

National Red List Assessment Final Report

Fungi



Hydnellum peckii, an endangered fungus species. Photo by Matthias Theiss.

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INTRODUCTION

N. Macedonia as a biodiversity hot-spot area is distinguished by huge fungal diversity. The initial publications on fungal diversity in N. Macedonia chiefly date from the 1930s but in the last three decades research into diversity and distribution of fungi has notably been intensified. The establishment of the Mycological Laboratory at the Faculty of Natural Science in Skopje was a milestone in launching comprehensive and systematic study of fungal diversity on the entire country's territory, which resulted in new fungi species galore. Notwithstanding the fact that species new to the country have constantly been discovered, the current status of fungi (macromycetes) is over 2,600 species (Karadelev et al. 2018, 2019). There are two species new to science: *Astraeus macedonicus* and *Clitopilus abprunulus*. Around 25,000 dry specimens i.e. circa 4,000 different species are stored in the Macedonian Collection of Fungi (MCF), and they are digitized in the MACFUNGI database, comprising information on 37,000 collected specimens or 5,000 various species. Published distribution maps of critically endangered fungi species are also available (Karadelev and Rusevska, 2016).

Pertaining to fungal protection, the ground-breaking endeavour to prepare a Preliminary Red List of Fungi of Macedonia was made by Karadelev (2000), which comprised 67 species - all affiliated with the class Basidiomycetes. In that list, three categories of threat were applied, as follows: a particularly rare or rare species in Macedonia, a species occurring only in endangered or rare habitats, and a particularly rare or rare species endangered due to excessive exploitation. The data from the aforesaid list was used for generating an Official List of Strictly Protected and Protected Wild Species, released in the Official Gazette of the Republic of Macedonia (2011). Nonetheless, in order to reinforce and update the list, Karadelev and Rusevska (2013) published the appendix to the red list of fungi, containing 213 species of Ascomycota and Basidiomycota following the strict IUCN Red List criteria and categories. Of the fungal species listed thereof, 21 were 'critically endangered' species (CR), 30 were 'endangered' (EN) and 71 were 'vulnerable' (VU) species.). Yet, the aforementioned list is a red list in the non-inclusive sense of the word given that detailed justification of each species conservation status is not provided.

With the progress of fungal research in N. Macedonia, new findings have emerged in connection with distribution of macromycetes in our country. Hence, it became indispensable to conduct a revision of the Red List of Fungi of Macedonia. Relying upon the newly-obtained data on large fungi distribution, IUCN categories have been altered for a number of species, and new species have been categorised i.e. the list has been thoroughly reviewed, in particular in the section of endangered species from the higher categories (VU, EN and CR). Sixty-four (64) species of fungi recorded in N. Macedonia have now been assessed, in an attempt to determine their national conservation status consistent with the Guidelines for Using the IUCN Red List Categories and Criteria (IUCN 2012b). The National Red List will be crucial for fungi conservation in the light of the major threats, such as loss and fragmentation of fungi habitats, loss of symbiotic hosts, overexploitation, pollution, and climate change. It will be used by the Ministry of

Environment and Physical Planning to inform the national conservation policy such as the List of Protected and Strictly Protected Species, and the Red List is also the main objective in our national biodiversity action plans and strategies.

These red-listing efforts have been made in collaboration with the Ministry of Environment and Physical Planning. In 2017, an opportunity was created to launch an implementation of a national red-listing initiative in N. Macedonia aimed at producing the first official national red lists fully aligned with all IUCN Red List guidelines. Since then, the Eastern Europe and Central Asia Regional Office (ECARO) of IUCN seated in Belgrade has guided and provided training for the roll-out of the national red list process in the country, and it has pursued this activity throughout the fungal red list assessment. The European Bank for Reconstruction and Development has supported the fungi red-listing via the project entitled “Biodiversity Capacity Building Programme: Promoting Good International Practices in Macedonia”, managed by Hardner & Gullison Associates from the USA.

It is worth underlining that in recent times there has been serious work on IUCN fungi categorisation on a global level - a process where part of Macedonian red list assessment team have been largely involved in the segments of species proposals and acceptance. Within the framework of this initiative, the joint Meeting of the European Mycological Association (EMA) and the International Society for Fungal Conservation (ISFC): ‘Fungal Conservation in a Changing Europe: the Challenges Ahead’ was convened in Ohrid, N. Macedonia, in 2017. The IUCN Red List of Threatened Species, the component dedicated to fungi, currently comprises 280 fungal species, and 13 of them are also on the pending Macedonian Red List of Fungi. Fungi are presently not listed in the appendices of either the Bern Convention or the EU Nature Directives.

METHODOLOGY

The proposed National Red List of Fungi including 64 taxa was generated based on field research results, published and unpublished records on species, exsiccates, research notes and information sourced from other individual fungi collectors. All vital data were assembled for final species assessment in harmony with the following IUCN criteria: distributional range, population and trends, habitat and ecology, threats, use and trade, etc. The assessment was conducted in three stages, as follows:

Pre-Assessment

The team reviewed data from different literature sources accompanied by data from the Macedonian Collection of Fungi (MCF) and the MACFUNGI database at the Mycological Laboratory within the Faculty of Natural Sciences and Mathematics in Skopje. The current unofficial Red List of Fungi (Karadelev and Rusevska, 2013) of N. Macedonia was also scrutinised. Field research for collection of mycological material and laboratory analyses of the collected material

was also conducted for the target species especially given that some were data deficient. Field research covered localities of diverse climate and vegetation features, and different substrates both on deciduous and coniferous trees, and in an array of habitats: Greek juniper forests, beech forests, spruce forests, Macedonian pine, Bosnian pine, oak forests etc., and in national parks (Galicica, Pelister, Mavrovo), Jasen nature reserve, pristine forests and other protected areas. Field activities occurred during springtime, summertime and particularly in autumn, which is the most favourable season for fungi growth. For species identification, standard methods were applied: microscoping, application of reagents (Melzer reagents, Sulphovanilin, Cotton blue, KOH, etc.), and consulting specialised identification books, as follows: Ahti et al. (2000); Alessio (1985); Bernicchia and Gorjon (2010); Breitenbach & Kränzlin (1981, 1986, 1991, 1995, 2000); Corfixen et al. (1997); Däncke (2001); Moser (1983); Jülich (1984); Ryvarden & Gilbertson (1993-1994); Eriksson & Ryvarden (1975); Eriksson, Hjortstam & Ryvarden (1973-1984); Horak (2005), Galli (2001); Pegler, Spooner & Young (1993); Heilmann-Clausen, Verbeken & Vesterhold (1998); Krieglsteiner (2000); Neubert, Nowotny & Baumann (1993) and Pegler, Roberts & Spooner (1997).

Assessment

Desktop analysis of the species pursuant to IUCN criteria. The taxa were assessed according to IUCN version 3.1. The assessor team members were previously trained to use the Species Information Service (SIS) - the IUCN's web application for conducting, management and storage of species assessments for the IUCN Red List. SIS comprises a standardised data format for assessments, thereby ensuring assessments use the same classification systems and ensuring taxonomic integrity. For IUCN categorization of species, we also relied on the experience of the neighbouring countries (Macedonia, Albania, Kosovo and Croatia), some European countries, and the fungi section of the IUCN Red List of Threatened Species.

Some of the hitherto proposed species from N. Macedonia for the Global Fungal Red List Initiative (<http://iucn.ekoo.se/iucn/selectspecies/>) are currently in an assessment phase while sixteen species have already been published, as follows: *Albatrellus confluens*, *Alessioporus ichnusanus*, *Amanita caesarea*, *Bovista paludosa*, *Cortinarius caperatus*, *Cortinarius haasii*, *Hericiium erinaceus*, *Hygrocybe punicea*, *Lenzitopsis oxycedri*, *Poronia punctata*, *Rubroboletus dupainii*, *Rubroboletus rhodoxanthus*, *Sarcodon leucopus*, *Tricholoma acerbum*, *Tricholoma apium* and *Xeromphalina junipericola*. In due course, a number of species from our country with global conservation interest will be proposed for assessment by the Global Fungal Red List Initiative.

All available data were analysed, and, ultimately, the appropriate category was assigned to each and every fungus species. Species taxonomy is in alignment with the latest nomenclature of Index Fungorum (<http://www.indexfungorum.org>) and the MycoBank Database (www.mycobank.org).

Review

The assessments of all fungal species were reviewed by a number of independent, international mycological experts. All their remarks and advice were incorporated and the assessments were completed. Our red-listing data have been stored in IUCN's global SIS (<https://www.iucnredlist.org/assessment/sis>), wherefrom they are extracted and transferred to the Macedonian National Red List website (<http://redlist.moepp.gov.mk/>), which is under the auspices of the Ministry of Environment and Physical Planning.

THREAT STATUS

The threat status of the sixty-four (64) assessed taxa is rendered in Table 1. The summary of the threat status is the following: six fungus species have been assigned the category of CR - Critically Endangered (9.3 %), nineteen EN – Endangered (29.6 %), thirty-four VU – Vulnerable (53.1 %), two NT - Near Threatened (3.1 %), two LC - Least Concern (3.1 %), and one species is data deficient (1,5 %).

The majority of the taxa—fifty-three (53) belong to the phylum Basidiomycota (82.8%) whereas ten (11) taxa (17.1 %) are affiliated with the phylum Ascomycota.

Table 1: The threat status of the assessed taxa of fungi.

<i>Alessioporus ichnusanus</i> (Alessio, Galli & Littini) Gelardi, Vizzini & Simonini	EN– Endangered; B2ab(iii); D
<i>Amanita caesarea</i> (Scop.) Pers.	LC – Least Concern
<i>Amanita curtipes</i> E.-J. Gilbert	VU – Vulnerable, D1
<i>Antrodia juniperina</i> (Murrill) Niemelä & Ryvarden	VU – Vulnerable, B1ab(iii,iv) + 2ab(iii,iv); D1
<i>Aspropaxillus giganteus</i> (Sowerby) Kühner & Maire	NT – Near Threatened, D1
<i>Baorangia emileorum</i> (Barbier) Vizzini, Simonini & Gelardi	VU– Vulnerable, B1ab(iii, iv) + 2ab(iii,iv)
<i>Battarrea phalloides</i> (Dicks.) Pers.	VU– Vulnerable, B1ab(i,iii,iv)+2ab(i,iii,iv)
<i>Bovista paludosa</i> Lév	CR – Critically Endangered: C2a(i), D
<i>Butyriboletus regius</i> (Krombh.) D. Arora & J.L. Frank	VU–Vulnerable, C2a(i)
<i>Chlorophyllum agaricoides</i> (Czern.) Vellinga	VU– Vulnerable, B1ab(iii,iv) + 2ab(iii,iv)
<i>Cudonia circinans</i> (Pers.) Fr.	VU– Vulnerable, D1
<i>Daedaleopsis nitida</i> (Durieu & Mont.) Zmitr. & Malysheva	VU – Vulnerable, B1ab (iii,iv) + 2ab(iii,iv); D1
<i>Dentipellis fragilis</i> (Pers.) Donk	VU– Vulnerable, D1
<i>Disciseda bovista</i> (Klotzsch) Henn	EN– Endangered, B1ab(iii,iv) + 2ab(iii,iv)
<i>Galerina jaapii</i> A.H. Sm. & Singer	EN – Endangered, B1ab(iii) + 2ab(iii)
<i>Galerina sphagnorum</i> (Pers.) Kühner	CR – Critically Endangered, B1ab (i,iii,iv,v); C1
<i>Galerina tibiicystis</i> (G.F. Atk.) Kühner	CR – Critically Endangered, B1ab(i,iii,iv,v), C1

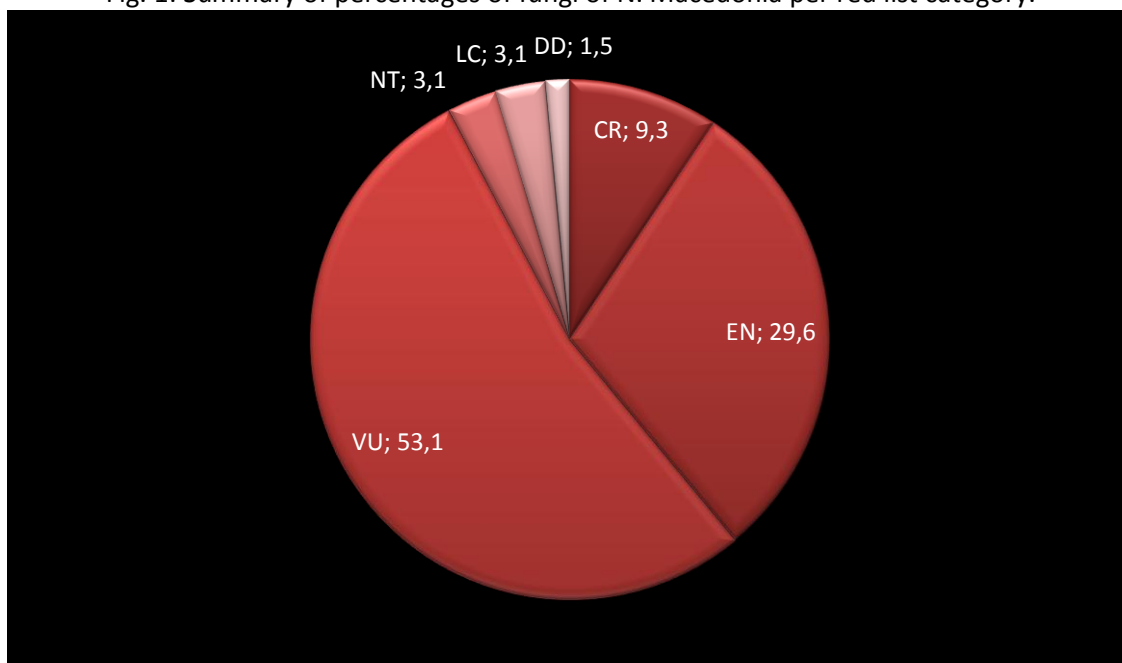
<i>Geastrum minimum</i> Schwein.	VU– Vulnerable, B1ab(i, iii, iv) + 2ab(i,iii,iv)
<i>Guepinia helvelloides</i> (DC.) Fr.	EN – Endangered, B1ab(iii) + 2ab(iii); D
<i>Gyrodon lividus</i> (Bull.) Sacc.	EN–Endangered, C2a(i)
<i>Gyromitra gigas</i> (Krombh.) Cooke	VU– Vulnerable, D1
<i>Helvella atra</i> J. König	VU– Vulnerable, B1ab(iii) + 2ab(iii); D1
<i>Hericium coralloides</i> (Scop.) Pers.	EN– Endangered, C2a(i)
<i>Hericium erinaceus</i> (Bull.) Pers.	EN– Endangered, C2a(i)
<i>Hortiboletus bubalinus</i> (Oolbekk. & Duin) L. Albert & Dima	DD – Data Deficient
<i>Hydnellum peckii</i> Banker	EN– Endangered, B1ab(iii,iv) + B2ab(iii,iv)
<i>Hygrocybe cantharellus</i> (Schwein.) Murrill	VU –Vulnerable, C1; D1
<i>Hygrocybe punicea</i> (Fr.) P. Kumm.	EN – Endangered, C2a(i)
<i>Hygrophorus marzuolus</i> (Fr.) Bres.	VU – Vulnerable, D1
<i>Hymenochaete cruenta</i> (Pers.) Donk	EN – Endangered, D
<i>Hyphoderma etrusiae</i> Bernicchia	CR – Critically Endangered, D
<i>Inocutis tamaricis</i> (Pat.) Fiasson & Niemelä	NT – Near Threatened, D1
<i>Lactarius omphaliformis</i> Romagn.	EN – Endangered, B1ab (iii,iv) + 2ab (iii,iv)
<i>Langermannia gigantea</i> (Batsch) Rostk.	LC – Least Concern
<i>Lenzitopsis oxycedri</i> Malençon & Bertault	EN – Endangered, D
<i>Leucopaxillus compactus</i> (P. Karst.) Neuhoff	VU – Vulnerable, D1
<i>Microstoma protractum</i> (Fr.) Kanouse	EN – Endangered, B1ab (iii,iv) + 2ab(iii,iv); D
<i>Mitrula paludosa</i>	EN – Endangered, B1ab(iii,iv) + 2ab (iii,iv); D
<i>Mycena juniperina</i> Aronsen	VU – Vulnerable, B1ab(i,iii,iv) + 2ab(i,iii,iv); D1
<i>Mycenastrum corium</i> (Guers.) Desv.	VU– Vulnerable, D1
<i>Myriostoma coliforme</i> (Dicks.) Corda	VU– Vulnerable, D1
<i>Neolentinus cyathiformis</i> (Schaeff.) Della Magg. & Trassin.	VU– Vulnerable, D1
<i>Perenniporia medulla-panis</i> (Jacq.) Donk	VU– Vulnerable, B1ab(iii,iv,v) + 2ab(iii,iv,v)
<i>Phylloporus pelletieri</i> (Lév.) Quél.	VU– Vulnerable, B1ab(i,iii,iv) + 2ab(i,iii,iv)
<i>Pilatotrampa ljubarskyi</i> (Pilát) Zmitrovich	VU– Vulnerable, D1
<i>Plectania melastoma</i> (Sowerby) Fucke	VU– Vulnerable, B1ab (iii) + 2ab(iii); D1
<i>Poronia punctata</i> (L.) Fr.	EN– Endangered, D
<i>Psilocybe serbica</i> M.M. Moser & E. Horak	VU– Vulnerable, D1
<i>Pyrofomes demidoffii</i> (Lév.) Kotl. & Pouzar	VU – Vulnerable, B1ab(iii,iv) + 2ab(iii,iv); D1
<i>Rubroboletus demonensis</i> Vasquez, Simonini, Svetash., Mikšič & Vizzini	VU – Vulnerable, D1
<i>Rubroboletus dupainii</i> (Boud.) Kuan Zhao & Zhu L. Yang	VU – Vulnerable, D1
<i>Rubroboletus rhodoxanthus</i> (Krombh.) Kuan Zhao & Zhu L. Yang	VU – Vulnerable, C2a(i)
<i>Rubroboletus satanas</i> (Lenz) Kuan Zhao & Zhu L. Yang	VU – Vulnerable, C2a(i)
<i>Sarcodon leucopus</i> (Pers.) Maas Geest. & Nannf.	EN – Endangered, D
<i>Sarcopeziza sicala</i> (Inzenga) Agnello, Loizides & P. Alvarado	EN– Endangered, B1ab(iii); 2ab(iii); D
<i>Sarcosphaera coronaria</i> (Jacq.) J. Schröt.	VU– Vulnerable, D1

<i>Skeletocutis odora</i> (Sacc.) Ginns	EN – Endangered, D
<i>Sparassis crispa</i> (Wulfen) Fr.	EN– Endangered: B1ab(i,iii,iv) + 2ab(i,iii,iv)
<i>Suillus americanus</i> (Peck) Snell	VU – Vulnerable, D1
<i>Tricholoma acerbum</i> (Bull.) Quél.	VU – Vulnerable, C2a(i)
<i>Tricholoma apium</i> Jul. Schäff.	VU– Vulnerable, D1
<i>Urnula craterium</i> (Schwein.) Fr.	VU– Vulnerable, D1
<i>Xeromphalina junipericola</i> G. Moreno & Heykoop	CR – Critically Endangered, D
<i>Zeus olympius</i> Minter & Diam.	CR – Critically Endangered, D

Table 2. Summary of numbers of N. Macedonia fungi per red list category.

IUCN Red List Categories	Fungi
Extinct (EX)	0
Extinct in the Wild (EW)	0
Critically Endangered (CR)	6
Endangered (EN)	19
Vulnerable (VU)	34
Near Threatened (NT)	2
Least Concern (LC)	2
DD – Data Deficient	1
TOTAL	64

Fig. 1: Summary of percentages of fungi of N. Macedonia per red list category.



As of Dec 2019, the global IUCN Red List of Threatened Species, the component dedicated to fungi, comprises 280 fungal species (<http://www.iucnredlist.org/>). Thirteen (13) of the 64 assessed Macedonian fungal species are enshrined in the IUCN Red List, as follows: *Alessioporus ichnusanus* (VU), *Amanita caesarea* (LC), *Bovista paludosa* (VU), *Hericium erinaceus* (LC), *Hygrocybe punicea* (VU), *Lenzitopsis oxycedri* (VU), *Poronia punctata* (LC), *Rubroboletus dupainii* (NT), *Rubroboletus rhodoxanthus* (NT), *Sarcodon leucopus* (NT), *Tricholoma acerbum* (VU), *Tricholoma apium* (VU), and *Xeromphalina junipericola* (VU).

MAJOR THREATS

In the assessment process of selected taxa, nearly all types of major IUCN threats were identified. The overarching threat is habitat loss or fragmentation, first and foremost by virtue of logging and wood harvesting or repurposing of land for commercial development. In practice, the silvicultural system applies clear-cutting in both oak and beech forests (Trajkov et al. 2016), the dominant forest associations in the country, resulting in bare lands and even-aged forests while old growth forests are in a state of decline, thus endangering the maintenance of stable fungus populations.

Tab. 3: Overview of the major threats affecting the assessed fungi species in compliance with IUCN's Threat Classification System.

1.	Residential & commercial development	
	1.1 Housing & urban areas	<i>Hericium erinaceus</i> , <i>Alessioporus ichnusanus</i> , <i>Hygrocybe cantharellus</i> , <i>Neolentinus cyathiformis</i> , <i>Sarcopeziza sicala</i> , <i>Geastrum minimum</i> , <i>Rubroboletus demonensis</i> , <i>Inocutis tamaricis</i>
	1.2 Commercial & industrial areas	<i>Myriostoma coliforme</i> , <i>Alessioporus ichnusanus</i>
	1.3 Tourism & recreation areas	<i>Hygrophorus marzuolus</i> , <i>Cudonia circinans</i> , <i>Guepinia helvelloides</i> , <i>Gyromitra gigas</i> , <i>Sarcosphaera crassa</i> , <i>Skeletocutis odora</i> , <i>Geastrum minimum</i> , <i>Langermannia gigantea</i> , <i>Phylloporus pelletieri</i> , <i>Plectania melastoma</i> , <i>Tricholoma apium</i> , <i>Urnula craterium</i> , <i>Psilocybe serbica</i>
2.	Agriculture & aquaculture	
	2.1 Annual & perennial non-timber crops	
	2.1.1 Shifting agriculture	<i>Inocutis tamaricis</i> , <i>Antrodia juniperina</i> , <i>Amanita caesarea</i> , <i>Hericium erinaceus</i> , <i>Inocutis tamaricis</i> , <i>Gyrodon lividus</i>

	2.1.2 Small-holder farming	<i>Chlorophyllum agaricoides</i> , <i>Hyphoderma etruriae</i> , <i>Mycena juniperina</i> , <i>Pyrofomes demmidoffii</i> , <i>Xeromphalina junipericola</i>
	2.1.3 Agro-industry farming	<i>Mycenastrum corium</i>
	2.1.4 Scale Unknown/Unrecorded	<i>Sarcopeziza sicula</i>
	2.2 Wood & pulp plantations	
	2.2.1 Small-holder plantations	<i>Microstoma protractum</i>
	2.2.2 Agro-industry plantations	<i>Helvella atra</i>
	2.2.3 Scale Unknown/Unrecorded	<i>Cudonia circinans</i>
	2.3 Livestock farming & ranching	
	2.3.1 Nomadic grazing	<i>Antrodia juniperina</i> , <i>Hyphoderma etruriae</i> , <i>Pyrofomes demmidoffii</i> , <i>Xeromphalina junipericola</i>
	2.3.2 Small-holder grazing, ranching or farming	<i>Disciseda bovista</i>
	2.3.3 Agro-industry grazing, ranching or farming	<i>Hygrocybe cantharellus</i>
3.	Energy Production & Mining	
	3.2 Mining & Quarrying	<i>Rubroboletus dupainii</i> , <i>Sarcodon leucopus</i> , <i>Leucopaxillus compactus</i>
4.	Transportation & service corridors	
	4.1 Roads & railroads	<i>Hygrophorus marzuolus</i> , <i>Skeletocutis odora</i>
5.	Biological resource use	
	5.2 Gathering terrestrial fungi	
	5.2.1 Intentional use (species being assessed is the target)	<i>Amanita caesarea</i> , <i>Herichium erinaceus</i> , <i>Alessioporus ichnusanus</i> , <i>Butyriboletus regius</i> , <i>Langermannia gigantea</i> , <i>Gyrodon lividus</i> , <i>Hygrophorus marzuolus</i> , <i>Sarcodon leucopus</i>
	5.2.2 Unintentional effects (species being assessed is not the target)	<i>Rubroboletus demonensis</i> , <i>Rubroboletus dupainii</i> , <i>Rubroboletus rhodoxanthus</i> , <i>Rubroboletus satanas</i>
	5.3 Logging & wood harvesting	
	5.3.3 Unintentional effects: subsistence/small scale (species being assessed is not the target)[harvest]	<i>Antrodia juniperina</i> , <i>Lenzitopsis oxycedri</i> , <i>Mycena juniperina</i> , <i>Pyrofomes demmidoffii</i> , <i>Xeromphalina junipericola</i> , <i>Leucopaxillus compactus</i>
	5.3.4 Unintentional effects: large scale (species being assessed is not the target)[harvest]	<i>Gyromitra gigas</i> , <i>Cudonia circinans</i> , <i>Myriostoma coliforme</i> , <i>Herichium coraloides</i> , <i>Herichium erinaceus</i> , <i>Suillus americanus</i> , <i>Tricholoma acerbum</i> , <i>Chlorophyllum agaricoides</i> , <i>Dentipellis fragilis</i> , <i>Guepinia helvelloides</i> , <i>Microstoma protractum</i> , <i>Pilatotrampa ljubarskyi</i> , <i>Rubroboletus dupainii</i> ,

		<i>Rubroboletus rhodoxanthus</i> , <i>Amanita caesarea</i> , <i>Gyrodon lividus</i> , <i>Leucopaxillus compactus</i> , <i>Phylloporus pelletieri</i> , <i>Plectania melastoma</i> , <i>Sparassis crispa</i>
	5.3.5 Motivation Unknown/Unrecorded	<i>Bovista paludosa</i> , <i>Chlorophyllum agaricoides</i> , <i>Hydnellum peckii</i> , <i>Neolentinus cyathiformis</i> , <i>Perenniporia medulla-panis</i> , <i>Sarcosphaera crassa</i> , <i>Butyriboletus regius</i> , <i>Rubroboletus satanas</i> , <i>Psilocybe serbica</i> , <i>Mitrula paludosa</i>
6.	Human intrusions & disturbance	
	6.1 Recreational activities	<i>Hygrophorus marzuolus</i> , <i>Battarrea phalloides</i> , <i>Alessioporus ichnusanus</i> , <i>Guepinia helvelloides</i> , <i>Lenzitopsis oxycedri</i> , <i>Microstoma protractum</i> , <i>Suillus americanus</i> , <i>Hygrocybe punicea</i> , <i>Leucopaxillus compactus</i> , <i>Phylloporus pelletieri</i> , <i>Plectania melastoma</i> , <i>Psilocybe serbica</i>
	6.3 Work & other activities	<i>Battarrea phalloides</i> , <i>Disciseda bovista</i> , <i>Hortiboletus bubalinus</i>
7.	Natural system modifications	
	7.1 Fire & fire suppression	
	7.1.1 Increase in fire frequency/intensity	<i>Hymenochaete cruenta</i> , <i>Daedaleopsis nitida</i> , <i>Dentipellis fragilis</i> , <i>Amanita caesarea</i> , <i>Amanita curtipes</i> , <i>Butyriboletus regius</i> , <i>Rubroboletus demonensis</i> , <i>Rubroboletus dupainii</i> , <i>Rubroboletus rhodoxanthus</i> , <i>Rubroboletus satanas</i> , <i>Tricholoma acerbum</i> , <i>Hericium coraloides</i> , <i>Hericium erinaceus</i> , <i>Sarcodon leucopus</i> , <i>Leucopaxillus compactus</i> , <i>Phylloporus pelletieri</i> , <i>Sparassis crispa</i> , <i>Hydnellum peckii</i> , <i>Gyromitra gigas</i> , <i>Psilocybe serbica</i>
	7.1.3 Trend Unknown/Unrecorded	<i>Baorangia emileorum</i> , <i>Mycena juniperina</i> , <i>Plectania melastoma</i> , <i>Tricholoma apium</i> , <i>Urnula craterium</i>
	7.2 Dams & water management/use	<i>Bovista paludosa</i>
	7.2.3 Abstraction of Surface Water (agricultural use)	<i>Gyrodon lividus</i>
	7.2.4 Abstraction of surface water (unknown use)	<i>Galerina tibiicystis</i> , <i>Lactarius omphaliformis</i> , <i>Galerina jaapii</i> , <i>Mitrula paludosa</i>
	7.3 Other ecosystem modifications	<i>Galerina sphagnorum</i> , <i>Langermannia gigantea</i> , <i>Aspropaxillus giganteus</i> , <i>Hygrocybe punicea</i>

8.	Invasive & other problematic species, genes & diseases	
	8.2 Problematic Native Species/Diseases	<i>Butyriboletus regius</i> , <i>Rubroboletus demonensis</i> , <i>Rubroboletus dupainii</i> , <i>Rubroboletus rhodoxanthus</i> , <i>Rubroboletus satanas</i> , <i>Tricholoma acerbum</i> , <i>Hericium coralloides</i> , <i>Hericium erina-ceus</i> , <i>Suillus americanus</i> , <i>Sarcodon leucopus</i> , <i>Leucopaxillus compactus</i>
9.	Pollution	
	9.1 Domestic & urban waste water	<i>Bovista paludosa</i> , <i>Chlorophyllum agaricoideis</i> , <i>Mycenastrum corium</i>
	9.3 Agricultural & forestry effluents	<i>Galerina tibiicystis</i>
	9.3.1. Nutrient loads	<i>Hygrocybe cantharellus</i> , <i>Lactarius omphaliformis</i> , <i>Galerina jaapii</i> , <i>Galerina sphagnorum</i> , <i>Mitrula paludosa</i>
	9.3.2 Soil Erosion, Sedimentation	<i>Bovista paludosa</i> , <i>Galerina tibiicystis</i> , <i>Galerina jaapii</i> , <i>Butyriboletus regius</i> , <i>Mitrula paludosa</i>
	9.3.3 Herbicides & pesticides	<i>Poronia punctata</i> , <i>Hygrocybe cantharellus</i>
	9.3.4 Type unknown / unrecorded	<i>Helvella atra</i>
	9.4 Garbage & solid waste	<i>Disciseda bovista</i>
	9.5 Air-borne pollutants	<i>Bovista paludosa</i> , <i>Galerina tibiicystis</i> , <i>Galerina jaapii</i> , <i>Galerina sphagnorum</i> , <i>Mitrula paludosa</i>
11.	Climate change & severe weather	
	11.1 Habitat shifting & alteration	<i>Sarcodon leucopus</i> , <i>Bovista paludosa</i> , <i>Daedaleopsis nitida</i> , <i>Disciseda bovista</i>
	11.2 Droughts	<i>Sparassis crispa</i> , <i>Amanita caesarea</i> , <i>Amanita curtipes</i> , <i>Butyriboletus regius</i> , <i>Rubroboletus demonensis</i> , <i>Rubroboletus dupainii</i> , <i>Rubroboletus rhodoxanthus</i> , <i>Rubroboletus satanas</i> , <i>Tricholoma acerbum</i> , <i>Sarcodon leucopus</i> , <i>Langermannia gigantea</i>
	11.3 Temperature extremes	<i>Battarrea phalloides</i> , <i>Sarcodon leucopus</i> , <i>Baorangia emileorum</i> , <i>Cudonia circinans</i> , <i>Lenzites oxycedri</i> , <i>Pilatotrampa ljubarskyi</i> , <i>Zeus olympius</i> , <i>Rubroboletus demonensis</i>
12.	Other	
	12.1 Reduced animal grazing	<i>Poronia punctata</i> , <i>Myriostoma coliforme</i> , <i>Hygrocybe cantharellus</i>

POPULATION TRENDS

Population trends are arguably pivotal in assessment of the red list status of species. According to the summarised data germane to the populations of the red-listed fungi of N. Macedonia, 60.9 % are declining, 25 % of the populations are stable, and 14 % are unknown.

Table 4: Population trends of the red-listed fungi of N. Macedonia.

Species	Declining	Stable	Unknown
<i>Alessioporus ichnusanus</i>	*		
<i>Amanita caesarea</i>		*	
<i>Amanita curtipes</i>		*	
<i>Antrodia juniperina</i>	*		
<i>Aspropaxillus giganteus</i>			*
<i>Baorangia emileorum</i>		*	
<i>Battarrea phalloides</i>	*		
<i>Bovista paludosa</i>	*		
<i>Butyriboletus regius</i>	*		
<i>Chlorophyllum agaricoides</i>		*	
<i>Cudonia circinans</i>	*		
<i>Daedaleopsis nitida</i>		*	
<i>Dentipellis fragilis</i>	*		
<i>Disciseda bovista</i>	*		
<i>Galerina jaapii</i>	*		
<i>Galerina sphagnum</i>	*		
<i>Galerina tibiicystis</i>	*		
<i>Geastrum minimum</i>	*		
<i>Guepinia helvelloides</i>	*		
<i>Gyrodon lividus</i>	*		
<i>Gyromitra gigas</i>	*		
<i>Helvella atra</i>		*	
<i>Hericium coralloides</i>	*		
<i>Hericium erinaceus</i>	*		
<i>Hortiboletus bubalinus</i>			*
<i>Hydnellum peckii</i>	*		
<i>Hygrocybe cantharellus</i>	*		

<i>Hygrocybe punicea</i>	*		
<i>Hygrophorus marzuolus</i>			*
<i>Hymenochaete cruenta</i>			*
<i>Hyphoderma etruscae</i>	*		
<i>Inonotus tamaricis</i>			*
<i>Lactarius omphaliformis</i>	*		
<i>Langermannia gigantea</i>		*	
<i>Lenzites oxycedri</i>		*	
<i>Leucopaxillus compactus</i>			*
<i>Microstoma protractum</i>	*		
<i>Mitrula paludosa</i>	*		
<i>Mycena juniperina</i>	*		
<i>Mycenastrum corium</i>	*		
<i>Myriostoma coliforme</i>		*	
<i>Neolentinus cyathiformis</i>	*		
<i>Perenniporia medulla-panis</i>	*		
<i>Phylloporus pelletieri</i>		*	
<i>Pilatotrama ljubarskyi</i>	*		
<i>Plectania melastoma</i>		*	
<i>Poronia punctata</i>	*		
<i>Psilocybe serbica</i>		*	
<i>Pyrofomes demidoffii</i>	*		
<i>Rubroboletus demonensis</i>			*
<i>Rubroboletus dupainii</i>			*
<i>Rubroboletus rhodoxanthus</i>	*		
<i>Rubroboletus satanas</i>	*		
<i>Sarcodon leucopus</i>			*
<i>Sarcopeziza sicula</i>	*		
<i>Sarcosphaera crassa</i>	*		
<i>Skeletocutis odora</i>	*		
<i>Sparassis crispa</i>	*		
<i>Suillus americanus</i>		*	
<i>Tricholoma acerbum</i>	*		
<i>Tricholoma apium</i>		*	
<i>Urnula craterium</i>		*	

<i>Xeromphalina junipericola</i>	*		
<i>Zeus olympius</i>		*	
TOTAL	39	16	9

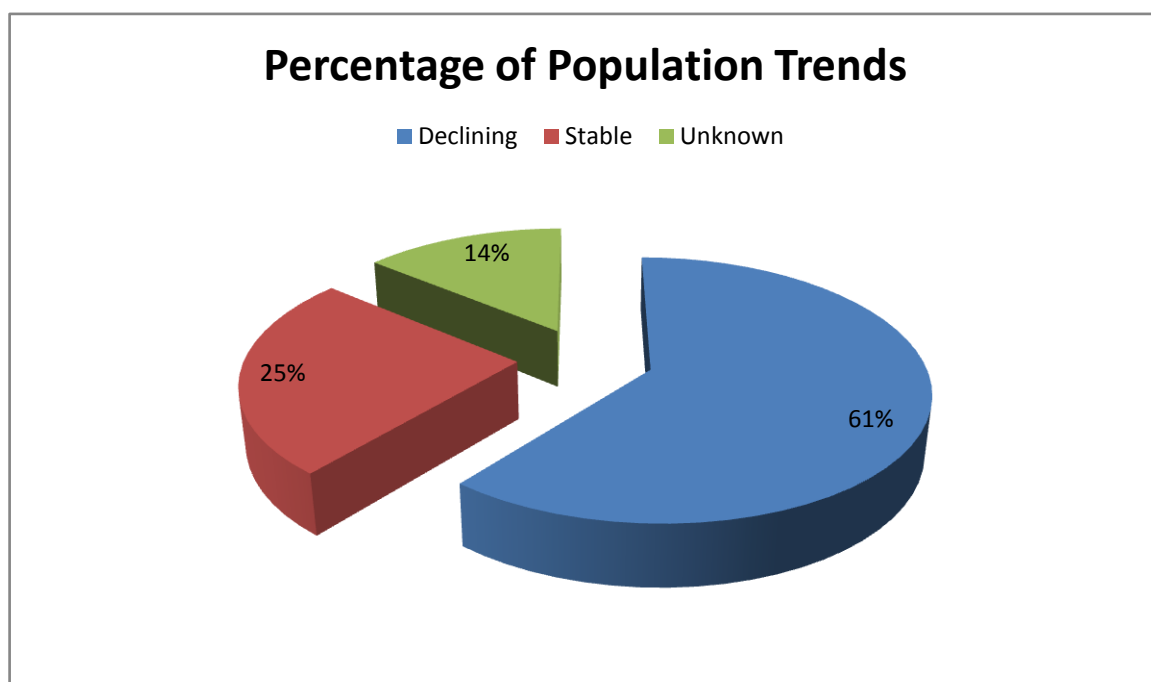


Fig. 2: Percentage of population trends of red-listed fungi in N. Macedonia.

SPATIAL DISTRIBUTION PATTERNS

The distribution maps of the red-listed fungal species have been generated by importing the coordinates of the observation sites in Google Earth.

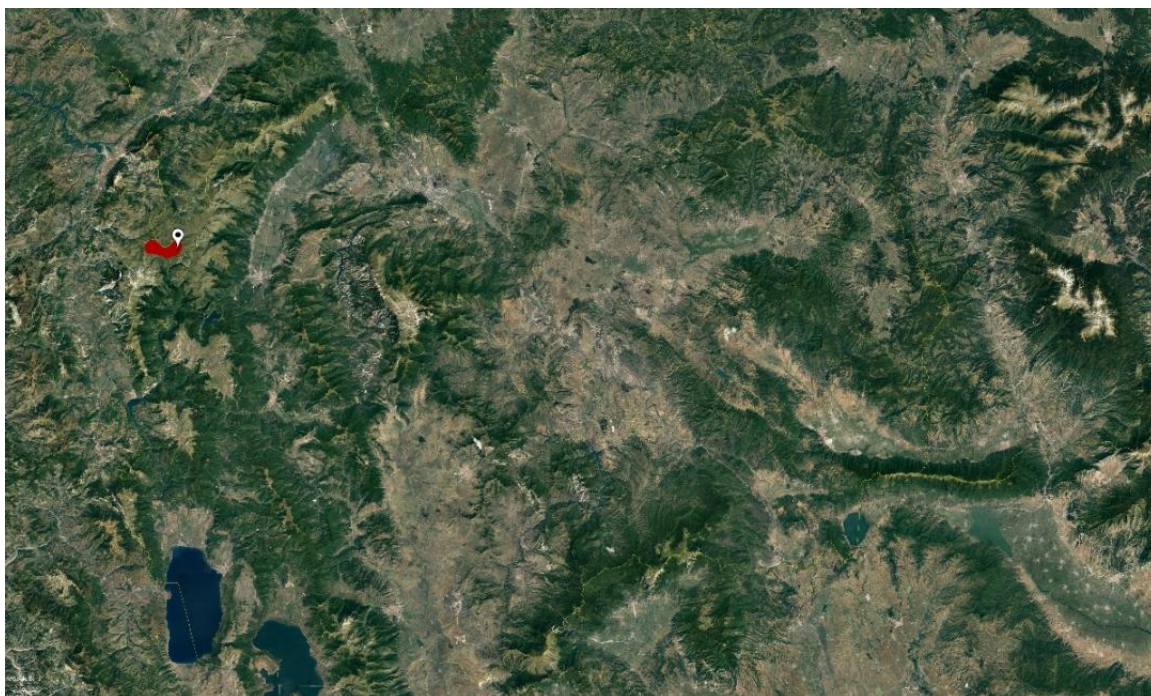


Fig. 3: Map of distribution of a critically endangered species - *Galerina sphagnorum*. It occurs in one of the most vulnerable habitats – peat bogs and mires.

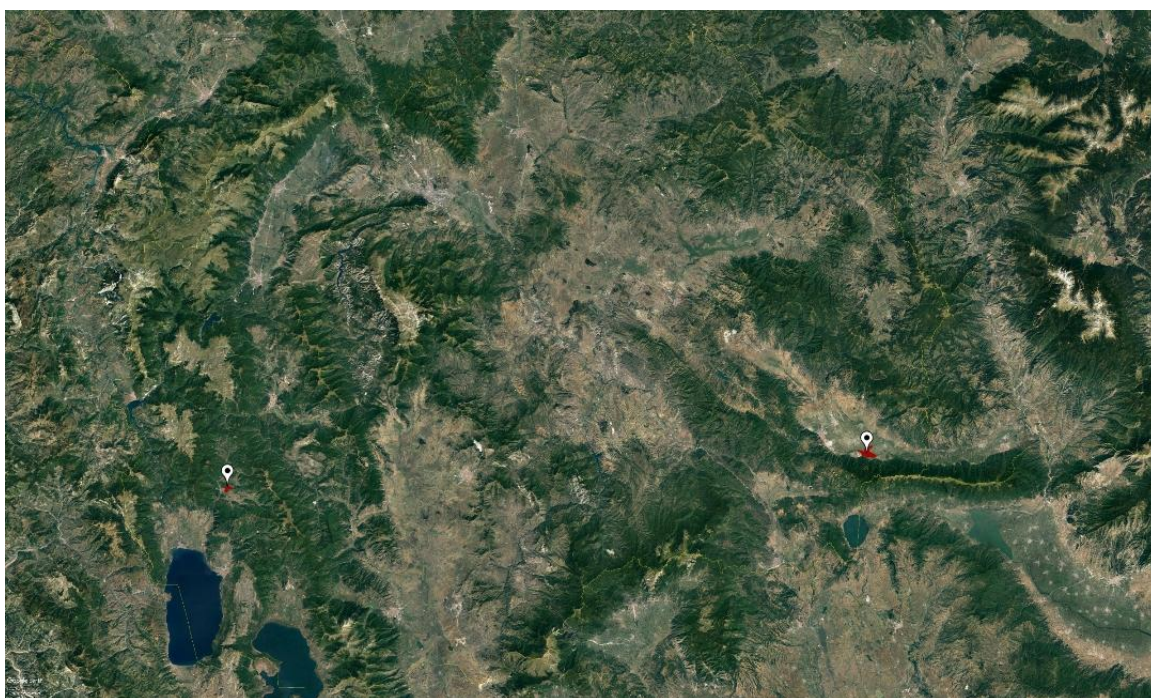


Fig. 4: Map of distribution of an endangered species - *Lactarius omphaliformis*; found in the only sites with well-developed alder communities in wet habitats, which are among the most declining habitats in the country.

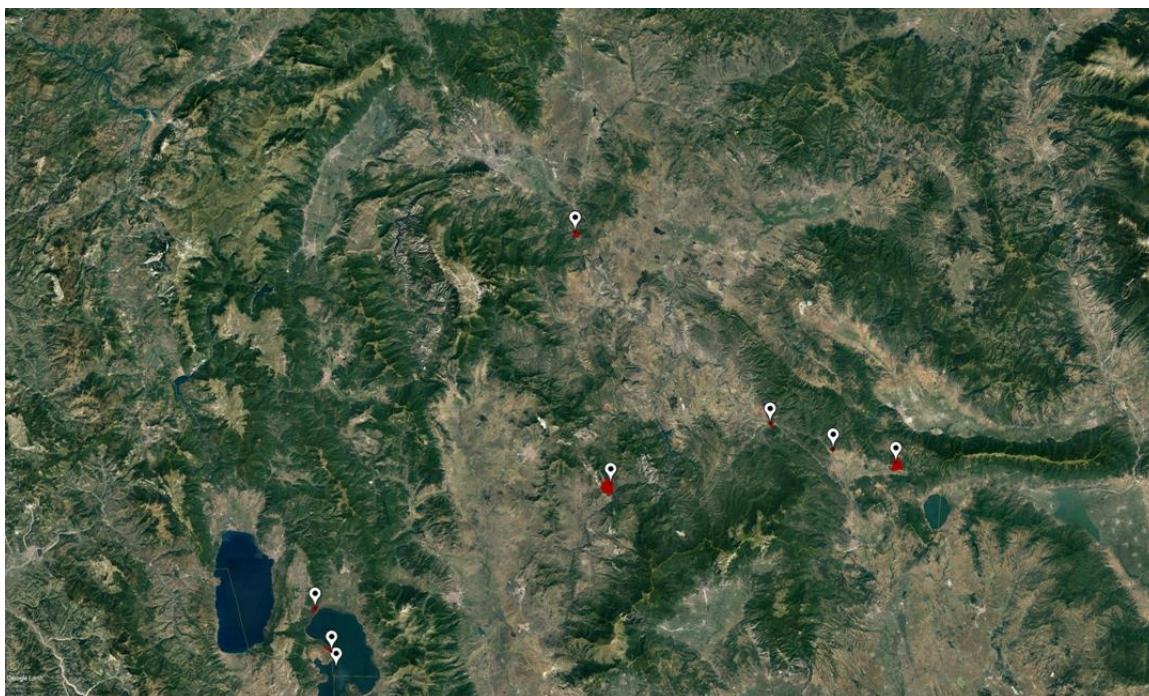


Fig. 5: Map of distribution of a vulnerable species - *Pyrofomes demidoffii*, occurring in well-developed Grecian juniper forests, a priority habitat in the Habitats Directive.

CONSERVATION ACTION

Four percent of fungi identified in N. Macedonia are included in the national List of Protected and Strictly Protected Species while 3% of lichenicolous fungi are listed (State Statistics Office, 2015). The National Strategy for Nature Protection with Action Plan (2017-2027) and the National Biodiversity Strategy and Action Plan (2018-2023) embrace the national red list objectives in N. Macedonia, fungi red-listing being one of them. The fungi list objective is also acknowledged in the national legislation. Specifically, the Law on Nature Protection stipulates the development of national red lists by adhering to the IUCN Red List methodology (Official Gazette 67/04). In the Strategy for Biodiversity of the Republic of Macedonia (Ministry of Environment and Physical Planning, 2018), within the framework of the target 'establish the level of threats of wild species, prevent reduction of populations and extinction of affected species', the following conservation actions are prioritised:

- 12.1 Elaboration of the red lists and red books;
- 12.2 Revision of the List of Strictly Protected and Protected Wild Species;
- 12.3 Amendments to the legislation to add an obligation for preparation of action plans on key species and habitats, invasive species, etc.
- 12.4 Preparation and implementation of action plans for conservation of threatened species identified in red lists.

Policy Recommendations

- Initiating a formal procedure for enacting an official National Red List of Fungi;
- Incorporation of the pooled red-listing data into the Law on Nature Conservation;
- Preparation of a Rulebook on Strictly Protected and Protected Wild Fungal Species by the Ministry of Environment and Physical Planning based on the Official Fungi Red List;
- Enforcement of the current fungal conservation legislation;
- Inclusion of specific species in the National Biodiversity Monitoring System;
- Implementation of measures for conservation of key fungal habitats by prevention of their degradation or fragmentation.
- Effective measures to prevent illegal logging particularly in view of the fact that some of the species are strictly bound to a single tree host as an ectomycorrhizal partner;
- In silvicultural management, clear-cutting as a practise must be abandoned to maintain forest stands with different age class, thereby creating a suitable habitat for fungi. Reforestation with alien species should also be abandoned.
- Mainstreaming the fungi assessment data into the NATURA 2000 ecological network in the country;
- Issuance of permits on edible fungi to trading firms with strict requirements so as to avert destructive methods of fungi picking;
- Issuance of individual collection permits to educated foragers related to the economically important species from the pending Official Red List of Fungi.

Conservation of Species and Habitats Recommendations

- Development and implementation of conservation measures for the red-listed fungal taxa.
- Protection of old host trees as the key conservation action for species protection.
- Identification of the most affected habitats in terms of threats to fungi and preparation of action plans for their conservation.
- Raising public and stakeholder awareness of the protected fungal species, and the significance of conservation of both species and their habitats by facilitation of permanent access to relevant information;
- Proposing new species with global conservation interest for global fungal red list assessment through the Global Fungal Red List Initiative;
- Publishing the Macedonian National Red List in the European Council for the Conservation of Fungi Newsletter and the European Mycological Association's Electronic Newsletter;
- Restriction on exploitation of commercial fungi in certain periods of the year to preserve part of fruiting bodies with the purpose of allowing spore dispersal.

Future Research

- Devising effective monitoring tools for specific fungi species seeking to comprehend population trend and range;
- Regular monitoring of ascertained sites, accompanied by field research at potential sites aiming to explore distribution and dynamics of occurrence.
- Interpretation of species status by means of reinforced understanding of species biology and ecology.
- Assessment of forest health and, occasionally, undertaking core measures to preserve the health of forest stands.
- Digitising and regular updating of forest inventories and forestry plans along with elaboration of a habitat map.

In conclusion, the proposed National Red List of Fungi of N. Macedonia comprises 64 species, and it will be available to the relevant authorities in charge of conservation and the pertinent biodiversity programmes. Nevertheless, the Red List is an open working document in view of the expectations that new species are expected to be identified during future research, alongside the potential changes in the extent of harvesting important edible fungal species by local population.

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