, so that harvesters have this space for community use for fungi post-harvest tasks, articulating with the secretary of Production, Employment and Social Economy of the Municipality. Drying and handling protocols for some species were also worked on, and the activities continue with product formulations.

Outreach: manuals, brochures, tools, and Patagonia Fungi App

We have developed different tools and strategies to work on this field, such as face-to-face and virtual lectures, workshops and courses, as well as producing printed and digital material in the form of brochures, informative leaflets, along with a series of manuals (Barroetaveña *et al.,* 2016, 2020, 2021a, 2021b; Toledo *et al.,* 2016a) that are freely available in PDF format on the CIEFAP institutional web page (www.ciefap.org.ar) (Fig. 3), in order to ensure that they are accessible to all interested persons. The written material, in addition to constituting the support for all the previously mentioned activities, is promoted through various channels, such as a radio program and institutional social networks, interviews and presentations by the members in various frameworks. To support transfer actions related to good harvesting practices, we designed and co-built a mushroom harvesting kit with designers, entrepreneurs, and local artisans. The selection of the materials used in the manufacture of each part of the kit privileged the use of native Patagonian woods and eco-friendly supplies (Fig. 4).

The incorporation of Information and Communication Technologies (ICTs) in recent decades constitutes a very usable innovation in the fields of education, production, environmental management, among others, since they offer support tools where society is involved with easy, affordable,

and widely distributed access (Hernández Nieto & Muñoz Aguirre, 2012). Therefore, the platform we developed, the "Patagonia Fungi App" (Fig. 3), that works for Android in this first stage, contains data on more than 30 species of edible fungi present in all forest environments of Patagonia. In addition, it offers information on the Kingdom Fungi, descriptions of the species, photos, criteria for sustainable harvesting, and a mycological technical glossary. This tool provides novice users and harvesters the possibility of interactively identifying edible fungi in nature, alerting of similar species that can cause confusion. Also, the App has a pre-structured form to share findings and make queries that we answer via email, which allows us to enrich our database at the same time, to encourage citizen science.

The aim is that all these transfer tools generate changes in environmental awareness in the face of the inappropriate use of natural resources, and skills to resolve issues that contribute to conservation (Cabero Almenara & Llorente Cejudo, 2005). Knowing and valuing wild edible fungi is a way to promote food safety, protect the health of people and of the biological systems which we are a part of.

Future perspectives

The lines of work outlined here seek to deepen the understanding of the taxonomy, ecology, and biology of the different species of wild edible fungi, and to investigate the existing forms of use and management, to strengthen their potential for social economies together with their conservation.

To achieve these objectives, it is necessary to continue with **training** programs for young people, adults, and for technical staff in different public sectors, rescuing the importance of non-formal education and popular knowledge. Simultaneously, we suggest **strengthening interagency cooperation** with the municipal and provincial administrations involved in the activities, creating work spaces, articulated between work actors (harvesters, local guides, mushroom producers), businessmen (tourism, gastronomy), scientists and technicians (universities, research centers), staff of public spaces (bromatology, municipal community kitchens, tourism references, Forest Directors, Science and Technology dependencies, and National Parks). Ongoing tasks for the next two years include: a) consolidating facilities to support the processing of municipal food products, and the management of mycotourism routes linked to mycogastronomy already installed or in the process of being installed; b) generating a framework for the sustainable harvest of wild fungi, which regulates the activity and tends to ensure the rights of access to the forest and protection of the resource and the harvesters; c) articulating and implementing safe and sustainable harvest protocols that strengthen food security and environment protection.

The main axes of starting R&D activities for the next five years focus on:

a) Investigate the distribution and collection patterns of wild fungi, the volumes collected, the number of harvesters involved, the accessibility to harvest sites and distances to towns and roads (collection effort), marketing circuits, and innovations. We will work with an ethnobiological approach together with GIS and remote sensing technology, to achieve a multi-scalar and interdisciplinary approach that allows us to analyze the processes of landscape use in qualitative and quantitative terms. Diversify the supply of food products and improve nutrition in vulnerable rural/peri-urban populations by incorporating mushroom cultivation in the family or community gardens, incorporating foods rich in protein and nutraceuticals that complement the fiber and carbohydrates provided by horticultural production.

b) Develop functional foods that incorporate wild and cultivated fungi species from Patagonia. This includes obtaining ferment protocols using wild fungi species, enriching products with prebiotics and probiotics formulations with added value and with a longer commercialization window. Also, the formulation of mycelial flours in collaboration with regional producers of organic flours from various cereals, and the formulation of dietetic jams and preserves that combine the use of regional wild berries and wild fungi with thickening properties.

Conclusions

The Andean Patagonian forests undergo a decline process due to forestry exploitation, ranching and associated effects of climate change, including wild fires, pests and drought stress (SAyDS, 2019; Eyring *et al.*, 2021). In this sense, the work developed by the platform aims to contribute to the understanding of the multiple uses of native forests and woodlands, focusing on the positive impact of the sustainable use of wild and cultivated fungi on the diversification of the productive matrix. This information is essential in the construction of a social and solidarity economy that is presented as an alternative to extractivist practices (Coraggio, 2018; Mónaco *et al.*, 2020). We believe that expanding the current variety of harvested species and their modalities of use, promoting sustainable harvest with education and outreach actions, will lead local development based on products and services. This process must be accompanied by proposals for public policies and new legislation for NWFPs that rules public and private models for action.

Acknowledgments

We truly thank Ing. Maria Fernanda Ríos for the map presented in Fig. 2, and the colleagues who shared photos for Fig. 1. Also, we are grateful to Dr. Efrén Cazares for kindly revising the English version of the manuscript.

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Data curation: not applicable
Formal analysis: not applicable
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References

Abeyá E, Durán P, Mangialavori G, Biglieri A, Kogan L, 2007. Encuesta Nacional de Nutrición y Salud. Documento de resultados. Ministerio de Salud. Plan Federal de Salud. Argentina.

Aigo JDC, Skewes JC, Bañales-Seguel C, Riquelme Maulén W, Molares S, Morales D, Guerra D, 2020. Waterscapes in Wallmapu: Lessons from Mapuche perspectives. Geogr Rev 7: 1-33. https://doi.org/10.1080/00167428.2020.1800410

Barroetaveña C, Toledo CV, 2016. Hongos silvestres comestibles novedosos en el bosque nativo y en las plantaciones de Patagonia andina, Argentina. Cienc Inv For 22(3): 73-88. https://doi.org/10.52904/0718-4646.2016.461

Barroetaveña C, Toledo CV, 2017. The nutritional benefits of mushrooms. In: Wild plants, mushrooms and nuts: functional food properties and applications; Ferreira ICFR, Morales P, Barros L (eds). pp: 65-81. Wiley-Blackwell, West Sussex. https://doi.org/10.1002/9781118944653.ch3

Barroetaveña C, Toledo CV, 2020. Diversity and ecology of edible mushrooms from Patagonia native forests, Argentina (Cap. 11). In: Mushrooms, humans and nature in a changing world; Perez Moreno J, Guerin Laguette A, Flores Arzú R. (eds). pp: 297-320. Springer, The Netherlands. https://doi.org/10.1007/978-3-030-37378-8_11

Barroetaveña C, Fernández MV, Rios MF, Bassani VM, 2010. Productividad potencial del hongo comestible *Suillus luteus* en plantaciones de pino del oeste de Chubut. Actas Reunión Eco Productos Forestales No Madereros, Esquel (Argentina), Dec 1-3. pp: 38-44.

Barroetaveña C, Toledo CV, Rajchenberg M, 2016. Hongos comestibles silvestres de las plantaciones forestales y praderas de la región andino patagónica de Argentina. Manual Nº 17, Centro Forestal CIEFAP, Esquel, Argentina. 64 pp.

Barroetaveña C, López S, Pildain MB, 2020. Cocinar con hongos silvestres, descripción nutricional, propiedades, modos de consumo y preservación de los hongos silvestres de Patagonia. Manual N°20. CIEFAP, Esquel, Argentina. 85 pp.

Barroetaveña C, Toledo CV, Rajchenberg M, 2021a. Hongos comestibles silvestres de la región andino patagónica de Argentina. Manual de campo Nº 19, 2ª edición. CIEFAP, Esquel, Argentina. 80 pp.

Barroetaveña C, Pildain MB, Peris P, 2021b. Micogastronomía patagónica, nuevos recursos productivos para la región. CIEFAP, Esquel, Argentina. 173 pp.

Barthel S, Crumley CL, Svedin U. 2013. Biocultural refugia: combating the erosion of diversity in landscapes of food production. Ecol Soc 18: 71. https://doi.org/10.5751/ES-06207-180471

Büntgen U, Latorre J, Egli S., Martínez-Peña F, 2017. Socio-economic, scientific, and political benefits of mycotourism. Ecosphere 8(7): e01870. https://doi.org/10.1002/ecs2.1870

Cabero Almenara J, Llorente Cejudo MDC, 2005. Las TIC y la educación ambiental. Rev Latinoam Tecnol Edu 4(2): 9-26.

Cámara Argentina de Comercio y Servicios, 2019. Estudio sobre asimetrías regionales en Argentina. https://www.cac.com.ar/data/documentos/33_Estudio%20sobre%20asimetr%C3%ADas%20regionales%20en%20Argentina%20-%20abril%202019%20-%20versi%C3%B3n%20final.pdf.

Ciampagna ML, Capparelli A, 2012. Historia del uso de las plantas por parte de las poblaciones que habitaron la Patagonia continental argentina. Cazadores-recolectores del Cono Sur 6: 45-75.

Coraggio JL, 2018. Potenciar la economía popular solidaria: una respuesta al neoliberalismo. Otra Economía 11(20): 4-18.

Chamorro MF, Ladio AH, Molares S, 2018. Patagonian berries: An ethnobotanical approach to exploration of their nutraceutical potential. In: Ethnobotany: Local knowledge and traditions; Martínez J, Muñoz-Acevedo A, Rai M (eds). pp: 50-69. CRC Press, Boca Raton. https://doi.org/10.1201/9780429424069-4

De Frutos P, Martínez F, Esteban S, 2012. Edible wild mushroom tourism as a source of income and employment in rural areas. The case of Castilla and León. Forest Syst 21(1): 81-98. https://doi.org/10.5424/fs/2112211-02545

De Frutos P, Martinez-Peña F, Aldea J, Campos P, 2016. A model to estimate willingness to pay for harvest permits for wild edible mushrooms: application to Andalusian Forests. Forests 7(12): 292. https://doi.org/10.3390/f7120292

Eyring V, NP Gillett, KM Achuta Rao, R Barimalala *et al.,* 2021: Human Influence on the Climate System. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assess-

ment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte *et al.* (eds.). pp. 423-552. Cambridge University Press, United Kingdom.

Fernández MV, Barroetaveña C, Basanni VM, Ríos F, 2012. Rentabilidad del aprovechamiento del hongo comestible *Suillus luteus* para productores forestales y para familias rurales de la zona cordillerana de la provincia del Chubut, Argentina. Bosque 33(1): 43-52. https://doi.org/10.4067/S0717-92002012000100005

Fernández MV, Pildaín MB, Barroetaveña C, 2020. Caracterización del estado del arte, uso y agregado de valor del recurso hongos comestibles en el sector gastronómico de la cordillera de Chubut. RIA 47(2): 209-215.

Gamundí IJ, Godeas AM, Cabello MN, 2017. The micological investigation in Argentina: Period 1978-2016. Darwiniana 5(1): 98-108. https://doi.org/10.14522/darwiniana.2017.51.711

González GC, Barroetaveña C, Visnovsky SB, Rajchenberg M, Pildain MB, 2021. A new species, phylogeny, and a worldwide key of the edible wood decay *Fistulina* (Agaricales). Mycol Prog 20(5): 733-746. https://doi.org/10.1007/s11557-021-01696-7

Hernández Nieto LK, Muñoz Aguirre LF, 2012. Usos de las tecnologías de la información y la comunicación (TIC) en un proceso formal de enseñanza y aprendizaje en la Educación Básica. Zona Próxima 16: 2-13. https://doi.org/10.14482/zp.16.124.63

INDEC, 2010. Indicadores demográficos de la Argentina. https://www.indec.gob.ar/indec/web/Institucional-Indec-IndicadoresDemograficos.

Kucuker DM, Baskent EZ, 2015. Spatial prediction of *Lactarius deliciosus* and *Lactarius salmonicolor* mushroom distribution with logistic regression models in the Kızılcasu Planning Unit, Turkey. Mycorrhiza 25(1): 1-11. https://doi.org/10.1007/s00572-014-0583-6

Latorre J, de-Magistris T, de Frutos P, García B, Martinez-Peña F, 2021. Demand for mycotourism products in rural forest areas. A choice model approach, Tourism Recreation Research. Tourism Recreation Research: 1-17. https://doi.org/10.1080/02508281.2021.1926749

Laudari D, 2010. Implication of traditional ecological knowledge on forest resource management. Him J Soc Anthropol 4: 77-90. https://doi.org/10.3126/hjsa.v4i0.4669

Moisan-De Serres A, Gélinas N, Marcotte P, 2017. Les produits forestiers non ligneux: Une opportunité de développement touristique régional. J Rural Community Dev 12(2-3): 168-185.

Molares S, Ladio A, 2012. Mapuche perceptions and conservation of Andean *Nothofagus* forests and their medicinal plants: a case study from a rural community in Patagonia, Argentina. Biodivers Conserv 21(4): 1079-1093. https://doi.org/10.1007/s10531-012-0241-2

Molares S, Ladio A, 2014. Medicinal plants in the cultural landscape of a Mapuche-Tehuelche community in arid Argentine Patagonia: an eco-sensorial approach. J Ethnobiol Ethnomed 10(1): 1-14. https://doi.org/10.1186/1746-4269-10-61

Molares S, Toledo CV, Stecher G, Barroetaveña C, 2019. Traditional mycological knowledge and processes of change in Mapuche communities from Patagonia, Argentina: a study on wild edible fungi in Nothofagaceae forests. Mycologia 112(1): 9-23. https://doi.org/10.1080/00275514.2019.1680219

Mónaco MH, Peri PL, Medina FA, Colomb HP, Rosales VA, Berón F *et al.,* 2020. Deforestación de los bosques nativos de Argentina: causas, impactos y propuestas de desarrollo alternativas. Quipu Forestal 6: 44-50.

Morales D, Molares S, Ladio A, 2017. A biocultural approach to firewood scarcity in rural communities inhabiting arid environments in Patagonia (Argentina). Ethnobiol Conserv 6: 1-17. https://doi.org/10.15451/ec2017-08-6.12-1-17

Ochoa JJ, 2019. Saberes locales y frutos comestibles de plantas nativas en la comarca andina del paralelo 42° (Patagonia, Argentina). Ethnoscientia 4: 1-9. https://doi.org/10.22276/ethnoscientia.v4i1.247

Ohaco EH, Barroetaveña C, 2018. Desarrollo de métodos de preservación en fresco de hongos comestibles: *Pleurotus ostreatus* y *Lentinula edodes*. VII Congr Int Ciencia y Tecnología de Alimentos (CiCYTAC 2018). Córdoba, Argentina. 2-3 oct.

Pérez-Moreno J, Martínez-Reyes M, 2014. Edible ectomycorrhizal mushrooms: biofactories for sustainable development. In: Biosystems engineering: biofactories for food production in the century XXI; Guevara-Gonzalez R, Torres-Pacheco I (eds.). pp: 151-233. Springer, Switzerland. https://doi.org/10.1007/978-3-319-03880-3_6

Pérez-Moreno J, Guerin-Laguette A, Rinaldi AC, Yu F, Verbeken A, Hernández-Santiago F, Martínez-Reyes M, 2021a. Edible mycorrhizal fungi of the world: What is their role in forest sustainability, food security, biocultural conservation and climate change? Plants, People, Planet 3(5): 471-490. https://doi.org/10.1002/ppp3.10199

Pérez-Moreno J, Mortimer PE, Ku J, Karunarathna SC, Li H, 2021b. Global perspectives on the ecological, cultural and socioeconomic relevance of wild edible fungi. Stud Fungi 6(1): 408-424. https://doi.org/10.5943/sif/6/1/31

Pildain MB, Visnovsky SB, Barroetaveña C, 2014. Phylogenetic diversity of true morels (Morchella), the main edible non-timber product from native Patagonian forests of Argentina. Fungal Biol 118(9): 755-763. https://doi.org/10.1016/j.funbio.2014.03.008

Pildain MB, Visnovsky SB, Barroetavena C, 2019. Diversity of exotic ectomycorrhizal *Rhizopogon* from pine plantations in Patagonia. Mycologia 111(5): 782-792. https://doi.org/10.1080/00275514.2019.1647395

Pildain MB, Marchelli P, Azpilicueta MM, Starik C, Barroetaveña C, 2021. Understanding introduction history: Genetic structure and diversity of the edible ectomycorrhizal fungus, *Suillus luteus*, in Patagonia (Argentina).

Mycologia 113(4): 715-724. https://doi.org/10.1080/00275514.2021.1909449

Porto N, Garcia C, 2020. Strategies for regional tourism development in Argentina. A path with new initiatives for tourism dispersal policies. In: Tourism Planning and Development in Latin America; Monterrubio C, Konstantinos A, Stylidis D (eds.). pp: 8-30. CABI, Wallingford. https://doi.org/10.1079/9781789243048.0008

Rajchenberg M, 2006. Polypores (Basidiomycetes) from the Patagonian Andes forests of Argentina. Bibliotheca Mycologica Band 201, J. Cramer Verlag, Stuttgart. 300 pp.

Rajchenberg M, PildainMB, de Errasti A, Riquelme C, Becerra J, Torres-Díaz C, Cabrera-Pardo JR, 2021. Species and genera in *Aleurodiscus sensu lato* as viewed from the Southern Hemisphere. Mycologia 113(6): 1264-1277. https://doi.org/10.1080/00275514.2021.1940671

Roggero Luque JM, Rugolo M, Rajchenberg M, Barroetaveña M, 2021. Evaluación de residuos lignocelulósicos de la Comarca Andina de provincia de Chubut (Argentina) para el cultivo de especies de *Pleurotus*. Universitas Scientiarum 26(2): 159-178.

Roggero Luque JM, Rugolo M, Barroetaveña C, 2022. Evaluación de residuos lignocelulósicos de Patagonia Argentina para el cultivo de *Lentinula edodes* (Marasmiaceae). Bonplandia 31(2): 1-14. https://doi.org/10.30972/bon.3125933

Royse DJ, Sánchez JE, 2017. Producción mundial de setas *Pleurotus* spp. con énfasis en países iberoamericanos. La biología, el cultivo y las propiedades nutricionales y medicinales de las setas *Pleurotus* spp. El Colegio de la Frontera Sur. Tapachula, 17-25.

Salgado Salomón ME, Dresch P, Horak E, Galleguillos F, Barroetaveña C, Peintner U, 2018. The enigmatic *Cortinarius magellanicus* complex occurring in Nothofagaceae forests of the Southern Hemisphere. Fungal Biol 122(11): 1077-1097. https://doi.org/10.1016/j.funbio.2018.08.009

Salgado Salomón ME, Barroetaveña C, Niskanen T, Liimatainen K, Smith ME, Peintner U, 2021. Loose ends in the *Cortinarius* phylogeny: five new myxotelamonoid species indicate a high diversity of these ectomycorrhizal fungi with South American Nothofagaceae. Life 11(5): 420. https://doi.org/10.3390/life11050420

SAyDS, 2019. Monitoreo de la superficie de Bosque Nativo de la Rep. Arg. Reg. Forestal BAP. Buenos Aires: Secretaría de Ambiente y Desarrollo Sustentable de la Nación. Work document for internal use.

Solans M, Barroetaveña C, Fariña M, Rajchenberg M, 2010. Aplicación de riego para incrementar la fructificación de *Suillus luteus* en plantaciones de pino ponderosa. Actas Reunión Eco Productos Forestales No Madereros. Esquel (Agentina), Dec 1-3. pp: 122-132.

Tacón Clavaín A, Fernández U, Ortega F, 2004. El mercado de los PFNM y su papel en la conservación de la ecorregión de los bosques valdivianos. WWF-Red PFNM de Chile, Valdivia, Chile. 134 pp.

Thome-Ortiz H, 2015. Turismo micológico. Una nueva mirada al bosque. Rev Cienc Desarr 1(1): 1-5.

Tsiaras S, Domakinis C, 2015. Correlating mushroom habitats and geology in Grevena Prefecture (Greece) with the use of geographic information systems (GIS). IJAEIS 6(2): 1-14. https://doi.org/10.4018/ijaeis.2015040101

Toledo CV, Barroetaveña C, 2017. Crecimiento miceliar de especies silvestres de hongos comestibles de los bosques andino-patagónicos: primeros pasos para su domesticación. Bol Soc Argent Bot 52(3): 435-446. https://doi.org/10.31055/1851.2372.v52.n3.18025

Toledo C, Barroetaveña C, Rajchenberg M, 2014. Fenología y variables ambientales que condicionan la fructificación de hongos silvestres comestibles de los bosques de *Nothofagus* spp. en Patagonia, Argentina Rev. Mex. Biodiv. 85: 1093-1103. https://doi.org/10.7550/rmb.40010

Toledo CV, Barroetaveña C, Rajchenberg M, 2016a. Hongos comestibles silvestres de los bosques nativos de la región andino patagónica de Argentina. Manual Nº 16, CIEFAP. Esquel, Argentina. 71 pp.

Toledo CV, Barroetaveña C, Fernandes A, Barros L, Ferreira ICFR, 2016b. Chemical and antioxidant properties of wild edible mushrooms from native *Nothofagus* spp. forest, Argentina. Molecules 21(9): 1201. https://doi.org/10.3390/molecules21091201

Valtriani A, Barroetaveña C, Stecher G, Fernández MV, Ceballos ME, 2017. Análisis comparativo de los recolectores primarios de hongos silvestres comestibles en la Patagonia chilena y argentina. Cienc Inv For (INFOR) 23(3): 57-72. https://doi.org/10.52904/0718-4646.2017.486

Zavala JM, 2000. Les indiens mapuche du Chili: dynamiques inter-ethniques et stratégies de résistance, XVIIIe siècle. Harmattan, Paris, France. 302 pp.