

Received: June 24, 2022
Accepted: October 24, 2022

ISSN 1857–9027
e-ISSN 1857–9949
UDC:582.28.063.6:502.172(497.7)“2021”
DOI: 10.20903/masa/nmbosci.2021.42.9

Original scientific paper

2021 NATIONAL RED LIST OF FUNGI: FOCUSING ON CRITICALLY ENDANGERED SPECIES

Mitko Karadelev*, Slavica Tofilovska, Katerina Rusevska

Institute of Biology, Faculty of Natural Sciences and Mathematics,
Ss Cyril and Methodius University in Skopje, RN Macedonia

*e-mail: mitkok@pmf.ukim.mk

The National Red List plays a crucial role in the conservation of fungi, considering the significant threats they face, such as habitat loss and fragmentation, decline in symbiotic hosts, overexploitation, pollution, and climate change. The importance of protecting fungi is evident, and although unofficial red lists were created in the past (2000 and 2010), the new National Red List of Fungi of North Macedonia holds official status. This document includes a total of 64 species, each assigned to specific categories. Among them, six fungal species are classified as Critically Endangered (CR), nineteen as Endangered (EN), thirty-four as Vulnerable (VU), two as Near Threatened (NT), two as Least Concern (LC), and one species is categorized as Data Deficient. The majority of the listed taxa (fifty-three) belong to the phylum Basidiomycota, while ten taxa are associated with the phylum Ascomycota. In this article, we will focus on the Critically Endangered species, which are as follows: *Bovista paludosa* Lév, *Galerina sphagnorum* (Pers.) Kühner, *Galerina tibiicystis* (G.F. Atk.) Kühner, *Hyphoderma etruriae* Bernicchia, *Xeromphalina junipericola* G. Moreno & Heykoop, and *Zeus olympius* Minter & Diam.

Key words: IUCN Red List, fungi conservation, North Macedonia

INTRODUCTION

North Macedonia, known as a biodiversity hot-spot, exhibits a remarkable fungal diversity. The earliest publications on fungal diversity in North Macedonia primarily date back to the 1930s, but over the past three decades, there has been a notable increase in research focusing on fungal diversity and distribution. A significant milestone in the comprehensive and systematic study of fungal diversity across the entire country was the establishment of the Mycological Laboratory at the Faculty of Natural Sciences in Skopje. This endeavor resulted in the discovery of numerous new taxa for the national inventory. Although new species continue to be discovered in the country, the current number of macro fungi species exceeds 2,600 [1, 2]. Additionally, two species, *Astraeus macedonicus* Rusevska, Karadelev, Telleria & M.P. Martín [3] and *Clitopilus*

abprunulus S.P. Jian, M. Karadelev & Zhu I. Yang [4], are newly described to science. The Macedonian Collection of Fungi (MCF) at the Faculty of Natural Sciences in Skopje houses approximately 25,000 dry specimens, representing around 4,000 different species. These specimens are digitized in the MACFUNGI database, which contains information on 37,000 collected specimens, representing 5,000 various species from Macedonia, the Balkans, and beyond. Distribution maps of critically endangered fungal species have also been published [5].

Regarding fungal conservation, an important initiative was undertaken by Karadelev [6], who prepared a Preliminary Red List of Fungi of Macedonia, comprising 67 species exclusively belonging to the class Basidiomycetes. The data from this list was utilized to generate an Official List of Strictly Protected and Protected Wild Species, which was published in the Official Gazette of the Republic of

Macedonia in 2011. However, in order to update the list, Karadelev and Rusevska [7] subsequently published an appendix to the red list of fungi, incorporating 213 species of Ascomycota and Basidiomycota. This updated list adhered to the rigorous criteria and categories of the IUCN Red List. Nevertheless, the latter publication lacked detailed descriptions of the conservation status for each species.

With the advancement of fungal research in North Macedonia, new insights have emerged regarding the distribution of macromycetes within the country. Consequently, it became imperative to conduct a revision of the Red List of Fungi of Macedonia. Drawing upon the newly acquired data on the distribution of macro fungi, adjustments have been made to the IUCN categories for several species, and new species have been assigned their respective categories. The entire list has undergone a comprehensive review, focusing particularly on the section pertaining to endangered species in the higher categories (Vulnerable, Endangered, and Critically Endangered). A total of 64 fungal species recorded in North Macedonia have now been assessed, aiming to determine their national conservation status in accordance with the Guidelines for Using the IUCN Red List Categories and Criteria [15].

METHODOLOGY

The development of the proposed National Red List of Fungi, which encompasses 64 taxa, relied on various sources of information. These sources included field research findings, published and unpublished species records, specimen collections, research notes, and contributions from other individual fungi collectors. All essential data were compiled to enable the final assessment of each species, taking into account the relevant IUCN criteria.

These criteria encompassed aspects such as distribution range, population trends, habitat and ecology, threats, and utilization and trade. The assessment process was carried out in three distinct stages, outlined as follows:

Pre-assessment

The research team conducted a thorough review of data from various literature sources, as well as data obtained from the Macedonian Collection of Fungi (MCF) and the MACFUNGI database, both housed at the Mycological Laboratory within the Faculty of Natural Sciences and Mathematics in Skopje. The unofficial Red List of Fungi for North Macedonia [7] was also carefully examined. In or-

der to gather mycological specimens and facilitate laboratory analyses, field research was carried out, particularly for species with limited available data. The field research encompassed diverse geographical locations with varying climates, vegetation types, and substrates, including both deciduous and coniferous trees. Various habitats were explored, such as Greek juniper forests, beech forests, spruce forests, Macedonian pine forests, Bosnian pine forests, oak forests, as well as national parks, nature monuments, pristine forests, and other protected areas. Field activities took place during spring, summer, and especially autumn, which is the most conducive season for fungal growth. For species identification, standard methods were employed, including microscopy, application of reagents, and consultation of specialized identification books.

Assessment

The assessment process began with a desktop analysis of the species, following the IUCN criteria. The taxa were evaluated according to the IUCN Guidelines, specifically version 1.1 [15]. The members of the assessment team underwent prior training to utilize the Species Information Service (SIS), which is the IUCN's web application designed for conducting, managing, and storing species assessments for the IUCN Red List. SIS employs a standardized data format for assessments, ensuring consistency in classification systems and maintaining taxonomic integrity. In categorizing the species according to IUCN criteria, we also took into consideration the experiences of neighboring countries, certain European countries, and the fungi section of the IUCN Red List of Threatened Species [16].

All available data were meticulously analyzed, leading to the assignment of the appropriate category for each fungal species. The species taxonomy adheres to the latest nomenclature provided by Index Fungorum [17] and the MycoBank Database [18].

Review

The assessments of all fungal species underwent a rigorous review process by multiple independent international mycological experts. Their feedback, remarks, and recommendations were carefully considered and integrated into the assessments. Following this comprehensive review, the assessments were finalized. The red-listing data were then entered into the global Species Information Service (SIS) provided by the IUCN, accessible at <https://www.iucnredlist.org/assessment/sis>. Subse-

quently, the data was transferred to the Macedonian National Red List website, hosted under the Ministry of Environment and Physical Planning, available at <http://redlist.moep.gov.mk/>. This website serves as the official platform for the Macedonian National Red List.

RESULTS AND DISCUSSION

The threat status of the sixty-four (64) assessed taxa is rendered in Table 1.

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

<i>Alessioporus ichnusanus</i> (Alessio, Galli & Littini) Gelardi, Viz- zini & 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 & Ryvar- den	VU – Vulnerable, B1ab(i,iii,iv); D1
<i>Aspropaxillus giganteus</i> (Sowerby) Kühner & Maire	NT – Near Threatened, D1
<i>Baorangia emileorum</i> (Barbier) Vizzini, Simonin i& Gelardi	VU – Vulnerable, B1ab(i, iii, iv)
<i>Battarrea phalloides</i> (Dicks.) Pers.	VU – Vulnerable, B1ab(i, iii, iv)
<i>Bovista paludosa</i> Lé- v	CR – Critically Endangered: C2a(i), D
<i>Butyriboletus sregius</i> (Krombh.) D. Arora & J.L. Frank	VU – Vulnerable, C2a(i)
<i>Chlorophyllum agaricoides</i> (Czern.) Vellinga	VU – Vulnerable, B2ab(iii,iv)
<i>Cudonia circinans</i> (Pers.) Fr.	VU – Vulnerable, D1
<i>Daedaleopsis nitida</i> (Durieu & Mont.) Zmitr. & Malysheva	VU – Vulnerable, B1ab (I,iii,iv); D1
<i>Dentipellis fragilis</i> (Pers.) Donk	VU – Vulnerable, D1
<i>Disciseda bovista</i> (Klotzsch) Henn	EN – Endangered, B1ab(iii) + 2ab(ii,iii,iv)
<i>Galerina jaapii</i> A.H. Sm. & Singer	EN – Endangered, B1ab(iii) + B2ab(i,ii,iv), D
<i>Galerina sphagnorum</i> (Pers.) Kühner	CR – Critically Endangered, B1ab (iii); C1
<i>Galerina tibiicystis</i> (G.F. Atk.) Kühner	CR – Critically Endangered, B1ab(iii), C1
<i>Geastrum minimum</i> Schwein.	VU – Vulnerable, B1ab(i, iii, iv, v)
<i>Guepinia helvelloides</i> (DC.) Fr.	EN – Endangered, B1ab(iii); B2ab(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); 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> (Oolbakk. & Duin) L. Albert & Dima	DD – Data Deficient
<i>Hydnellum peckii</i> Banker	EN – Endangered, B1ab(iii) + B2ab(i,ii,iv)
<i>Hygrocybe cantharellus</i> (Schwein.) Murrill	VU – Vulnerable, 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 etrusciae</i> Bernicchia	CR – Critically Endangered, B2ab(iii); D
<i>Inocutis tamaricis</i> (Pat.) Fiasson & Niemelä	NT – Near Threatened, D1
<i>Lactarius omphaliformis</i> Romagn.	EN – Endangered, B1ab (i,iii,iv); B2ab (ii,iii,iv)
<i>Langermannia gigantea</i> (Batsch) Rostk.	LC - Least Concern
<i>Lenzites 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 (i,iv); B2ab(ii,iv); D
<i>Mitrella paludosa</i>	EN – Endangered, B1ab(i,iii,iv); B2ab (ii,iii,iv); D
<i>Mycena juniperina</i> Aronsen	VU – Vulnerable, B1ab(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, B1b(iii,iv,v)
<i>Phylloporus pelletieri</i> (Lév.) Quéf.	VU – Vulnerable, B1ab(i,iii,iv)
<i>Pilatotrampa ljubarskyi</i> (Pilát) Zmitrovich	VU – Vulnerable, D1
<i>Plectania melastoma</i> (Sowerby) Fucke	VU – Vulnerable, B1ab (i,iii,iv); D1
<i>Poronia punctata</i> (L.) Fr.	EN – Endangered, C2a; D
<i>Psilocybe serbica</i> M.M. Moser & E. Horak	VU – Vulnerable, D1
<i>Pyrofomes demidoffii</i> (Lév.) Kotl. & Pouzar	VU – Vulnerable, B1ab(i,iii); D1
<i>Rubroboletus demonensis</i> Vasquez, Simonini, Svetash., Mikšik & 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 sicula</i> (Inzenga) Agnello, Loizides & P. Alvarado	EN – Endangered, B2ab(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); B2ab(ii,iii,iv)
<i>Suillus americanus</i> (Peck) Snell	VU – Vulnerable, B1ab(iii)+2ab(iii); D1
<i>Tricholoma acerbum</i> (Bull.) Quéf.	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, B2ab(iii); D
<i>Zeus olympius</i> Minter & Diam.	CR – Critically Endangered, D

The summary of the threat status, as shown in Table 2, is as follows: out of the identified fungus species, six species are classified as Critically Endangered (9.3 %), nineteen species are classified as Endangered (29.6 %), thirty-four species are classified as Vulnerable (53.1 %), two species are classified as Near Threatened (3.1 %), two species are classified as Least Concern (3.1 %), and one species has insufficient data to determine its status (1.5 %).

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

The majority of the taxa, consisting of fifty-three species (82.8 %), belong to the phylum Basidiomycota, while eleven species (17.1 %) are affiliated with the phylum Ascomycota.

The Critically Endangered species identified are as follows: *Bovista paludosa* Lév, *Galerina sphagnorum* (Pers.) Kühner, *Galerina tibiicystis* (G.F. Atk.) Kühner, *Hyphoderma etruriae* Bernicchia, *Xeromphalina junipericola* G. Moreno & Heykoop, and *Zeus olympius* Minter & Diam.

Bovista paludosa (Figure 1) is primarily found in wet habitats, particularly in high alpine peat bogs situated above 1,800 meters in altitude [8]. It is a species that thrives in association with mosses and is predominantly found in one of the most vulnerable and diminishing habitats – peat bogs and mires. These habitats face significant threats due to modifications in the hydrological system, pollution from surface water and air (eutrophication), natural succession and erosion, as well as forest management practices. In Macedonia, *Bovista paludosa* has been discovered in Sar Mountain (two sites) and Korab Mountain (a single site), specifically in wet peat bogs with *Sphagnum*. The population

size is small, and there is an expected decline in population trend.

The situation is similar for two *Galerina* species, *G. sphagnorum* (Figure 1) and *G. tibiicystis*, both of which have been found in wet habitats [5, 7]. Currently, only one site has been documented in the western part of the country, specifically in peat bogs with *Sphagnum* in Sar Mountain (Lukovo Pole) at an altitude of approximately 1,700 meters.

Considering the limited extent of peat bogs in North Macedonia, which serve as the primary habitats for these species, as well as the importance of peat bogs in the country and throughout Europe, it is crucial to protect these three species by conserving their habitat and preventing the degradation of sites where they currently occur or have the potential to occur.

The species *Hyphoderma etruariae* and *Xeromphalina junipericola* are found only in a single

location, specifically in Greek juniper forests in the southeastern part of the country (Figure 2). *H. etruariae* is a wood-inhabiting fungus that thrives on old shrubs of juniper species, growing in hollows created by old wounds on trunks and large branches. It is endemic to southern Europe and has been recorded from only ten locations in two countries, Italy and North Macedonia [9, 10]. *X. junipericola* is an extremely rare species known only from North Macedonia, Spain, and Turkey [11, 12]. In North Macedonia, the population size is very small, with only two individuals observed.

The collection site is facing threats due to extensive exploitation of juniper trees by local inhabitants. The strong anthropogenic pressure on the habitat poses risks to habitat quality, area of occupancy, and the number of mature individuals. Consequently, the species is critically endangered due to the high risk of decline resulting from these factors.



Figure 1. *Bovista paludosa* (left) and *Galerina sphagnorum* (right), a critically endangered species from high alpine peat bogs.
Photo: Matthias Theiss



Figure 2. *Hyphoderma etruariae* (left) and *Xeromphalina junipericola* (right), a critically endangered species from Greek juniper forest in the south-eastern part of the country.
Photo: Mitko Karadelev

The species *Zeus olympius* (Figure 3) primarily grows on dead stems of young trees, twigs, and branches of Bosnian pine (*Pinus heldreichii*). It is known to occur in Bulgaria (Pirin Mountain, Slavyanka Mountain, Vitosa Mountain) and in Greece (Olympus Mountain, Pindus Mountain) [13,

14]. In North Macedonia, it has been observed at only one location, specifically in Galicica National Park, with a small population and a limited area of occupancy. The fungus appears to be restricted to the Bosnian pine and has never been found growing on any other pine species.



Figure 3. *Zeus olympius* from dead twigs and branches of Bosnian pine. Photo: Mitko Karadelev

CONCLUSION

The official National Red List of Fungi, consisting of 64 species, has been compiled and made accessible to the relevant conservation authorities and biodiversity programs. The list was created based on field research findings, published and unpublished species records, research notes, and information obtained from individual fungi collectors. All available data were thoroughly analysed, leading to the assignment of appropriate conservation categories for each fungal species. The red-listing data have been stored in the global Species Information Service (SIS) of the IUCN and subsequently transferred to the Macedonian National Red List website, overseen by the Ministry of Environment and Physical Planning. The summary of the threat status is as follows: six species are categorized as Critically Endangered (CR), nineteen as Endangered (EN), thirty-four as Vulnerable (VU), two as Near Threatened (NT), two as Least Concern (LC), and one species is classified as Data Deficient. The majority of the taxa (fifty-three) belong to the phylum Basidiomycota, while ten taxa are associated with the phylum Ascomycota. However, it is important to note that the Red List remains a dynamic document as new species may be discovered in future research,

and there may be changes in the harvesting practices of important edible fungi by the local population.

Acknowledgement: We would like to express our gratitude to the European Bank for Reconstruction and Development for their support in the red-listing project for fungi through the "Biodiversity Capacity Building Programme: Promoting Good International Practices in Macedonia." This project was managed by Hardner & Gullison Associates from the USA. We also extend our sincere appreciation to Tome Jovanovski for his valuable contribution in providing information on several endangered species of fungi.

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НАЦИОНАЛНА ЦРВЕНА ЛИСТА НА ГАБИ (2021), СО ПОСЕБЕН ОСВРТ НА КРИТИЧНО ЗАГРОЗЕНИТЕ ВИДОВИ

Митко Караделев, Катерина Русевска, Славица Тофиловска

Институт за биологија, Природно-математички факултет,
Универзитет „Св. Кирил и Методиј“ во Скопје, РС Македонија

Националната Црвена листа на габи претставува круцијален документ за заштита на габите во државата. При нејзината изработка се спроведоа бројни теренски истражувања, а беа инкорпорирани и податоци од публикувани и непубликувани наоди за различни видови габи, ексикати, како и информации од различни извори. Листата како официјален документ содржи податоци за 64 вида габи, од кои шест вида се категоризирани како критично загрозени (CR), деветнаесет вида се загрозени (EN), триесет и четири вида се ранливи (VU), два вида се речиси засеegnати (NT), два се малку засеegnати (LC) и еден вид е без доволно податоци (DD). Најголем дел од видовите (53) припаѓаат на типот Basidiomycota, додека десет вида се систематизирани во типот Ascomycota. Критично загрозените видови *Bovista paludosa*, *Galerina sphagnum*, *Galerina tibiicystis*, *Hyphoderma etruriae*, *Xeromphalina junipericola* and *Zeus olympius* се посебно обработени и дискутирани во трудот.

Клучни зборови: IUCN Црвена листа; заштита на габите; Република Северна Македонија