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Conservation and trade of wild edible mushrooms of Serbia – history, state of the art and perspectives

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Abstract

Wild edible mushrooms have received significant scientific and socio-economic attention in the last few decades, since they have become the subject of a booming trade business. Through last decades, Serbia, a small country positioned in the South East of Europe, has become a source country for extensive export of commercially important species of wild mushrooms. The data used for international analyses of national policy on mushroom protection and trade are cited usually from personal communications and therefore are not really reliable. Extensive investigations into diversity or ecology of macro fungi in Serbia have never been undertaken. The forestry sector, which is managing all forests in the country, has absolutely neglected its role in ecosystems while habitats of macro fungi have been permanently destroyed. There are only two legal acts that refer to mushroom protection directly and none aims to protect their habitats or diversity in practice. In this contribution, a comprehensive review of official data on research, conservation, socio-economic importance and legislation on wild edible mushrooms and truffles in Serbia was provided. Additionally, the application of existing legal acts on conservation of macro fungi and data on wild mushroom trade in the period between 1993–2016, during which time the trade control has been initiated was analysed. The currently valid system of conservation and trade control are discussed in the frame of protection of wild mushroom species and their habitats and measures for upgrading this system in order to meet the requirements of the sustainable use of natural resources in the socio-economic conditions of Serbia are proposed.

Keywords

Wild mushrooms conservation, wild mushrooms trade, mushrooms of Serbia, truffle trade in Serbia

Introduction

Mushrooms have probably been a part of the human omnivore diet ever since humans have evolved as a species. Actually, it is quite possible that many fungal species developed the highly nutritious sporocarps concurrently with the evolution of omnivores, as a very small number of animal species has been reported to be strictly mycophagous (Witte and Maschwitz 2008). This group, often called macro-fungi, includes all species that produce sporocarps larger than 1 mm. Through human evolution, fungal species that produced edible sporocarps may have served as a good source of food in the specific times of the temperate seasons (as in Europe) – they could be gathered for immediate consumption or dried and preserved for cold seasons when nutrient rich food was scarce (Peintner et al. 2013, Heilmann-Clausen et al. 2015). Once, gathering of mushrooms was a necessity, now it is a relaxing hobby or a good business, depending on the country's resources and socio-economic status. Regarded at one time as staple food, mushrooms have now become a luxury and a delicacy.

Due to the concentration of inhabitants in large cities and social evolution that defines working time, the habit of collecting mushrooms for food in Europe became unavailable for the majority of those who consume them. Even though many of the saprotrophic species could be easily cultivated, very few are part of the usual European diet – in the market, the white button mushroom (*Agaricus bisporus* (J. E. Lange) Imbach), oyster mushroom (*Pleurotus ostreatus* (Jacq.) P. Kumm) and Asia-origin shii-take (*Lentinula edodes* (Berk.) Pegler) dominate (Valverde et al. 2015). The ectomycorhizal (ECM) species, that are far more appreciated, are still collected from their natural habitats and that is why they fetch far higher prices. For that reason, in some European countries, the wild mushroom trade has become a huge business in the last few decades (Sitta and Floriani 2008). Here it is mainly referred to species of porcini (*Boletus edulis* Bull.:Fr., *B. aereus* Bull.:Fr., *B. reticulatus* Schaeff. and *B. pinophilus* Pilát & Dermek), chanterelle (*Cantharellu scibarius* Fr.:Fr., *Craterellus lutescens* (Pers.: Fr.) Fr.), morels (*Morchella deliciosa* (Fr.: Fr.) Quélet, *M. vulgaris* (Pers.: Fr.) Boudier, *M. esculenta* (L.: Fr.) Pers.) and milky caps (*Lactarius deliciosus* (L.: Fr.) S.F. Gray, *L. deterrimus* Gröger). The most expensive of them are certainly European truffles (*Tuber magnatum* Pico, *T. melanosporum* Vitt., *T. aestivum* Vitt., *T. brumale* Vitt, *T. borchii* Vitt.).

The expansion of commercial harvesting in Europe has resulted in the introduction of national, regional and even communal regulatory and licensing systems in several countries, but with significant differences (Brainerd and Doornbos 2013). In Scandinavia, fungi gatherers have open access and can pick as long as they do not harm property (Saastamoinen 1999). Finland promotes the greater harvesting of fungi as an under-utilised resource (Härkönen and Järvinen 1993), while, in the Netherlands, gathering of fungi is strongly discouraged through codes and local acts (Arnolds 2001). In France and Italy, there are gathering permits and timing and the volume of harvest is regulated through daily limits and harvesting calendars depending on regional regulations (in France there are no national rules, Regis Courtecuisse, personal

communication). In some regions in Italy, this is complemented by the requirement to pass a proficiency test (Brainerd and Doornbos 2013). The aim of this paper was to review diversity, conservation, socio-economic importance and legislation on wild edible mushrooms and truffles in Serbia from different perspectives, for the first time presenting a realistic dimension for research, harvesting and trade. In order to make available all the written data on the topic, existing publicly available recourses and also some personal testimonies where the written data were missing were listed.

Methods

The review first describes the environment that has determined the state of fungal communities in Serbia: country position, nature, climate and socio-economic state concerning the topic. All research data that could be detected have been briefly presented on macro fungi as well as the regulations concerning mushroom conservation and trade. In the second part of the paper, some analyses have been undertaken to enable direct insight into the efficiency of the country's legislation system concerning mushroom trade.

In order to visualise the realistic state of knowledge on macro fungal diversity, data were used from available literature to compile the map of areas that have been investigated so far. To compare these data to the level of usage of forests for mushroom harvesting, the points of mushrooms purchase from the gatherers were added, based on the data obtained from the Institute for Nature Conservation of Serbia (INCS). Records from historical literature were not included in this presentation due to the unreliable nomenclature and imprecision of findings. Truffle distribution was illustrated elsewhere (Marjanović et al. 2010a).

In order to analyse the efficiency of the current system of regulation for the collection and trade with wild mushrooms, all data that could be obtained from the public institutions have been used. The data provided by INCS include: the annual quota (AQ, the annual amount that can be permitted for harvesting); the amounts that were permitted for harvesting and trade for each year from the beginning of the regulation in 1993 up to the year 2016 (AGH, annual gross harvest); the data on the purchasing points (affiliated addresses where the trading companies buy mushrooms from the harvesters, which can be subject to inspection) and numbers of companies that applied for permission for the period 2006–2016. As almost all mushrooms gathered in Serbia are exported, the authors included in their analyses the data obtained from the Customs service of Serbia on annual gross export (AGE) and annual gross values (AGV) of mushroom exports in Euros, as provided in the export documents. In order to avoid misinterpretation of the presented data due to the weather influence on mushroom production, the data on annual average maximal rainfall (AMR) for the country obtained from the Institute of Hydrology and Meteorology of Serbia were included. For comparison of the data, correlation coefficients were calculated using the software Microsoft Excel 2007.

Results

The positioning and nature of Serbia

Serbia is located in the heart of the Balkan Peninsula, a region not geologically old, but with a geographic position and geologic, topographic and climatic diversity that have produced an environment conducive to very high biodiversity rates at species, community and ecosystem levels (Stevanović et al. 1995, Myers 1999, Figure 1). The northern part - province Vojvodina belongs to the flat Pannonian Basin with a typical semi-arid continental climate. Central Serbia is a hilly depression surrounded by high mountains of differing origins and ages, with a sub-mediterranean, semi-arid, mild climate. Mountains produce a rain shadow and humidity gradient from the humid climate with a strong mediterranean influence in the western part of the country (average annual precipitation 720–900 mm,1500 mm in the mountains), to the very arid and warm climate in the south-east (650–700 mm, 1000 mm in the mountains). Average yearly temperatures vary between 9.5–11.7 °C in the lowlands (0.5–5 °C in the mountains). The coldest month is January with averages between – 0.6 °C in mountains and 0°C in lowlands, while the warmest is July with averages 11–22 °C in the lowlands and 11–16 °C in the mountains. The Northeast receives only 520–590 mm of precipitation yearly and the temperature difference between annual minimum and maximum can be as much as 80 °C. More than 20 different soil types have so far been recorded in Serbia.

The natural vegetation of Serbia consists primarily of temperate forests dominated by numerous ECM species of Fagaceae and few species of Pinaceae. Native lowland forests are dominated by pedunculate oak (*Quercus robur* L.) mixed with poplars (*Populus alba* L., *P. nigra* L.) and ash (*Fraxinus angustifolia* Vahl, F.) in wet areas and linden (*Tilia cordata* Mill.) and maples (*Acer sp.*) in drier soils. Most hilly regions are dominated by various oaks (*Querscus cerris* L., *Q. frainetto* Ten., *Q. petrea* (Matt.) Liebl., *Q. pubescens* Willd.), but also hornbeams (*Carpinus betulus* L., *C. orientalis* Mill., *Ostrya carpinifolia* Scop.), linden (*Tilia argentea* D.C.) and hazelnuts (*Corylus avellana* L., *C. colurna* L.). Typical European forests dominated by European beech (*Fagus sylvatica* L.) or Norway spruce (*Picea abies* (L.) H.Karst.), occur at the higher elevations, while the uppermost regions can be inhabited by some endemic pines (*Pinus heldreichii* Christ., *P. peuce* Griseb., *P. mugo* Turra). The majority of the native vegetation has been continuously destroyed since human civilisation appeared in Europe. The percentage of the preserved forests varies from there being almost no forests in the areas of intense agriculture (northern flat areas and river valleys) to the somewhat forested mountains, National parks and hunting reservations.

Brief overview on published scientific data on biodiversity of macro fungi of Serbia

What marks the written scientific work on macro fungi in Serbia is the fact that there has never been any serious mycological taxonomic literature written in Serbian or any of the languages spoken in the ex-Yugoslavian republic, in which Serbia until recently

Figure 1. Geographical position of Serbia in the Balkan Peninsula.

belonged. All investigations on diversity of epigeic macro fungi of Serbia were based on sporocarp descriptions (Listed in supplementary material 1, Figure 2). The vegetation types present in Serbia are very well characterised (Kojić et al. 1998), but the knowledge on fungal communities within those vegetation types is minimal (See supplementary material 1). Unfortunately, authors with the background in forestry in Serbia consider forests exclusively as timber production or hunting tourism areas (See supplementary material 1). The importance of macro fungal saprotrophs in forest ecosystems is not recognised in their work (wood degrading species were usually treated as pests), while the existence of ECM has only recently been documented (Katanić et al. 2015a, b). The single experimental attempt of using seedlings inoculated with ECM fungi in forestry was in remediation of polluted soils (Karličić et al. 2016). Finally, the cooperation between forestry specialists and biologists on this topic is almost non-existent (Marjanović 2000).

Unlike other macro fungi, interest and research on truffles has been flourishing in the last two decades (details in supplementary material 1). The check-list of 12 species

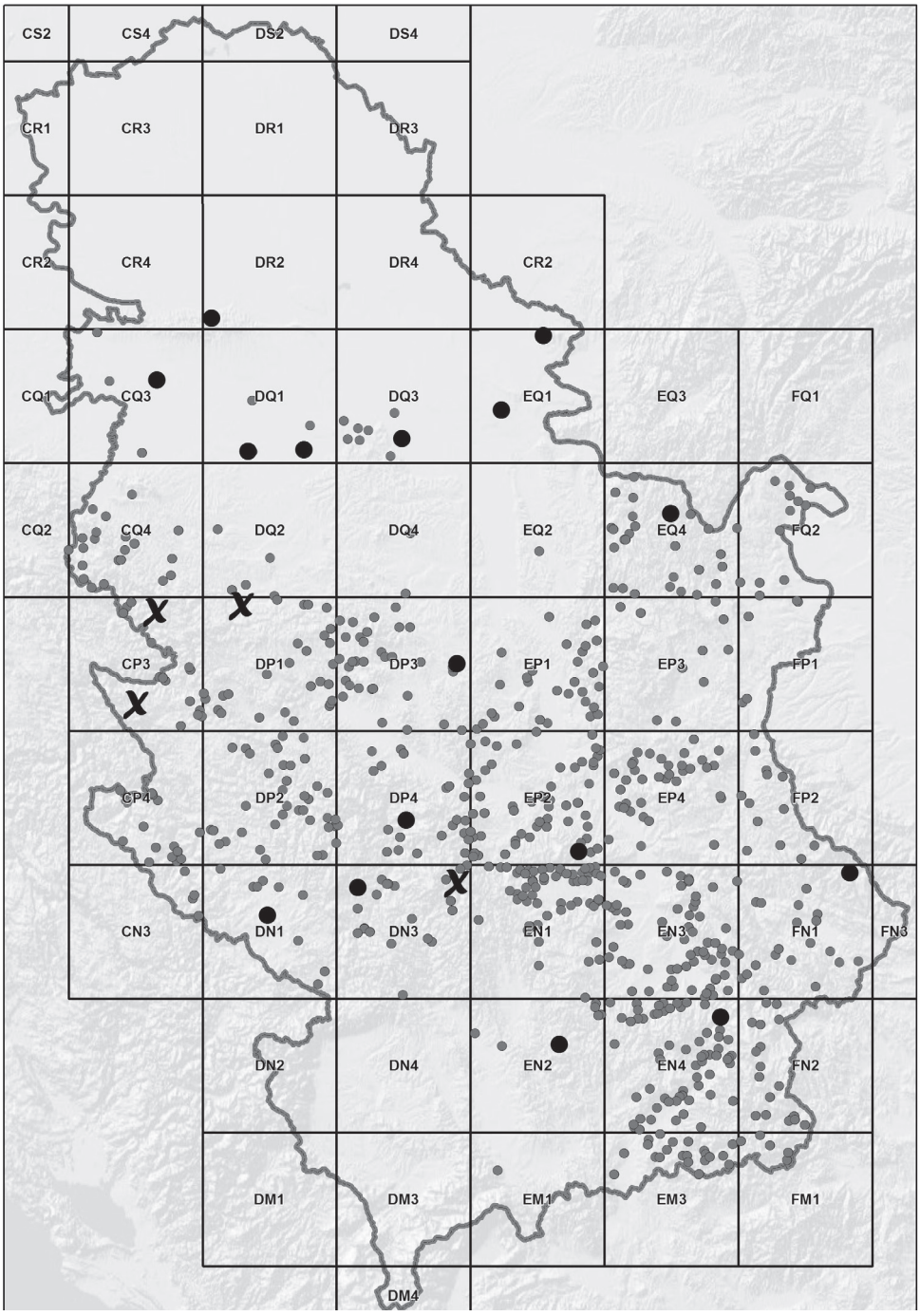

Figure 2. Mushroom research and purchase map**.** Small dots - points of epigeic mushrooms purchase from the gatherers based on the data obtained from the INCS; big dots - data on epigeic macro fungal diversity existing; X–diversity and ecology data existing.

of true truffles have been described using morphological features of ascocarps combined with the analysis of rDNA sequences (Marjanović et al. 2010a) and a new species from the mountain Tara was described (Milenković et al. 2016). Detailed descriptions of ecological features and habitats of the economically most important truffle species in Serbia (*Tuber aestivum* Vitt. and especially *Tuber magnatum* Pico) have been published recently (Marjanović et al. 2010a,b, 2013a,b, 2015, Bragato and Marjanović 2016). The single official national collection of fungal dry exsiccates is in the Natural Museum in Belgrade (See supplementary material 1), while so far, the authors are not aware of any official attempts about forming the national collection of macro fungal mycelia.

Socio – economical importance of wild macro fungi in Serbia

Within the authors' knowledge, there have been no data on using mushrooms in the local diet by inhabitants in the territory of present-day Serbia until the 19th Century, when the first written data on mushrooms appeared (See supplementary material 1). The long-lasting impoverishment of the inhabitants, caused by the previous rule of Ottomans (14–19th Century), probably induced the widespread usage of forests products, but the written data on that is scarce. Nowadays, mushrooms are normally gathered by people who enjoy eating them (hobbyists, inhabitants of the rural parts), but the major reason for harvesting mushrooms is gaining income by selling them to the trading companies. Only symbolic amounts of the wild mushrooms are consumed within the country. The species widely used in the local cuisine and sold on the local markets are: *Boletus edulis* Bull..:Fr*, B. reticulatus* Schaeff., *B. aereus* Bull.:Fr*., Cantharellus cibarius* Fr.: Fr., *Lactarius piperatus* (L.: Fr.) Pers., *Amanita caesarea* (Scop.: Fr.) Pers., *A. rubescens* (Pers.: Fr.) Pers., *Macrolepiota procera* (Scop.: Fr.) Singer, *Laetiporus sulphureus* (Bull.: Fr.) Murrill, *Russula cyanoxantha* (Schaeff.) Fr., *R. virescens* (Schaeff.) Fr. *and Agaricus campestris* L.: Fr. (Marjanović, Ž. unpublished).

Harvesting and trade with economically important species of mushrooms started in the early seventies of the last century, when Serbia, one of the least developed countries of Europe, with its turbulent war history and political instability, became one of the source countries for edible mushrooms (Sitta and Floriani 2008). Italy began importing fresh porcini from Yugoslavia during the early 20th century and, by 1930, commercial imports of fresh porcini had reached significant levels (Bellini 1933). According to Sitta and Floriani (2008), Serbia has been an important exporter of fresh and dried mushrooms to Italy due to the high quality of products. The economical breakdown of the country and extreme poverty of inhabitants during 90s pushed many of them to search for income in collecting species of interest for trading companies. At the time, social events called "The Days of Mushrooms" started to be organised all over the country with the goal of educating and providing wide publicity on recognising edible mushrooms. Subsequently, an increasing number of people started to collect them for personal use or for sale, while wild mushrooms harvesting in Serbia became an important business and the number of mushroom trade companies has expanded (Figure 3).

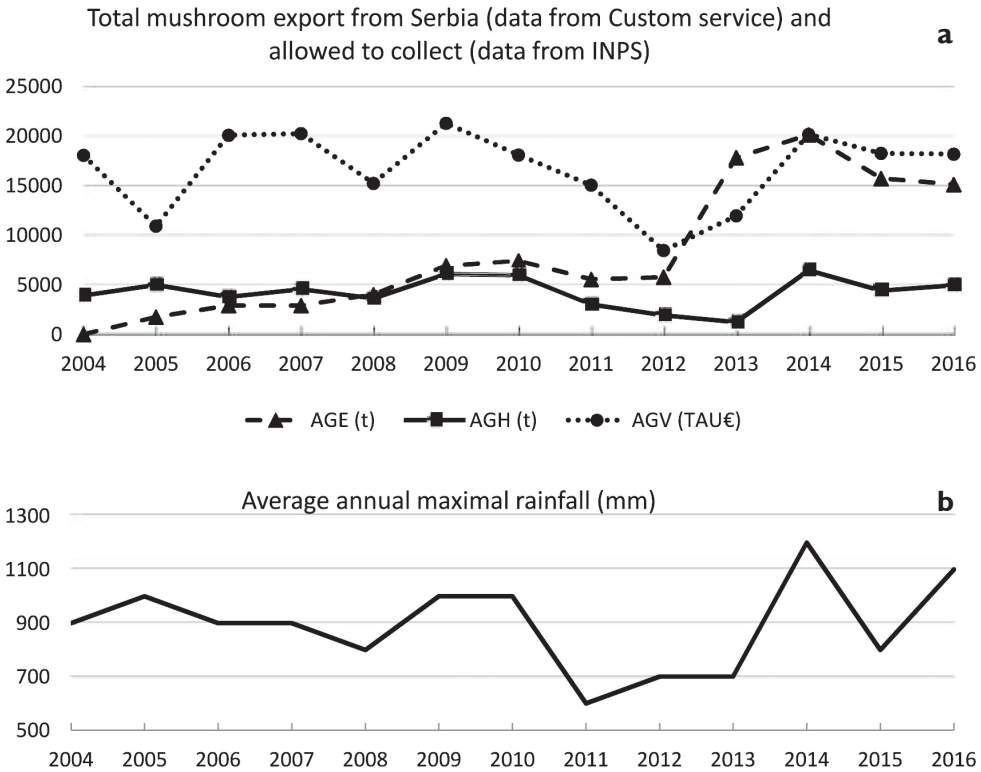

Figure 3. a Comparison between permitted and traded amounts of wild mushrooms in Serbia for the period 2004–2016. AGE of all mushroom species under control and their AGV as indicated on the export documents and provided by the Custom service of Serbia and AQ according to INCS **b** Average maximal rainfall rates for the investigated period.

Since their detection in the 70s , the traditionally illegal truffle market, mainly held by the Slovenian smugglers, has been the only route for selling truffles from Serbia (Ivan Ratoša, personal communication). In early 2000s, Milenković M. (See supplementary material 1) was organising paid courses (for 150+ people) and sold privately written instructions on truffle hunting on an even larger scale (M. Milenković, personal communication). Due to these activities, the number of truffle hunters in Serbia grew rapidly and the black market has been flourishing ever since. The majority of the truffle export is nowadays going through illegal routes (M. Milenković, personal communication), but the level of legal trade is also growing (Figure 5).

Mushroom collecting due to socio-economic drivers is not the crucial factor affecting the conservation of fungi. The far larger danger is the excessive and frequently uncontrolled harvesting of vast amounts of wood. In the last two centuries, forest cover in central Serbia was significantly decreased, from 80 % in 1801 to 21.4 % just after the Second World War (Aleksić and Vučićević 2006). Today, forests in the Republic

of Serbia cover 2,252,000 ha, 29.1 % of the country's area: 37.6 % in Central Serbia and 7.1 % in Vojvodina (Banković et al. 2009). The majority of the harvested wood is used for heating, since 40.9 % of households in Serbia still use wood for heating and even cooking all year around (Glavonjić 2011). The state-owned agencies for forest management that are in charge of all forests in the country except National parks (Srbijašume and Vojvodinašume) perform very symbolic afforestation–only 7 % of forests belong to plantations, but with non-native tree species (American hybrids of *Populus sp.*, *Paulownia tomentosa* (Thunb) Steud., *Pseudotsuga menziesii* (Mirb.) Franco, invasive *Robinia pseudoaccia* L.) or non-native for the habitat (*Pinus nigra* J.F.Arnold or *Picea abies* L. H. Karst. on all habitats, Ivetić 2015).

Another major socio-economic danger for macro fungal communities in Serbia is the problem of pollution (uncontrolled air pollution, application of fertilisers and pesticides) absolutely not recognised by the forestry sector and a serious problem with waste deposition (http://www.sepa.gov.rs/). Only 60 % of the municipal waste is gathered, while all the rest ends up in the natural environment (http://www.sepa.gov.rs), with traditional places for disposing of the unwanted waste of different origin being forests.

Mushroom conservation, legislation and trade control in Serbia

The first attempt at placing macro fungi into a process of protection was the proposed preliminary red list of that time Yugoslavia (Ivančević 1995, 1998). However, these data were quite useless assuming the fact that: the checklist of detected species in the territory of Serbia (or previous Yugoslavia) has never existed; there are only three spots for which any kind of data officially exists about abundance of sporocarp production based on the few seasons' examination: (Čolić 1967, Ivančević and Marjanović 1987,1988,1990, Marjanović 2000); no survey on the country level has ever been conducted in order to obtain even an estimation on the diversity or abundance. Still, there are many legal acts that passively concern macro fungi. On the international level, Serbia has joined the Convention on Biological Diversity (CBD), Convention on the Conservation of European Wildlife and Natural Wildlife (Bern convention, www.zzps.rs). Eight percent of the total territory has been assigned for 61 IPA sites (Important Plant Areas, Stevanović and Šinžar-Sekulić 2009), while under the Bern convention, the EMERALD network within Serbia is expected to cover 11.54 % of the territory with 61 officially nominated sites proposed (www.zzps.rs). The State protects 6.5 % of the territory within: 5 national parks, 16 parks of nature, 20 areas of landscapes of exceptional quality, 70 reserves of nature, 314 monuments of nature and 4 habitats (www.zzps.rs). All of them, plus areas of international importance for nature conservation, constitute the Ecological net of Serbia (Official Gazette of the Republic of Serbia No 102/10) that covers 20.49 % of Serbian territory. There is only one protected fungal habitat in Serbia (www.zzps.rs), but through protecting other areas of

high biodiversity, they were passively included. Also, macro fungi recently appeared in the Biodiversity Strategy of the Republic of Serbia for the period 2011–2018, issued by the Government of Serbia in compliance with international agreements and the Serbian Law on Ratification of the Convention on Biological Diversity (Radović and Kozomara 2011). On the other hand, fungi are not mentioned even once and mushroom gatherers and traders do not exist as stakeholders in the Forestry Development Strategy for the public of Serbia (2006).

On the national level, general Laws on nature protection (See supplementary material 2) passively regulate fungi by regulating protection of the environment, biodiversity, diversity of ecosystems or landscapes in the country, in a way that should meet the requirements of the EU legislation system, through processes for EU joining that are expected in the near future. The Law on Forests, issued by the Ministry of Agriculture and Forestry (MAF) directly treats mushrooms in two articles: Article 9 forbids collection of any secondary forest products, unless stated differently by that same Law; Article 62 allows collection of secondary forest products only upon approval of the forest manager. It is not stated how these two articles were correlated with other legislation acts that refer to wild mushrooms.

Legal acts that directly regulate macro fungi protection are components of the Law on Nature Conservation (See supplementary material 2) issued by the Ministry of Environmental Protection (MEP): Regulation on protection of protected and strictly protected wild species of plants, animals and fungi (in the future text "The Regulation", Official Gazette of the republic of Serbia, No 5/10, 47/11, 32/16) and Bylaw on placing the use and trade of wildlife under control (in future text "The Bylaw", Official Gazette of the republic of Serbia No. 31/05, 45/05, 22/07, 38/08, 9/10, 69/11). The Regulation lists 38 strictly protected and 26 protected macro fungal species, including 15 species that may be harvested and traded under control (supplementary material 2: Tables 1 and 2). The document provided no explanation on the criteria for compiling the lists in this legal act. By The Regulation, strictly protected species and their habitats are forbidden to be disturbed in any way and should be monitored and repopulated if possible. Species listed as "protected" can be collected under conditions regulated by other legal acts, but the regulation of their protection is not clear.

The current version of The Bylaw allows the controlled harvesting and trade with 15 species of macro-fungi (supplementary material 2: Table 2). Since the beginning of its application, the list of species has been changed few times: originally (1991), it included all species of *Lactarius sp., Morchella sp., Agaricus sp., Boletus edulis*, *Cantharellus cibrius* and *Pleurotus ostreatus*; in 1996, *Amanita caesarea* was added and removed again in 1999 together with *Morchella sp.*, while two inedible species of *Bovista sp.* appeared in 1996 and were removed in 2005, when truffle species appeared on the list. *Tuber brumale* that was listed in 2005 was exchanged for *T. macrosporum* in 2011. No rationale was provided for any of these changes nor explained in any way.

The Bylaw forbids trade on the species listed outside the frameworks described and regulates the methods of sporocarp collection to avoid damage to soils and plants in

the ecosystems. It declares a taxation of 10% of the nominal value per kg of sporocarps for every species, for the "permission to harvest and trade" (in further text The Permission). Only legal entities that are registered for such business are eligible for applying (natural persons undertaking mushrooms harvesting or trading are not included). The Permissions issues MEP after the opinion of INCS. INCS is obliged to perform monitoring of mushroom production and habitat state and to decide on an annual quota allowed for harvesting (AQ). The Permission holders are obliged to organise education and issue certificates on mushroom recognition for the gatherers whom they engage, as well as providing the annual reports on harvesting to the MEP. The Bylaw defines penalty payments for those who do not obey the rules defined in the text (legal entities or natural persons). It does not define who is supposed to control fungal habitats *in situ* for illegal activities or who is supposed to be informed about the illegal mushroom gatherers or to whom.

The functioning of the regulation of mushroom trade in practice

One of the aims of this paper was to investigate the actual practice of macro fungal trade control in Serbia, hence the analyzes of the data obtained from legal public sources and evaluation of the effects and level of application of Legal Acts in the period 1993–2016 since The Bylaw was established has been performed. Comparison of the data on AGE of all mushroom species under control and their AGV, together with the AGH according to INCS were presented in Figure 3a, while the values for AMR were presented in Figure 3b. The correlation coefficients for all the data presented in Figure 3a and b were calculated and only the AGH appeared strongly correlated with AMR (r = 0.85). AGH was weakly correlated with AGV (r = 0.5), which was not the case with AGE and AGV (r = 0.36). Rainfall rates did not significantly influence the values of export (r = 0.34), while no correlation was detected between AGE and AGH (r = 0.08). The number of companies that have applied for the Permissions did not influence the gross amount of trade in the examined period (data not shown).

The most ubiquitous mushrooms that have been the subject of trade on a large scale in Serbia were *Boletus sp.* (50.2 % in 2013 to 80.3 % in 2014, on average 68.5 %) and *Cantharellus cibarius* (11 % in 2014 to 41.2 % in 2013, on average 25.1 %, data from supplementary material 3). In Figure 4, AQ and AGH for these species were compared (other species that were listed in The Bylaw were collected and traded in much smaller amounts - less than 10 % of AGH and therefore not presented, see supplementary material 3). By calculating the correlation coefficients between AGH (Figure 4) and AMR for the period 2004–2016 (Figure 3b), a strong influence of rainfall on trade with *Boletus* sp. (r=0.85) was detected but not on *Cantharellus cibarius* (r = 0.35). The data on truffle species (*Tuber magnatum*, *T. aestivum* and *T. brumale* / *T. macrosporum*) were presented in the Figure 5.

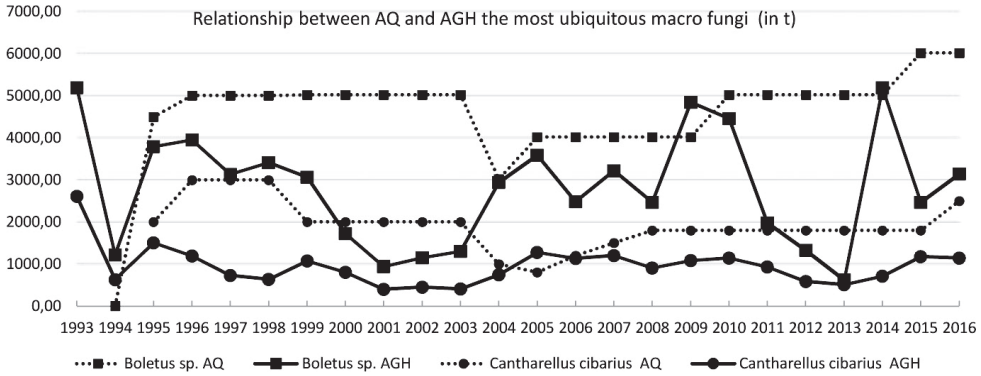

Figure 4. The estimation and demand of the most ubiquitous mushrooms trade in Serbia. AQ and AGH according to INCS for porcini *Boletus sp.* (*B. edulis*, *B. aereus*, *B. reticulates* and *B. pinophilus*) and *Cantharellu scibarius*.

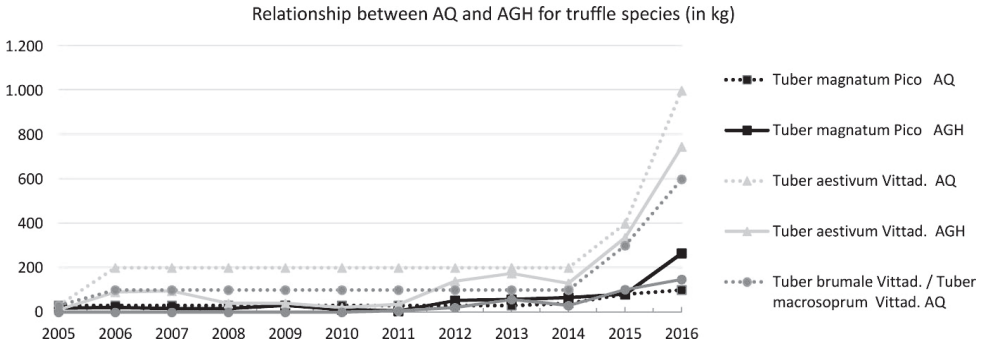

Figure 5. The estimation and demand of truffles trade in Serbia. AQ and AGH according to INCS for truffle species.

Discussion

In this contribution, the authors have provided a comprehensive overview on different types of data on macro fungi from the country positioned on the borderlines of different climate, geological and vegetation zones of the Balkan Peninsula, with consequently high rates of biodiversity. Throughout history, common fungal habitats forests, once covering probably the great majority of the country, have become endangered. At the present time, with evident planet climate and atmosphere composition equilibriums changing as a consequence of global forest decrease, the desire for their preservation and enlargement has become evident (Meyfroidt and Lambin 2011). In the background, the organisms i.e. the fungi that serve crucial roles in maintaining the equilibrium of the forest ecosystems, especially in temperate regions with seasonally changing climates are hidden. Whether they degrade wood or forest litter enabling nutrient cycling and taking direct roles in soil formation or form symbiotic relations with trees enabling them to reach unavailable nutrients and water, forest ecosystems could

never have functioned without complex macro fungal communities that obligatorily accompany them (Dix and Webster 1994). Therefore, when conservation of macro fungi is referred to, it must be kept in mind that it does not just mean protecting species, but it always means protecting entire ecosystems in their habitation.

Considering macro fungi conservation, differences should be made between the so-called rare species and those harvested in large amounts. In Serbia, the former are listed as 38 strictly protected species, a significantly smaller number than bordering Croatia, which strictly protects 314 species (http://www.dzzp.hr). From the content of the list (See supplementary material 2, Table 1) to a local specialist, it appears clear that there are many rare species that can be found in Serbia, but were not listed (for example, *Cortinarius* sp. or *Inocybe* sp., the species rich genera and which are numerous in Serbia (Marjanović 2000), are missing). Within Europe, the lists of protected species have recently been recognised only as the basic line for conservation of fungi, while habitat preservation, its reclamation and *ex situ* conservation have been proposed practices (Courtecuisse 2001). In Serbia, The Regulation forbids destroying habitats of strictly protected species, but would the average person intending to destroy the habitat (either by harvesting the wood or by depositing pollutants) ever think if such a spot hosts a very rare mushroom? Apparently, without habitat investigation, mapping, clear marking on spot and monitoring, the protection on paper has absolutely no effect (Dahlberg et al. 2010, Brainerd and Doornbos 2013).

Species that have been harvested on the large scale are listed as "protected" in The Regulation (See supplementary material 2, Table 2) and some of them are regulated by The Bylaw, with odd occasional changes in the list content. The appearance of inedible *Bovista sp*. was odd enough and their extraction from the list was no surprise. On the other hand, *Amanita caesarea* and *Morchella* sp., are widespread, collected and sold in Serbia, but were extracted from the list in 1999 and have never appeared there again. The protection of habitats for listed species was regulated briefly by The Bylaw, but this applies only to the gatherers and not to other stakeholders. On the other hand, the detailed investigations of habitats defining ecological demands of economically important macro fungal species are recent and sporadic (Marjanović et al. 2010a,b; 2013a,b; 2015; Bragato and Marjanović 2016). However, such an approach revealed how crucial it was to understand inseparable ecosystem features like soil water, nutrients and organic matter seasonal dynamics, the size of the soil particles that define the size and distribution of soil pores, which further define the dynamics of soil aeration, up to the influence of seasonal leaf development and senescence on dynamics of nutrient uptake by the trees or their transport toward roots. All these elements are obligatory for appearance and fructification of the most precious ECM mushroom in the world, *Tuber magnatum* (Marjanović et al. 2015) and a small change in these vulnerable ecosystem dynamics may lead towards species disappearance from the site (Bruns 1995) .

The recent legal acts of Serbia concerning fungal conservation were certainly influenced by similar acts of other EU countries and probably shaped by the political demands of processes leading towards EU joining. Forest protection, their sustainable usage and reforestation are very highly listed goals in the Law on forests (2015), but

actual research (Ivetić 2015), the reports of non-governmental organisations and the situation observed *in situ* reveal a very different reality. According to the recent report of REC (2009) about illegal logging in Serbia: 64.7 % of forests are very low quality coppice forests; officially registered volume of logging (in gross amount) ranges from 3–3.5 million m^3 annually, but estimations are that this amount could be even 9 million m^3 – equal to the estimated annual wood increment; the estimated illegal wood cut in privately owned forests (about 47 % of all forests in Serbia) is ca. 1.2 million m^3 annually. The areas abandoned from agriculture or clear cuts are permanently changed environments concerning EMC communities (Jones et al. 2003) and in Serbia usually quickly overgrown by black locust and other invasive species that do not form ECM (Radtke et al. 2013). Apart from areas where clear cuts and intense coppicing were left to naturally regenerate, the authors are not aware of any reforestation attempt with native tree species in a suitable habitat. While establishment of autochthonous ECM fungal communities in non-native plantations is not expected, in coppice forests that dominate the forest resources of Serbia, degradation of such communities is highly likely as the amount of carbohydrates that reaches ECM roots is much lower and the micro-environment is significantly changed (Bruns 1995, Jones et al. 2003).

A recent detailed report based on 30 years of investigation revealed no influence of sporocarp collection on populations of ECM fungi in undisturbed habitats (Egli et al. 2006), changing the opinion of the mycological scientific community on measures for mushroom protection (Brainerd and Doornbos 2013). However, the data which is presented here reveal the level of the legislation application in Serbia. The discrepancy between AGE and AGH is obvious (Figure 3). While AGH of sporocarps and the most important environmental factor for their production (rainfall) were strongly correlated, this was not the case with AGE. It is not clear from where these huge exported amounts of mushrooms could originate, but it might be possible that part of them were re-exported from other countries. The AGE was lower than or following the curve of AGH up to the year of 2008, when export started to be higher than permitted, especially from 2012 when 2–10 times more mushrooms were officially exported than was permitted for harvesting. The possible explanations are that Permissions were falsified, that they were issued illegally or that there was a serious violation of the Customs' procedure.

Simultaneously with the vast growth of the AGE (2012–2014), the AGV was dropping (Figure 3). While the average price of one kg of mushrooms in 2006 was 6.8 Euros, in 2013 (when AGE was more than 10 times higher than AGH), the average price per kg was 0.7 Euros (calculated from the raw data presented in Figure 3a). Palumbo and Sitta (2005) reported that the prices of dried porcini in Italy (main target country for Serbian mushrooms) for 2005 were between 40 and 70 EUR/kg. In the data that have been received from the Customs service, it was not stated if the sold mushrooms were fresh, frozen or dried, but it is hard to imagine that they could ever cost 0.7 EUR/kg on average. The probable explanation is that the values on the invoices that were provided to the Customs service were manipulated.

The AQ for the most important commercial mushrooms was obviously changing during the period of investigation (Figures 4, 5), but no explanation could be found for this,

as the monitoring proposed by The Bylaw has never been undertaken. For truffles, AQ grew rapidly from 2014, while for *T. magnatum* in 2016, it was exceeded by a factor of 2.5 (Figure 5). This was not the first time for such practice (Figure 4), but the legal mechanism enabling it is not known. Obviously, the regulations on trading with protected mushroom species has been severely violated starting from 2008. On top of these official data, it must be added that significant amounts of mushrooms, especially truffles, have been regularly smuggled over the borders in the last decade. The taxation for harvesting and trading with truffles is extremely high, while the smuggling routes have been well established a long time ago, the reason why the truffle smugglers are in a much better position than the legal traders in Serbia. Additionally, such taxation for truffle trading does not exist in other truffle source country, which discourages the legal truffle trading in Serbia.

Proposals for the legal measures that would improve the effects of conservation of rare and sustainable use of commercial mushrooms as a natural resource of Serbia

After serious evaluation of the situation in Serbia, considering solutions taken in other EU countries (Moore et al. 2001, Brainerd and Doornbos 2013), as well as respecting the newest scientific achievements concerning macro fungi and their habitats, some measures are suggested that could lead towards much more effective conservation and control of trade with wild mushrooms.

Considering the current status of the existing resources, the logical starting point for establishing the background for forming the official National database on macro fungal species in Serbia would be publishing the data on collection in the Natural Museum in Belgrade. In this way, the check-list would be formed and the mapping and monitoring system would be facilitated. Only then the realistic list of strictly protected species could be compiled, their habitats properly marked and further legally protected from disturbance.

Harvesting of the commercial epigeic species regulated by The Bylaw has a large economical potential and the preservation or enlargement of their fructification, which depend strictly on preservation of stability of their habitats, should be of special interest. They inhabit soils and ecosystems that are widely present, the reason why their protection should be strongly connected to the sustainable wood harvesting organised in an appropriate way (e.g. according to the recommendations in Kraus and Krumm 2013). As the number of researchers specialised in macro fungal ecology in Serbia is minimal, the projects supported by the Government should be set to enlarge the number of people working in this area. Such projects should involve combined investigations of fungal communities (ECM morphotyping or molecular analyses) and fructification, accompanied by the investigation of seasonal dynamics and spatial distribution of mycelia for all highly exploited mushroom species in selected spots (e.g. van der Linde et al. 2012, Ovaskainen et al. 2013). These data should be correlated with microclimate parameters in order to define specific indicators of habitat functionality and fungal population dynamics (Marjanović et al 2015). Such parameters would be reliable subjects of monitoring and key factors for decision-making on conservation practices.

Reforestation of deserted bare land with autochthonous tree species inoculated with local strains of ECM fungi would be the best way to invest in renewable resources - mushroom and wood production (Schwartz et al. 2006). Under field conditions, late-stage fungi like porcini were able to compete effectively with early stage fungi for colonisation of new roots only if they were already associated with other living roots (through mycelia), while spore-based inoculations failed (Deacon et al. 1983, Fleming 1983, 1984). Also, mycelia of saprotrophs that perform final stages of wood degradation are highly threatened by wood exploitation (Stokland et al. 2012), may be interesting material for preservation. Therefore, in addition to the improvements *in situ*, simple measures that could be effectively developed from the existing resources in research institutions include the formation of the National Bank of macro-fungal mycelia, in order to compensate for disappearing habitats/substrates and provide the basis for their possible reclamation (Courtecuisse 2001).

The most endangered and the most economically potential macro fungal species in Serbia is certainly *Tuber magnatum*. The very specific ecological demands of this species and continuous destruction of its habitats at the global level, combined with the high demand on the market formed its very high prices (up to 4000 EUR per kg of the best quality in Italy). The white truffle of Piedmont or Alba has been long accepted as a strictly Italian delicacy, but since the natural habitats in Italy have been permanently destroyed (Gilberto Bragato, personal communication) and the new habitats discovered first in Istria (probably early 20th century) and, later on, in Serbia (Marjanović and Milenković 1998) and Hungary (Bratek et al. 2004), the market has been widened. As this truffle is of highest economic importance for all these countries, the regional initiative for protection of existing habitats and reintroduction on suitable lands would be the best solution for its preservation and sustainable use. This truffle competes with the wood industry (its dominating host is *Quercus robur*, highly prized for its wood quality) and agronomy, as the soils it inhabits are of the highest quality. Therefore, a well organised action at state level must be applied for strict protection of existing habitats and detecting areas where this truffle species could be reintroduced.

Following these proposals, legislation regulating macro fungi protection and trade should be substantially changed. The conflict of jurisdiction between the Law on Forests and the Law on Nature Protection indicates a need for further harmonisation on the conflict of interests. If biodiversity conservation should be a priority, then the protection of habitats of strictly protected fungi must be an official part of the Law on Forests, which should enable monitoring governed by the MEP and INCS. As it does not recognise mushroom gathering as an economic interest for rural citizenship at all, a clearly stated connection to The Bylaw should be included. The Permissions issued by MEP that the holders buy from the State for a relatively high price, should be recognised in the field by the forest managers. The current chaos in legislation may be solved only by agreement between all stakeholders of the forest ecosystems - users, specialists and MEP and MAF, at State level.

Concerning the worrying information on the multi-level violation of the regulations on the mushroom trade, it is believed that the State should try to understand the causes of such a situation and react adequately. The number of citizens (mostly from the impoverished rural regions) that are involved in the mushroom trade in Serbia is increasing; the

reason why the valid attempt for limitation of this business is obviously not functioning. The only outcome is the creation of the mighty black market, which is endangering the natural resources in the country and attracting criminal characters. Reduction in the taxes for mushrooms (especially truffles) trade and introducing the issuing of licences for gatherers, as in other EU states (Brainerd and Doornbos 2013), would meet the interests of both State and traders and reduce the number of illegal gatherers. This way, they would achieve their role in the entire system and become visible to the instruments of the Law. Investing in the currently non-existent control of the mushroom gathering in nature by formation of an educated ranger net, as well as detecting and sentencing of the illegal traders and gatherers, would be much more effective than the existing system of office- and Customs- based regulation. In addition, many members of the local mushroom gathering societies could be introduced to the monitoring process. This way, jobs could be created in very impoverished regions where the mushroom gathering is a significant source of income. In other words, sustainable usage of mushrooms as natural resources that would allow the trade to develop, but with investment in habitat protection, development and control would be the only model that would satisfy the needs of all stakeholders involved.

Conclusions

The current state of knowledge, research and published data on diversity, ecology and population dynamics of macro fungi in Serbia is not satisfactory. The existing regulations on mushroom conservation and trade control in Serbia are confusing, non-efficient, hardly applicable and regularly violated. In order to fulfil the requirements of mushroom conservation and sustainable harvesting from the existing forest ecosystems, actions are proposed that would be efficient in practice: creating a fund that would enable protection and conservation of fungi and their habitats at the State level; directing the research towards fungal population and ecosystems dynamics using up-to-date techniques; establishing agreements between all stakeholders of the forest ecosystems - users, specialists, managers, MEP and MAF and then reforming the existing regulations at the State level; for endangered species, organising habitat mapping, clear on-spot marking and monitoring by specialists and INCS; for commercially important species, organising wide-range monitoring that would include mushroom gathering societies, traders, professional gatherers, specialists and INCS; introduce the wide practice of enlargement of areas afforested by autochthonous tree species, inoculated by autochthonous ECM fungi on suitable soils. Due to the highly threatened habitats and high commercial potential, strictly protect truffle habitats and organise their re-introduction on suitable land; stimulate establishment of truffle plantations and reconstruct the regulations towards better application in practice that would be obligatory for all stakeholders (including the forestry sector). The formation of an educated organisation of rangers that would inspect the activities *in situ* would be the best solution against illegal collection and trade of mushrooms, while the systematic reform of The Bylaw should enable strict definition of rules in this field.

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Supplementary material 1

Overview of mycological literature, research and herbaria collections on macro fungi of Serbia with reference list

Authors: Mandić Radomir, Adžemović Mesud, Marjanović Žaklina

Data type: Additional data PDF.

Explanation note: The document provides brief descriptions of the scientific and hobbyist published data on epigeic and hypogeic macro fungi in Serbia, including the history of their recognition with reference lists. It also provides information on official herbaria collections of macro fungi.

Link: https://doi.org/10.3897/natureconservation.25.21919.suppl1

Supplementary material 2

The lists of strictly protected and protected species of macro fungi in Serbia

Authors: Mandić Radomir, Adžemović Mesud, Marjanović Žaklina

Data type: Additional data PDF.

Explanation note: The document lists the legal acts that regulate macro fungi and their habitats in Serbia, as well as species that are regulated by The Regulation and The Bylaw.

Link: https://doi.org/10.3897/natureconservation.25.21919.suppl2

Supplementary material 3

Annual amounts of mushrooms allowed to harvest (in kg, according to INCS)

Authors: Mandić Radomir, Adžemović Mesud, Marjanović Žaklina

Data type: Data set (Excel spreadsheet).

Explanation note: The document provides table with official data on mushroom and truffle amounts that have been allowed to harvest since 1993, according to INCS.

Link: https://doi.org/10.3897/natureconservation.25.21919.suppl3