JoNeF

Joint Network for wild Fungi

JoNeF PROJECT

TOWARDS COMMON PROCEDURES FOR MACROFUNGI

State-of-the-art and recommendations for implementing conservation in Europe

European Union Network for the Implementation and Enforcement of Environmental Law

JONEF PROJECT: TOWARDS COMMON PROCEDURES FOR MACROFUNGI

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Introduction to IMPEL

The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) is an international non-profit association of the environmental authorities of the European Union (EU) Member States, and of other European authorities, namely from acceding and candidate countries of the EU and European Economic Area (EEA). The association is registered in Belgium and its legal seat is in Brussels, Belgium.

IMPEL was set up in 1992 as an informal Network of European regulators and authorities concerned with the implementation and enforcement of environmental law. The Network's objective is to create the necessary impetus in the European Community to make progress on ensuring a more effective application of environmental legislation. The core of the IMPEL activities concerns awareness raising, capacity building and exchange of information and experiences on implementation, enforcement and international enforcement collaboration as well as promoting and supporting the practicability and enforceability of European environmental legislation.

During the previous years IMPEL has developed into a considerable, widely known organisation, being mentioned in a number of EU legislative and policy documents, e.g. the 8th Environment Action Programme that guide European environmental policy until 2030, the EU Action Plan: "Towards a Zero Pollution for Air, Water and Soil" on Flagship 5 and the Recommendation on Minimum Criteria for Environmental Inspections.

The expertise and experience of the participants within IMPEL make the network uniquely qualified to work on both technical and regulatory aspects of EU environmental legislation.

Information on the IMPEL Network is also available through its website at: www.impel.eu

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Executive Summary

The JoNeF project is committed to advancing the conservation of macrofungi by promoting their integration into environmental laws and policies across Europe. Initiated in July 2023, the project conducted a comprehensive survey on the conservation and data collection of macrofungi, engaging experts from Europe and beyond. Contributions from specialists in 32 countries were compiled into an extensive report (IMPEL, 2024).

Based upon the survey results, this guidance examines the current state of macrofungi conservation (Chapter 2) and monitoring activities (Chapter 3) in Europe. It provides targeted recommendations for highlighting the ecological importance of macrofungi, promoting their role as indicators of habitat quality and ensuring their inclusion in environmental policies (Chapter 4). The findings demonstrate pathways for integrating macrofungi into legislative frameworks and conservation policies, with some European countries already offering successful examples.

This guidance delivers practical recommendations designed both for technicians and policymakers, fostering innovative approaches to global biodiversity and ecosystem conservation. By adopting these recommendations, policymakers can play a crucial role in preserving natural heritage and ensuring the protection of macrofungi for future generations.

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By Merlin Sheldrake

Fungi are ecosystem engineers that underwrite the regenerative capacity of the living world. However, despite their key roles in sustaining global biodiversity and driving vital biogeochemical processes, fungi have been overlooked in climate change strategies, conservation agendas and restoration efforts. This is a problem: the destruction of fungal communities accelerates both climate change and biodiversity loss, jeopardising the health and resilience of the ecosystems on which so much of life on Earth depends, including our own.

There's a good reason why so much work goes into assessing the conservation status of different species: from the point of view of policymakers, if nothing is under threat, there's nothing to protect. But despite their minimal presence in our lists of endangered species, we know of many threats to fungi. Large swathes of the fungal kingdom are intimately associated with plants and so are killed off by the same activities, such as deforestation. Fungi are subject to additional disruptions, from ploughing to the overuse of fungicides and fertilisers, to habitat fragmentation.

The urgent need for fungal conservation is becoming ever more widely accepted among decision makers. There is no better indicator of this than the historic Fungal Conservation Pledge, launched at the sixteenth meeting of the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) in Colombia, October 2024, by Chile and the United Kingdom in collaboration with the Fungi Foundation. The pledge seeks to advance concrete measures to prioritise fungi in national and international legislation, policies, and agreements, and will hopefully be adopted by the UN CBD Secretariat at the next COP of the CBD, paving the way for a new era in fungal conservation.

More than ever, decision makers need guidance to develop meaningful measures and targets for fungal conservation. This report by the Joint Network for Wild Fungi (JoNeF) – the outcome of many hours of painstaking work by a Europe-wide consortium of fungal researchers – provides exactly this kind of guidance. Contained within its pages are concrete recommendations for including fungi in legislative frameworks, enhancing data collection and monitoring, and developing effective conservation strategies at both national and European levels.

There are indeed challenges ahead, ranging from the need for more comprehensive datasets and standardised monitoring protocols to a lack of public awareness of fungi. The JoNeF consortium is clear-eyed about the difficulties associated with effective fungal conservation and provides helpful suggestions and advice on how best to overcome these obstacles.

Fungi have long supported and enriched life on our planet. It's time that this kingdom of life received a kingdom's worth of attention. The JoNeF report helps to chart a way forward and could not come at a better time.

Merlin is a biologist and author of Entangled Life: How Fungi Make Our Worlds, Change Our Minds, and Shape Our Futures, a New York Times and Sunday Times bestseller, and winner of the Royal Society Book Prize and the Wainwright Prize. He is the presenter of Fungi: Web of Life, a giant screen documentary narrated by Björk. Merlin is an honorary research associate of the University of Oxford, a research associate of the Vrije University Amsterdam, the UK Policy Lead for the Fungi Foundation, a core member of the More-Than-Human Life Project and works closely with the Society for the Protection of Underground Networks.

Preface

To the IMPEL Network, IMPEL National Coordinators, IMPEL Nature Protection Expert Team, European Commission, National Ministries of Member States, Environmental Agencies of Member States, European Environmental Agency, and ISPRA.

This guidance marks the culmination of a year and a half of dedicated work by the JoNeF project team, driven by a shared commitment to elevating the importance of macrofungi within the broader framework of biodiversity conservation.

Why We Did This Work

Macrofungi play a critical role in ecosystems, yet their significance is often overlooked in biodiversity conservation policies. Recognizing this gap, the JoNeF project set out to bridge the divide between the scientific community and governmental bodies, aiming to elevate macrofungi to a position of greater prominence in environmental legislation.

What We Found

One of the most significant challenges from the outset was securing the engagement of government officials who aligned with our vision. This challenge underscored the gap between scientific insights and policy implementation, a major obstacle in advancing macrofungi conservation. Despite these hurdles, the team remained resolute, producing the Survey Report (IMPEL, 2024) and this Guidance.

The project revealed that while awareness of macrofungi's ecological importance is growing, there is still a long way to go in ensuring they are included in biodiversity frameworks. This process reinforced the urgency of fostering stronger collaborations between scientists and policymakers to translate evidence into actionable policies.

Where This Leads

The JoNeF project has laid a strong foundation for future progress by identifying the right government contacts, building relationships, and emphasizing the importance of scientific evidence. This guidance aims to empower policymakers to drive significant change in macrofungi conservation, ensuring their protection for generations to come.

We are pleased to announce that the JoNeF project will continue for the next three years, allowing us to build on this progress and further strengthen efforts to integrate macrofungi into biodiversity conservation policies.

Looking Ahead

We call on policymakers, legislators, and government officials to commit to ongoing collaboration with us beyond the project's completion. Working together will be essential in driving our shared goals forward and ensuring the inclusion of macrofungi in environmental legislation.

Acknowledgments

The JoNeF project team would like to extend its gratitude to all those who contributed to the success of this initiative. First and foremost, we wish to thank the experts and researchers from 32 countries who shared their invaluable insights and knowledge, shaping the survey report and providing critical input for the development of this guidance.

We are especially grateful to the IMPEL General Assembly for their endorsement of the JoNeF Survey Report and for recognizing the importance of macrofungi conservation in the broader context of biodiversity and environmental policy.

To everyone involved, thank you for your support and belief in the critical role fungi play in our ecosystems.

Overview of the Guidance Document: Structure and Content

The Guidance document, titled "JONEF PROJECT: TOWARDS COMMON PROCEDURES FOR FUNGI. State-of-the-art and recommendations for implementing fungi conservation in Europe", is organized into **four main chapters**, each addressing critical aspects of fungal conservation and providing a comprehensive framework for future actions. Below is an overview of the contents:

The JoNeF Project

- This chapter introduces the JoNeF initiative, outlining its background, aims, project team, and main actions. It also includes a SWOT analysis to assess the project's strengths, weaknesses, opportunities, and threats.

State of the Art of Fungi Conservation in Europe

- This chapter provides an in-depth review of the current state of fungal conservation across Europe, including the legislative context, notable initiatives and projects, and future priorities for macrofungi conservation.

Macrofungal Monitoring and Assessment Initiatives in Europe

- This chapter focuses on data collection, monitoring, and assessment practices at the national level. It highlights the importance of data resources, storage systems, and the use of data for creating national checklists, Red Lists, and trends, culminating in a proposal to establish a European Fungi Monitoring Network.

Recommendations for Implementing Macrofungi Conservation in Europe

- This final chapter outlines specific recommendations to integrate macrofungi into European conservation frameworks.

Additional sections include bibliographic references, useful websites, a glossary of key terms, and an annex listing JoNeF team members by country and affiliation.

Short contributions on specific topics or case studies are placed in **focus boxes**.

This Guidance Document has been collaboratively developed by several working groups, each led by a chapter coordinator. These coordinators guided the contributions of their respective teams, ensuring that the content reflects a comprehensive and expert-driven approach to the topics addressed.

The Guidance builds upon the findings of the IMPEL 2024 Survey Report, which provides an overview of the current state of fungal conservation in Europe. While some overlap between the two documents is intentional, this one focuses on translating key findings into actionable recommendations for IMPEL, environmental agencies, ministries, and policymakers. For further details and in-depth data on the survey results, readers are encouraged to refer to the Survey Report (IMPEL, 2024).

1. The JoNeF Project

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> "FUNGI ARE IN A SEPARATE KINGDOM, ARE MEGADIVERSE, AND HAVE IMPORTANT FUNCTIONAL ROLES, SUCH AS DECOMPOSITION AND NUTRIENT CYCLING, THAT ARE NOT OR LITTLE DUPLICATED IN OTHER KINGDOMS."
>
> May & McMullan-Fisher, 2012

1.1. Background and aims

The conservation of fungal diversity is crucial for preserving global ecological cycles. Historically, public attention has largely focused on fungi for food and commercial purposes. However, in recent years, awareness of their ecological importance and the need for fungal conservation has grown significantly, driven by the efforts of scientists, conservationists, and policymakers across Europe.

While legislative instruments for fungal conservation remain limited — fungi are not yet directly considered in key international frameworks such as the Bern Convention (*Convention on the Conservation of European Wildlife and Natural Habitats*, 1982[5]) or the Habitats Directive (*Council Directive on the conservation of natural habitats and wild fauna and flora*, 1992[6]) — important steps have been taken to highlight their role. For instance, the Habitats Directive mandates the protection of numerous habitats (Annex I) where fungal species thrive, indirectly offering some protection.

It was in this context that, in 2022, the Italian Institute for Environmental Protection and Research (ISPRA)[7] proposed the "Joint Network for Wild Fungi – JoNeF" project to the European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL)[8]. The JoNeF project builds on existing initiatives (Dahlberg et al., 2010; Senn-Irlet et al., 2007; Fraiture & Otto, 2015) and aims to raise awareness about the need for improved fungal protection in Europe. It focuses on enhancing data collection, strengthening cooperation among stakeholders, and identifying common conservation strategies at European and national levels.

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[5] https://www.coe.int/en/web/bern-convention

[6] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:31992L0043&from=EN

[7] https://www.isprambiente.gov.it/en

[8] https://www.impel.eu/en

A key objective of JoNeF has been to assess the current state of legislative protection for macrofungi[9] in European countries and to propose practical recommendations to support future progress. The project emphasizes the importance of building on existing knowledge, networks, and best practices to advance fungal conservation.

The project required active involvement from European environmental authorities to encourage professional cooperation, information exchange, and sharing of successful approaches among environmental regulators, the key stakeholders and target audience of JoNeF recommendations. Approved by the IMPEL General Assembly in June 2023 under the Nature Protection Expert Team, the JoNeF project officially began in July 2023 and concluded in December 2024.

1.2. Project team and contributing countries

The JoNeF project team is a comprehensive, multidisciplinary group that consists of experts from European countries situated at various latitudes, with different climates, and biogeographical regions. The team covers a large area, from Iceland to Greece on the latitude scale and from Portugal to the easternmost Greek islands on the longitude scale.

During the project's development, the team expanded **from 10 members at its inception to 38 members** contributing to the preparation of the Guidance Document.

Specifically, each member contacted fellow mycologists and experts in other countries to request their participation, aiming to create a broad network of collaborators and contributors for the project.

The 38 members come from the following 21 European countries: Albania, Croatia, France, Greece, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Lithuania, Malta, Montenegro, North Macedonia, Poland, Portugal, Romania, Sweden, Switzerland, The Netherlands, United Kingdom (Figure 1).

The team is composed of experts with different training, skills and experience, working in different types of organisations, such as national public authorities, public research institutions, academic institutions and non-governmental organisations.

The final team includes mycologists, botanists, forest officers, academics, experts in nature conservation, and biologists who are also involved in communication.

Due to the lack of dedicated offices or working groups on mycology within many Ministries or National Environmental Agencies, the project team has expanded its search for collaborators to universities, research institutes, and non-governmental organisations, creating an enriched network of experts with diverse skills and backgrounds.

Most members are employed by national public authorities: 18 members work within national ministries and environmental agencies, representing countries such as Albania, Croatia, Hungary, Italy, Lithuania, Kosovo, Malta, Montenegro, and the Netherlands.

Additionally, nine organisations are part of the IMPEL Network, with representation from Albania, Croatia, Hungary, Italy, Lithuania, Malta, Montenegro, Kosovo, and the Netherlands, and 17 experts officially involved in the project.

[9] Note: The project focuses on “macrofungi”, i.e., fungi that produce sporocarps (fruiting bodies) visible to the naked eye. We also used the terms "macromycetes" or "fungi", avoiding the commonly used term "mushrooms" to ensure scientific precision and to highlight the broader ecological significance of wild fungi, not restricted only to edible ones.

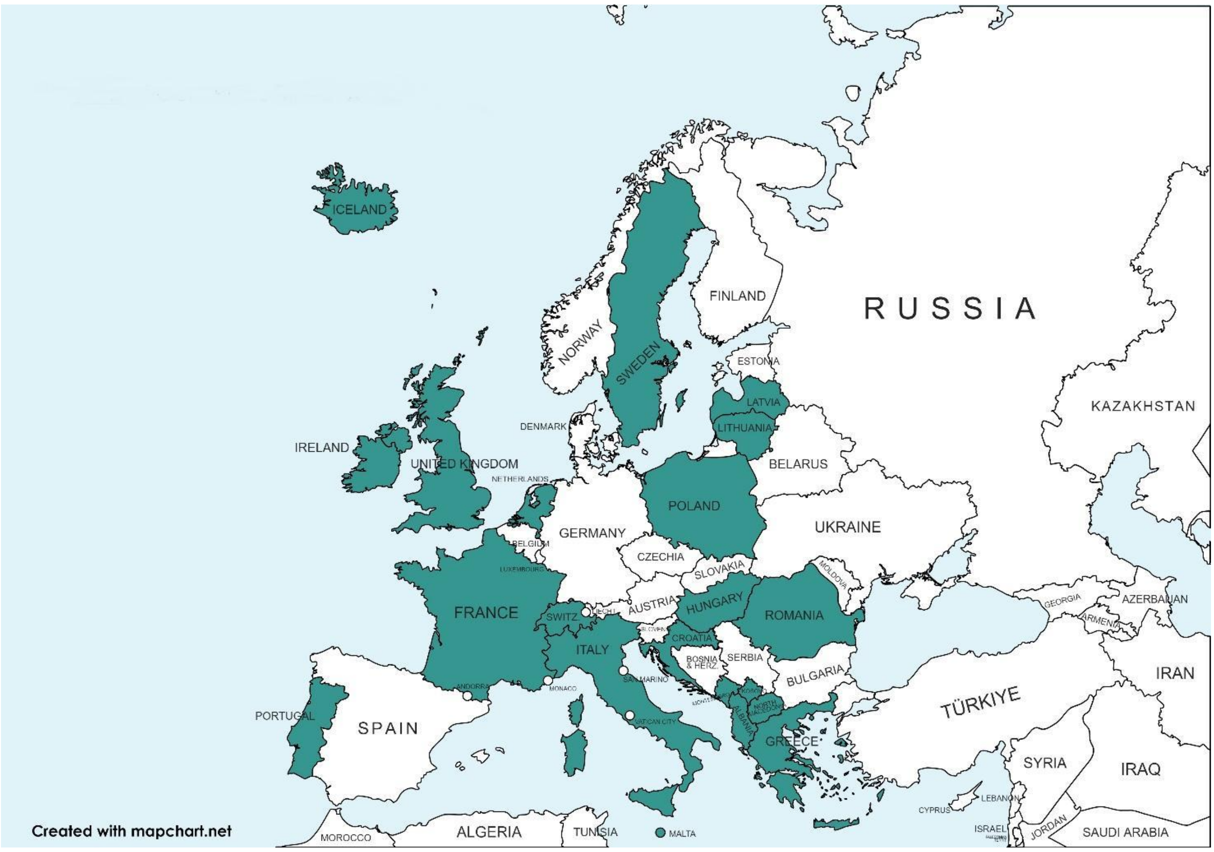

Figure 1. JoNeF members countries

Academic institutions from Greece, North Macedonia, Poland, Portugal, Romania, and Kosovo employ seven members, while eight members are from research institutions in France, Greece, Iceland, Ireland, Latvia, Sweden, and Switzerland. Furthermore, three members are affiliated with NGOs from the Netherlands, the UK, and the USA. One member is from a non-departmental public body in the UK, and another is a freelance professional (Figure 2).

Members' names and affiliations are reported in Annex 1.

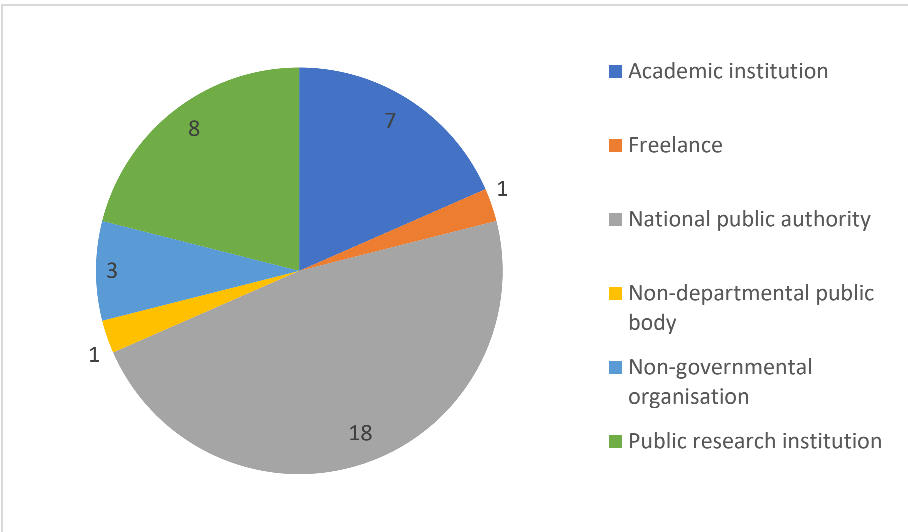

Figure 2. Types of institutions employing JoNeF members

1.3. Main actions

The JoNeF project was initiated by ISPRA and proposed to the IMPEL Network in November 2022. It received approval in June 2023 under the Nature Protection Expert Team.

The project officially began in July 2023, with its first activity focused on developing a questionnaire-based survey on fungal conservation and data collection. The questionnaire was distributed between October and December 2023, and the findings were compiled in the JoNeF Survey Report, which was approved by the IMPEL General Assembly in June 2024.

Building on the Survey Report, the team then proceeded to develop the Guidance, which was completed and delivered to IMPEL in December 2024.

The main actions of the project are summarised in Figure 3.

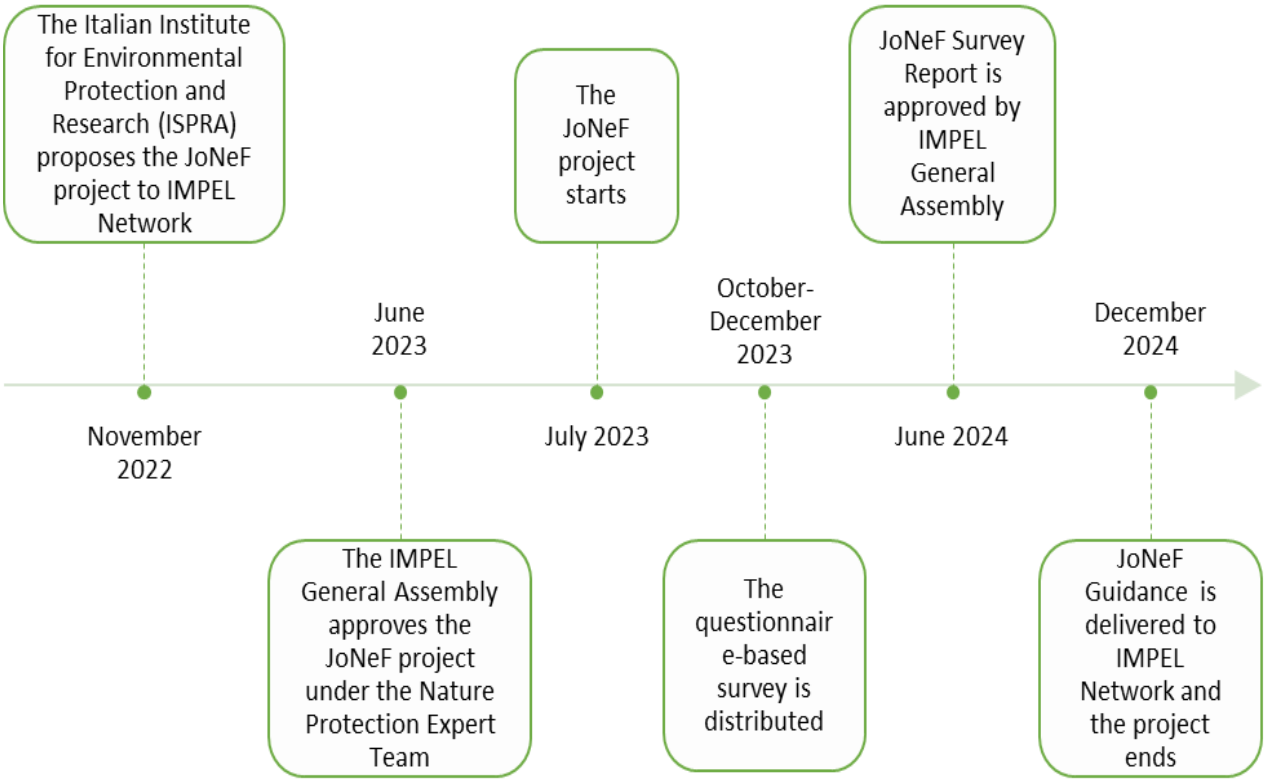

Figure 3. Timetable of JoNeF project

Project team meetings

The JoNeF project team convened multiple times between July 2023 and December 2024, holding a total of nine meetings. Of these, six were conducted online, while three were held in a hybrid format and included site visits (Figure 4).

Site visits took place respectively in Italy at the Circeo National Park, in Romania at the Comana Natural Park, and in Greece at Paiko Mountain (Figures 5, 6, 7).

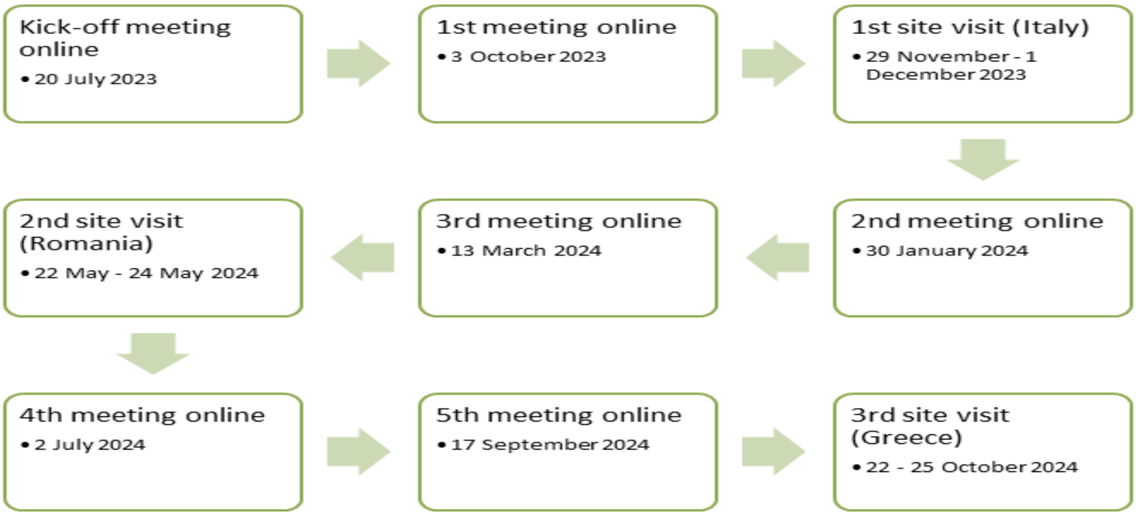

Figure 4. JoNeF meetings

Figure 5. JoNeF project team site visit in Italy

Figure 6. JoNeF project team site visit in Romania

Figure 7. JoNeF project team site visit in Greece

The questionnaire-based survey

The first activity for the project was the development of a questionnaire to gather information on fungal conservation and data collection in Europe.

The questionnaire was distributed from October to December 2023 to IMPEL and non-IMPEL organisations.

The questionnaire was shared both with JoNeF members and National Coordinators of IMPEL countries, and with experts and institutions interested in fungal conservation and data collection. JoNeF members and IMPEL National Coordinators disseminated the questionnaire both in their own country and in other countries not involved in the JoNeF team.

The questionnaire included **82 questions** divided in two parts.

An online form was used to disseminate the questionnaire. The form was linked to the JoNeF webpage on IMPEL website and on the website of the Italian Network for Mycological Diversity (NMD).

Sixty-nine respondents from 32 European countries replied to the questionnaire.

Further details about the respondents to the questionnaire are included in the Survey Report (IMPEL, 2024). The responses showed the interest in fungal conservation as well as differences between countries.

The team analysed the answers and developed the statistics and graphs. On 15th March 2024 the team released the report titled "**JoNeF Survey Report. Survey on macrofungi conservation and data collection in Europe**", approved by the IMPEL General Assembly on 26-29 June 2024 (Figure 8).

The survey report is available on the JoNeF web pages, which can be accessed via the IMPEL website [IMPEL - JoNeF Project] (https://www.impel.eu/en/projects/joint-network-for-wild-fungi-jonef) and the website of the Italian Network for Mycological Diversity (NMD) [NMD - JoNeF Survey Report] (https://ndm.isprambiente.it/attivita/progetti-e-iniziative/progetto-jonef/jonef-survey-report/).

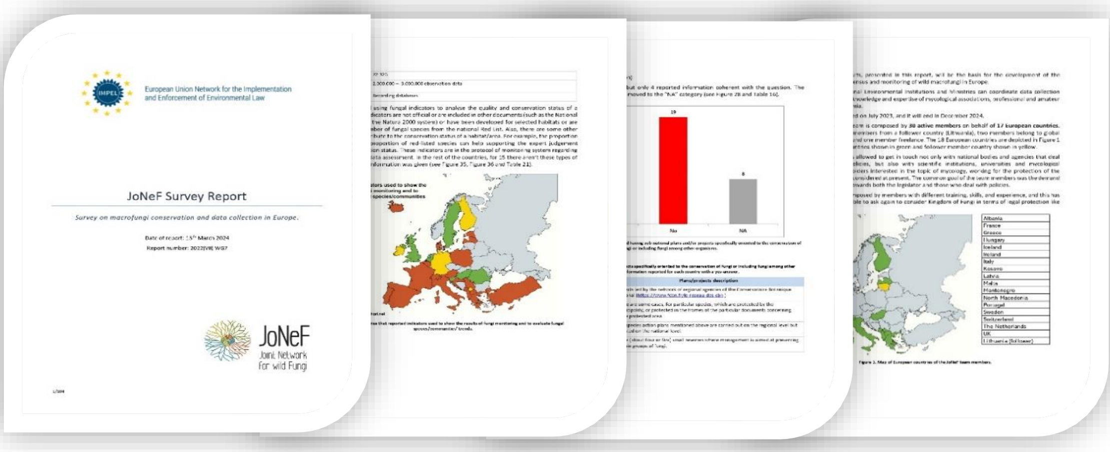

Figure 8. JoNeF Survey Report

1.4. SWOT analysis

The JoNeF project aims to raise awareness about the need for protecting fungi in European habitats, improve data collection and knowledge, and encourage the inclusion of fungi in European environmental legislation and policies. To identify the best strategies for achieving these objectives, the project team conducted a SWOT analysis, as follows.

Strengths (Internal)	Weaknesses (Internal)	Opportunities (External)	Threats (External)
Multidisciplinary Expertise: The JoNeF team comprises 38 experts with diverse backgrounds, including mycologists, botanists, forestry experts, conservation officers, and nature conservation specialists.	**Lack of dedicated funding**: The JoNeF project is not funded except for reimbursements for in-person meetings and site visits.	**Growing Global Interest in Fungi Conservation**: Increasing global initiatives and rising public interest in fungi highlight an opportunity to advocate for their conservation.	**Lack of Expertise in Government Bodies**: Ministries and environmental agencies in many European countries lack specific expertise in fungi.
Institutional Diversity: Team members work in a variety of environmental institutions such as ministries, environmental agencies, academic institutions and NGOs.	**Insufficient Policy Influence**: Only a few JoNeF members are directly involved in public institutions that can influence European-level policy development.	**European Commission Actions**: Recent European Commission initiatives have focused on under-represented species, providing a potential avenue for fungi to gain attention.	**Absence of dedicated Fungal Legislation**: European legislation currently lacks explicit protections for fungi, making it difficult to enforce conservation measures.
Geographical Representation: JoNeF includes members from 21 countries across various European biogeographical regions.	**Incomplete Geographic Coverage**: The project does not have members from all European countries.	**Habitat Conservation Benefits**: The conservation of habitats under the Directive 92/43/EEC (Annex I) indirectly supports the conservation of fungal species.	**Misconceptions about Fungi**: Fungi are often viewed primarily through the lens of their commercial value or health implications, rather than their ecological importance.
Expertise in Fungal Conservation: Members possess significant expertise and experience in fungi conservation and data collection, and their extensive networks facilitate the creation of a European-wide knowledge base.	**Limited availability of time**: Many JoNeF members have limited time to devote to the project due to their primary work commitments.	**Institutional Support**: Leading conservation bodies like IUCN support the conservation of fungi as one of the most neglected taxonomic groups, giving support and value to the cause.	**Data Collection challenges**: National information systems are often not interoperable, and there is a lack of European common standards for fungal data collection, hindering the creation of a comprehensive data network.

Based on the SWOT analysis, the internal and external obstacles could be overcome through the following actions:

- **expand geographic representation:** consider ways to involve representatives from more European countries to strengthen reach and comprehensiveness of the conservation aims
- **seek additional funding:** actively pursue funding opportunities, through European Union grants or other conservation funding sources

2. **engage policymakers:** target outreach efforts toward government bodies and policymakers to advocate for the development of specific fungal conservation policies
3. **leverage citizen science:** promote opportunities for non-professional mycologists and citizen scientists to participate in data collection and awareness-raising campaigns.

2. State of the Art of Fungi Conservation in Europe

Authors: Eleni Topalidou, Panagiotis Madesis, Dheeraj Singh Rathore

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> "DUE TO THEIR CRYPTIC NATURE AND FREQUENTLY SPORADIC AND OFTEN SHORT-LIVED SPOROCARPS, FUNGI HAVE BEEN CONSIDERED A STRANGE GROUP OF ORGANISMS, POORLY UNDERSTOOD AND DIFFICULT TO STUDY."
>
> Dahlberg et al., 2010

2.1. Introduction

Classified under the *phyla* Basidiomycota and Ascomycota (Singh et al., 2018; Kinge et al., 2020), macrofungi are found in a variety of ecosystems including terrestrial, freshwater, and maritime habitats. These fungi are among the most important organisms for the ecosystem functioning due to their vital roles in ecosystem services, such as nutrient cycling, soil formation, carbon sequestration, and pollutant remediation (Sridhar & Deshmukh, 2023).

Macrofungi (including all fungi that produce reproductive structures visible to the human eye) are classified into two major functional groups (Read & Perez-Moreno, 2003; Caiafa et al., 2017; Niego et al., 2022):

a) Saprotrophs: these fungi contribute to the decomposition of organic matter, nutrient cycling and soil formation
b) Biotrophs: these fungi establish a long-term feeding relationship with the living cells of their hosts and they are divided to mutualists (e.g. mycorrhizal fungi that establish symbiotic relationships with plants/trees, exploring the soil for nutrients that they provide to the plant in exchange for carbon) and parasites (which obtain the nutrients necessary for their growth and reproduction from a living host at its expense).

The diversity and distribution of macrofungi are strongly associated with the habitat type and the environmental conditions. However, they are rarely included in management schemes that mainly focus on the protection of animals and plants. Many fungal species are threatened, but only a few European countries have produced complete Red Lists. There is notable lack of ecological studies on macrofungal communities and the effects of biotic and abiotic factors on their population dynamics (Perez-Rosas et al., 2022).

The ecology of macrofungi is fundamental for environmental protection and plant productivity. For instance, they contribute to carbon (C) dynamics through C allocated by plants to mycorrhizal fungi in soil. Additionally, they degrade organic matter and assimilate C-rich degradation products, acting as a C sink by retaining C in the soil. Macrofungi are also capable of degrading or transforming a wide range of harmful substances into less toxic or non-toxic forms through the intricate process of mycoremediation. A variety of macrofungi species, such as *Pleurotus ostreatus*, *Trametes hirsuta*, *T. versicolor*, *Lentinus tigrinus*, *Lentinula edodes* etc., are employed as mycoremediators which through the special metabolic capabilities they exhibit they degrade and detoxify a variety of contaminants such as pesticides, heavy metals, hydrocarbons and many more (Niego et al., 2022; Dinakarkumar et al., 2024).

Besides their ecological roles, macrofungi are valuable for humans (Peláez et al., 1995; Pointing, 2001; Pointing et al., 2005; Oberwinkler, 2012; Zotti et al., 2013; Kinge et al., 2020; Lagiotis et al., 2021). They are nutrient-rich sources of food for humans, provide important feed for animals and contain metabolites and bioactive compounds traditionally used in medicine. Nowadays, such compounds are considered to have significant potential for development and application in numerous industries, including agriculture, biomedicine, cosmetics, pest and waste management, nutraceutics and biotechnology (bioprospecting) (Fung & Mohamad, 2021). Besides provisioning ecosystem services, fungi play an important role in several regulating ecosystem services as well such as water supply (via mycorrhizal fungi) or CO_2 sequestration and storage, and in cultural services e.g. recreational activities. Despite their environmental importance, macrofungi are largely unexplored, and often overlooked in planning processes and policymaking (Niego et al., 2022).

*Figure 9. Glistening inkcaps (*Coprinellus micaceus*) flourishing on the mossy floor of a sitka spruce forest in Ireland.*

Threats and challenges facing fungal biodiversity

Most fungal species face the same threats as animals and plants, often compounded by multiple synergistic pressures that heighten their risk of local or regional extinction (Mueller et al., 2022). Addressing these challenges is crucial, and it begins with filling knowledge gaps: there is considerable potential for discovery in understanding the compositional diversity, community structure, and population dynamics of macrofungi, and these areas, that are not yet fully explored, hold great promise for future research.

Understanding the threat assessments and conservation status of macrofungi can provide a foundation for urgent actions, including: (a) optimising land and habitat management; and (b) developing and implementing targeted policies to prevent potential extinctions and their associated ecological impacts (Mueller et al., 2022).

In Europe, the intensification and changes in land-use, along with the enlargement of urban settlements since 1950, are considered the major causes for the decline of fungi diversity (Senn-Irlet et al., 2007). It is widely known that plant and fungal communities are influenced by forest disturbances and land use (Bader et al., 1995). Activities that alter vegetation communities, tree species, composition, and soil factors such as forest management practices or unsuitable human activities (e.g. illegal logging) confer continuous environmental destruction and deforestation, posing a major risk to biodiversity loss of macrofungi (Njuguini et al., 2018). Recent studies also highlight that habitat modification, including fragmentation and conversion to agriculture, can significantly reduce fungal diversity and disrupt symbiotic relationships essential for ecosystem health (Ding et al., 2024; Yiallouris et al., 2024). Several countries including the UK, Estonia, Finland, Lithuania, Norway, Sweden, and Russia use the occurrence of indicator and threatened macrofungi along with other criteria (e.g., habitat structure, occurrence of other indicator species such as plants and mosses) to identify the habitat quality and sites of conservation value (Dahlberg et al., 2010).

Some of the main threats identified for the macrofungi in Europe include (Senn-Irlet et al., 2007; Mueller et al., 2022):

- **Decline of forests and loss of suitable habitats:** The shortage of old-growth forests, the decline in the availability of coarse dead wood, and the decrease in the number of veteran trees are among the negative effects that need to be mitigated to protect biodiversity within forests (Senn-Irlet et al., 2007; Minter, 2011). Moreover, clear-cutting practices and forest monocultures contribute to habitat loss and reduce fungal diversity (Durall et al., 2005; Tomao et al., 2020). Despite grasslands are still rich with many different species of wild plants and fungi, in many countries, such as the UK, they are considered among the most threatened habitats because of their decline due to their conversion into cropland, the intensive management, tree planting etc[10].
- **Habitat fragmentation**: Although, the influence of landscape factors on macrofungi diversity patterns remains largely unknown (Mony et al., 2020), habitat fragmentation is suggested to have negative effects on macromycetes diversity, especially to those with lower dispersal abilities, with significant variations according to the different trophic groups (Raimbault et al., 2024). Fragmentation can lead to isolated fungal populations, reducing genetic diversity and resilience to environmental changes (Berlinches de Gea et al., 2024).

[10] https://www.plantlife.org.uk/protecting-plants-fungi/grassland/

- **Climate change:** The impact of climate change on the structure and function of macromycetes communities is still unknown, making it difficult to predict their effects on future landscapes (Bazzicalupo et al., 2022). Rising temperatures and altered precipitation patterns are expected to shift fungal distributions and phenology, potentially leading to mismatches with their plant hosts (Karlsson, 2024; Kauserud et al., 2012).
- **Further anthropogenic influences/disturbances:** Nitrogen deposition, over-fertilization, over-harvesting, infrastructure and tourism facilities, fire etc. are among the factors that accelerate environmental change and impact the diversity and population dynamics of macromycetes. Increased nitrogen levels from agricultural runoff can favour nitrophilous fungi while suppressing other species, leading to homogenization of fungal communities (Xiankai et al., 2008; Orumaa et al., 2022; Burrascano et al., 2023).

Understanding of the consequences of habitat degradation and fragmentation for macromycetes assemblages is a decisive factor for the development of successful conservation strategies (Brown et al., 2006). Macromycetes overharvesting for commercial or recreational purposes has raised widespread concern in many European countries about the possible damage to the indigenous fungal resources (Senn-Irlet et al., 2007).

In many countries legal restrictions have been established for the conservation and the protection of macromycete populations, especially for the red-listed species (Senn-Irlet et al., 2007; IMPEL, 2024). The interest in fungal diversity and its conservation has continuously increased, and it is currently the founding element of several European institutions. In this context, in 2022 the Italian Institute for the Environmental Protection and Research (ISPRA) proposed to the European Union Network for the Implementation and Enforcement of Environmental Law the project “Joint Network for wild Fungi (IMPEL, 2024). The main goal of JoNeF was to discuss and propose to the European Commission a way to integrate fungal conservation into European legislation on nature conservation and in decision-making processes, to implement a comprehensive conservation strategy (Dahlberg et al., 2010). As a first step, a questionnaire was prepared by JoNeF members and was distributed to different European countries. Questionnaire results were the basis for the development of the practical Guidance for census and monitoring of wild macrofungi in Europe. The JoNeF project’s first objective has been collecting and curating the information of current national legislation on fungal protection, conservation and data collection and the existing procedures for the census and monitoring of macrofungi in Europe. The JoNeF survey revealed that national environmental legislation related to the conservation of fungi exists only for 15 (out of the 31 that participated in the survey) European countries, although with a fragmented legal framework and with different kinds of rules and/or implementation measures. Moreover, the JoNeF survey showed that most European countries have produced checklists which range from simple lists of species to annotated checklists with metadata on taxonomy, distribution, threat status etc. (IMPEL, 2024). The JoNeF survey pointed out the need for updating the existing checklists, improving their quality and scope. Organising the gathering of information to fill up the gap of legal protection of fungi at European level seems the greatest challenge.

However, one of the most important barriers to implementing macrofungi conservation initiatives in most European countries is the lack of knowledge about their geographic distribution or habitat requirements, occurrence, or abundance. Macrofungi fruit only for a few days of the year, and this makes it difficult to evaluate the level of their vulnerability and overcome the incertitude of distinguishing rarity of species from under-sampling and/or data deficiency. This hinders the assessment of species' extinction risk according to IUCN Red List criteria, which are the basis of prioritisation and conservation actions targeting species.

Currently, ten (10) countries [Austria, Croatia, Denmark, Estonia, Germany, Italy, North Macedonia, Romania, Sweden, and Switzerland (IMPEL, 2024)] have fungal Red Lists developed using the IUCN criteria, which represent a recognized international standard for conservation assessments. However, it is equally important to value all efforts made to assess extinction risk of fungal species, even if using different criteria and methodologies.

Additionally, the UK has developed a Red List specifically for Boletes, though this was not included in the JoNeF Survey Report (IMPEL, 2024).

In Latvia, macrofungi species have also been evaluated using IUCN criteria, and a new Red List, along with an updated list of protected species, is expected to be released soon.

In Poland, where the last edition of the Red List of fungi was based on older IUCN criteria, the work on the update has just recently begun.

Nevertheless, there is significant variability in the number of evaluated species, which ranges from 13 (Italy) to 4,450 (Austria) (IMPEL, 2024) and highlights the importance for collecting data on distribution and population trends at the European level. The legislative context for macrofungi conservation in Ireland is still developing. While there are general conservation measures in place for habitats and biodiversity, specific actions targeted at macrofungi are limited (O'Hanlon & Harrington, 2011). Recent initiatives have begun to focus more on the importance of fungi, but comprehensive national strategies and detailed Red Lists are still lacking. Collaborative efforts across European countries and the incorporation of fungal conservation into broader biodiversity policies are needed to enhance the protection of macrofungi in European countries where such conservation policies are lacking.

Red Lists for macrofungi are available for 19 out of the 31 European countries that responded to the JoNeF survey. Some of the most recent Red Lists (such as those from Serbia, Slovenia and Netherlands) did not employ the IUCN criteria, whereas some of the outdated Red Lists were also not based on current IUCN criteria for the evaluation of species (IMPEL, 2024).

In Greece, an official Red List based on the IUCN criteria was announced in May 2024. The Red List was based on all diversity data available for macrofungi in Greece. These included both published records and identified specimens maintained in public and private fungaria. Population trends are in any case hard to assess since long-term monitoring data are needed for the habitats under study. This outcome points out the necessity for the establishment of policies which can be implemented at both national and European levels and the gathering/collection of comparative data among different European countries.

Figure 10. Phaeolepiota aurea *in Frakto Forest, Greece (Photo: Vasileios Vougiatzis).*

Figure 11. Hymenopellis radicata *in Mount Olympus, Greece (Photo: Vasileios Vougiatzis)*

Figure 12: Clavariadelphus pistillaris *in Mount Olympus, Greece (Photo: Vasileios Vougiatzis)*

Knowledge gaps in the conservation and management of macrofungi at the European level

Strategies for the conservation of macrofungi are urgently needed due to their vital ecological role and their significant economic importance (Zotti et al., 2013).

Macrofungi are often excluded from conservation plans because there is insufficient data to demonstrate population declines over time (Bazzicalupo et al., 2022). Furthermore, our understanding of the ecology and basic biology of macromycetes - including their geographic range, host range, associations with plants and other organisms, diversity of life cycle stages, soil preferences, geoclimatic requirements, and habitat specificity - remains limited and fragmented (Osmundson et al., 2013). However, despite these knowledge gaps, we know enough to take meaningful action. It is crucial to: (a) compile and synthesise the scattered information, (b) implement urgent actions and targeted policies to protect fungi, and (c) optimise habitat management by incorporating measures that enhance fungal diversity and mitigate threats to macromycetes.

The 3F (Flora, Fauna, Funga) initiative[11] has been adopted globally to refer to life on Earth and aims to acknowledge the existence and the importance of fungi (macro- and micro- or filamentous) in governmental decisions. This initiative aims to write this neglected kingdom of life into conservation and agricultural policy frameworks, protect it under international and domestic laws, and unlock crucial funding for mycological research, surveys and educational programs.

The conservation of macrofungi is hampered by important **knowledge gaps**, which can be summarised in the following list:

- Basic taxonomic knowledge remains incomplete in certain areas, particularly with respect to the availability of DNA sequence data for type material. While many species have been described, gaps persist in the comprehensive documentation of certain fungal groups, especially for those with limited taxonomic attention or for cryptic and morphologically similar species.
- There is a need to link genetic diversity to functional and ecological diversity (Lofgren and Stajich, 2021).
- Data on the diversity and dynamics of macromycete communities vary widely across European countries. While some regions have substantial datasets, others lack comprehensive or consistent monitoring efforts, particularly regarding long-term studies and the inclusion of underexplored habitats.
- Most European countries lack official checklists and Red Lists.
- The ecological services provided by macromycetes, such as nutrient cycling, decomposition, and symbiotic interactions, are well-documented. However, there is still a need to deepen our understanding of how these services vary across specific habitats and how environmental changes impact their functioning and effectiveness.
- Data on decline in the production of fruit bodies and shifts on phenology due to changing or extreme weather patterns and the impacts of climate change on the structure and function of fungal communities are lacking (Bazzicalupo et al., 2022).
- National data from all the European countries need to be compiled in collaboration to produce an official European checklist.

[11] ffungi.org/eng/conservation/

- Common European census/monitoring protocols and standards for the collection of macrofungal data should be established.
- Strategies to minimise habitat destruction and fragmentation are needed.

Until now, fungi have seldom been considered in conservation biology. However, this is changing as the field shifts from focusing on single species to adopting a more integrative, ecosystem-based approach (Heilmann-Clausen et al., 2015).

2.2. Legislation context in the European countries

The existing legislation for the conservation of macrofungi varies greatly among European countries at both national and sub-national level.

In 2023 the questionnaire-based survey developed by the JoNeF project team collected several pieces of information on conservation of macrofungi in Europe.

A total of thirty-four countries (32 European countries plus USA and Canada) participated in the questionnaire.

The results of the survey cannot be considered exhaustive or complete but provide a picture of the state of fungi conservation in Europe and have been summarised and explained in the JoNeF Survey Report (IMPEL, 2024).

The questionnaire examined the legal context regarding the conservation of fungi and the existence of lists of protected fungal species in the legislation.

Fourteen (14) countries reported to have national laws specifically dedicated to the conservation of fungi.

Among those 14 countries, 13 have provided information about law titles, if there is a list of protected species and how many species are included (Figure 13 and Figure 14) (IMPEL, 2024).

Fifteen (15) countries have national laws dedicated to gathering fungi, with different kinds of rules (Figure 15) (IMPEL, 2024).

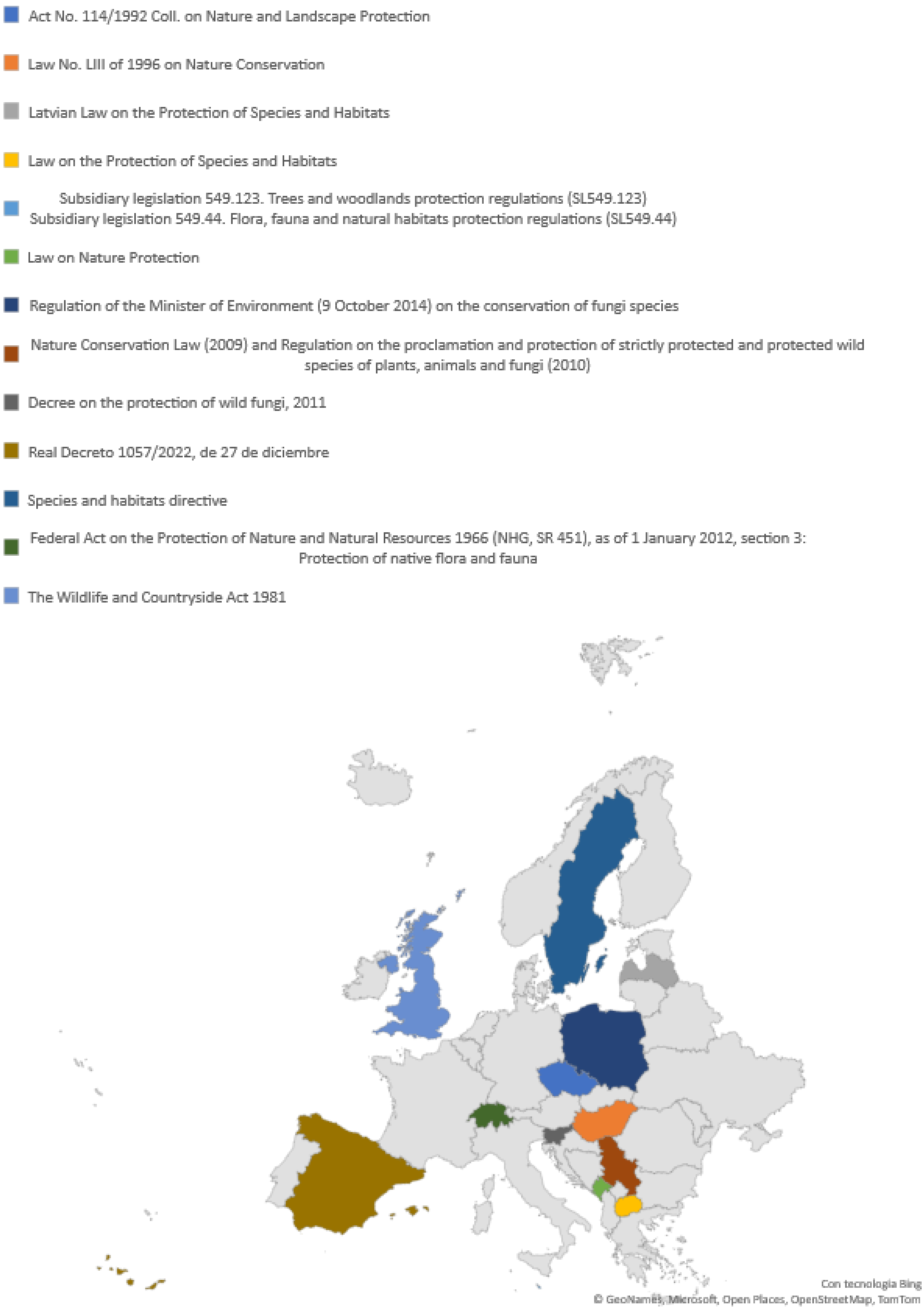

Figure 13. Countries with national laws that include fungi conservation (data from JoNeF survey report, IMPEL 2024).

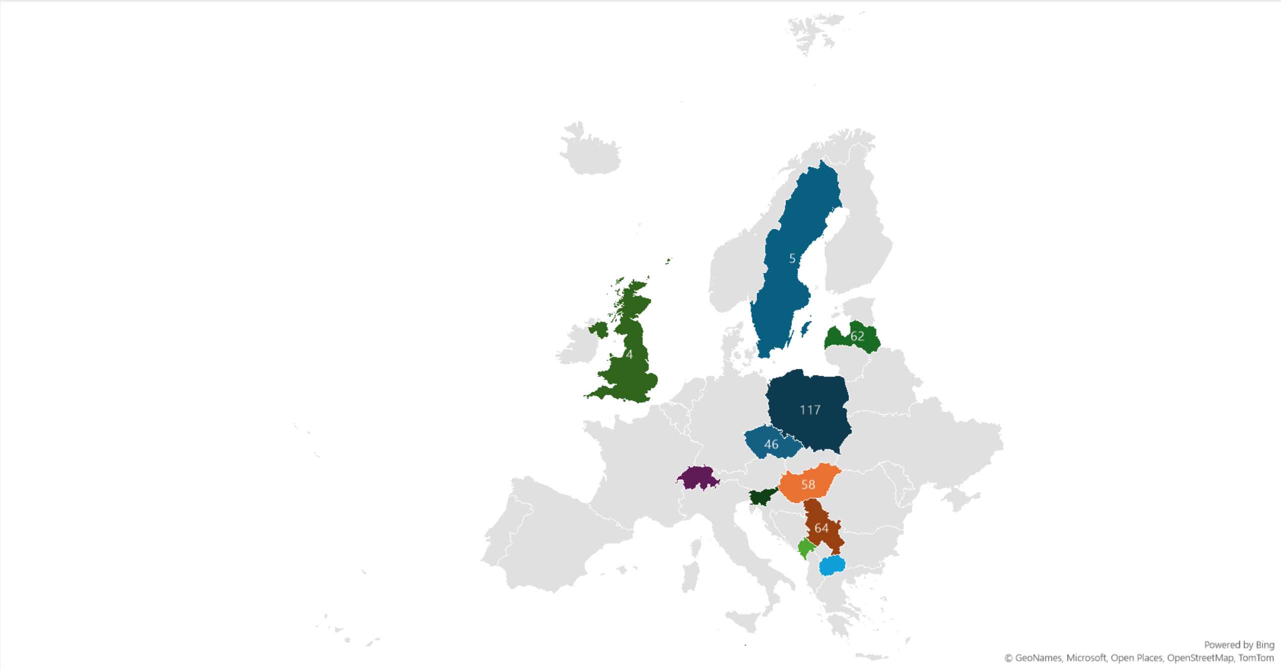

Figure 14. Number of fungal species protected by national law (data from JoNeF Survey Report, IMPEL 2024)[12].

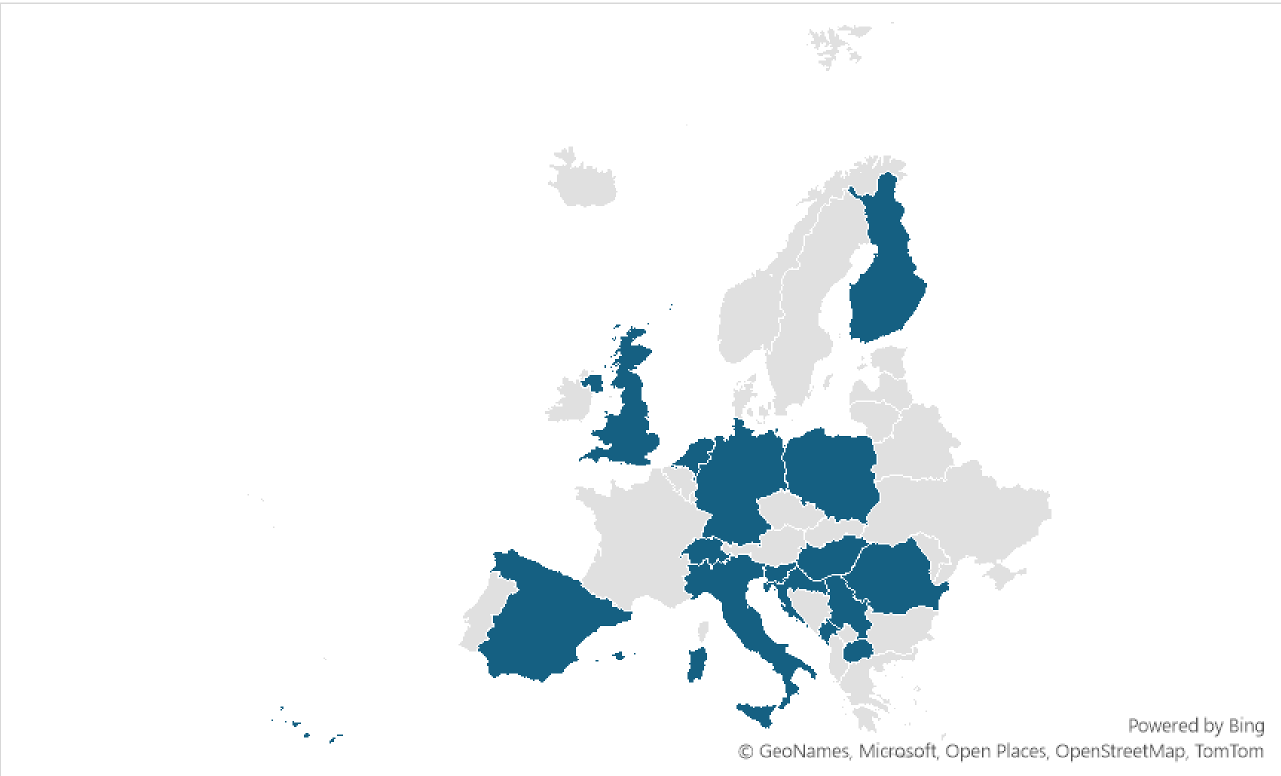

Figure 15. Countries with legislation on gathering of fungi (data from JoNeF survey report, IMPEL, 2024)[13].

[12] Note: The map displays only countries that reported to have national law protecting fungal species. For more information see the Survey Report.

[13] Note: The map displays only countries that reported to have legislation on gathering of fungi. For more information see the Survey Report.

The information regarding distribution, biodiversity and conservation of macrofungi is essential to have effective legislation for fungal conservation, but currently data range from limited to comprehensive, with some countries having detailed mycological studies while others have very little information available.

Existing regulations and policies often focus more on ensuring equitable access to the resource than on establishing conservation measures (Brainerd & Doornbos, 2013). Kotowski (2016) reported that 24 European countries have introduced lists of macromycetes species (mushrooms) allowed for commerce, with 16 of them creating suitable trade legislations, and seven of them include special guidelines released by their governments.

Recently, the JoNeF Survey Report showed that 15 countries, out of the 32 that participated in the questionnaire, have a national framework for the regulation of gathering fungi and 12 reported that there is no national regulation. Results clearly stated that most of the countries that have regulations on gathering of fungi are related to prohibitions that concern either protected species and/or protected areas. In addition, some countries reported that regulations on gathering fungi exist only by extension through the regulations for the conservation of animals and plants. Only in Italy there is specific regulation regarding the collection and marketing of fresh and preserved epigeal mushrooms (IMPEL, 2024). Moreover, only 8 European countries have a sub-national legal framework for gathering fungi for personal and/or commercial use (IMPEL, 2024).

Legislation on macrofungi should go beyond regulating the collection of wild species—such as setting limits on timing, quantities, methods, and permitted habitats—to include proactive conservation measures aimed at preserving, enhancing, or reintroducing fungal populations and improving their natural habitats.

A prerequisite for making informed decisions regarding conservation measures is the availability of adequate data to guide the implementation of the conservation policies (Bazzicalupo et al., 2022). However, as mentioned earlier, most European countries lack sufficient data for macrofungi, and they are not included in any conservation plans due to the shortfall in data to demonstrate a population decline over time. The development of guidelines for planning and monitoring macrofungi biodiversity should include measurable goals and objectives and a set of core linked indicators that allows comparisons across all the European countries. In the past, some countries such as Denmark, Finland, France, Norway, Sweden, and Switzerland have attempted to assess as many macrofungi species as possible in terms of evaluated species and the proportion of the total number of macrofungi assessed (Dahlberg et al., 2010). The current IUCN criteria were adapted for fungal Red Lists by Dahlberg and Mueller (2011) and initiated efforts to identify research needs, provide more robust estimates of the distribution, frequency and ecology of fungal species and identify the threats to their existence.

To support the development of conservation policies and legislations, it is essential to provide clear and concise guidelines which incorporate macrofungi conservation and allow implementation by the land-managers, and the conservation practitioners (Dahlberg et al., 2010).

Generally, two main approaches are used for the conservation implementation:

a) assessments targeting specific habitats (e.g. grasslands, woodland key habitats, etc.), and
b) assessments of target species particularly those endemics only to specific regions (Bazzicalupo et al., 2022).

In Europe, the Habitats Directive has been instrumental in fungal conservation, even if Fungi are not explicitly protected under this EU policy. This directive mandates Member States to designate protected areas known as Special Areas of Conservation (SACs) where not only target species are safeguarded, but also the other species living in those sites, including fungi. For instance, in the UK, under the Conservation of Habitats and Species Regulations 2017 (S.I. No. 1012 of 2017), fungi are protected within these designated areas, ensuring their habitats remain intact and conducive to their survival[14]. Moreover, under Great Britain's national legislation, 26 protected sites have been designated in part for their fungi through the Wildlife and Countryside Act 1981. In these sites, fungi are monitored, and site management is targeted towards them (Focus Box 13).

Efforts to compile lists for IMA (Important Mycological Areas, or Important Mushrooms Areas[15]) or IFA (Important Fungi Areas) have been made by various organisations such as the European Council for Conservation of Fungi (ECCF). IMA and IFA focus on the ecological importance of specific sites for fungal biodiversity and contribute to a better understanding of fungal ecology and to the need for targeted conservation strategies to protect fungi and their habitats. IMA refers to areas that exhibit exceptional diversity and abundance of fungi and particularly macrofungi, whereas IFA emphasises the identification of areas which are crucial for the survival of both macro and microfungi. Under this premise, areas important for macrofungal diversity and biodiversity have been made only in a few European countries, including the Netherlands, the UK and Croatia (Dahlberg et al., 2010). However, those compilations may need to be updated - as indicated by the JoNeF survey - to provide clear and specific guidelines for favourable and unfavourable activities and practices (such as logging and land development) for the occurrence of fungal species at specific habitats.

These legislative measures are essential as they provide a legal basis for conservation actions and underscore the importance of proactive management and preservation efforts to maintain fungal diversity worldwide. The state of fungal conservation in Europe remains insufficient and needs to be prioritised to develop a comprehensive conservation strategy. The production of an official European checklist and the development of a guidance at cooperative level for all the European countries, incorporating macrofungi into law-making and decision-making processes and environmental initiatives, is more than necessary for their conservation. JoNeF survey results indicated the need to ensure fungal conservation and integration of fungal species into environmental policies.

[14] https://www.legislation.gov.uk/uksi/2017/1012/contents
[15] http://www.eccf.eu/newsletter12.pdf

2.3. Initiatives and projects for fungal conservation

Despite projects and action plans explicitly dedicated to the conservation of fungi in Europe are few, some initiatives, like the FunDive project[16], focused on fungal diversity and conservation, demonstrate a growing recognition of the importance of fungi in biodiversity strategies.

The survey conducted in the framework of the JoNeF project highlighted this lack of initiatives, projects and action plans, both oriented to single species and/or to the habitat for the species. Out of 31 respondent countries, only five reported about conservation management plans for fungal species (Estonia), national strategy for nature conservation (North Macedonia), action plans for mapping distributions and preserving/restoring habitat (Sweden) and other conservation projects at national scale. In Latvia the project "Life for species", aimed to improve the conservation of natural diversity by assessing the vulnerability of wild species and the need for their legal protection, includes fungi among other organisms (IMPEL, 2024).

The practical importance of a European mapping for conservation

Mapping is crucial for effective conservation, offering insights into spatial understanding of species distribution, habitat requirements and guiding efforts to protect biodiversity. Mapping tools help identify critical habitats, monitor changes, and prioritise areas for conservation action. While plants and animals benefit from such initiatives, fungi remain underrepresented, highlighting an urgent need for dedicated mapping to safeguard these vital organisms and ensure their inclusion in broader conservation strategies.

In Europe, comprehensive mapping efforts are essential for identifying areas of high biodiversity, planning conservation actions, and monitoring changes in species populations and habitats. European mapping for conservation, such as the EU's Natura 2000 network, helps prioritise areas for protection and ensures that conservation efforts are targeted and effective. This mapping informs policymakers, conservationists, and researchers, guiding them in making data-driven decisions to safeguard biodiversity.

Several forest, marine, and other biodiversity conservation projects are ongoing across Europe, leveraging mapping and spatial data to enhance conservation outcomes. For instance, the LIFE Programme[17] by the European Union funds projects like LIFE Forest CO2, aimed at forest conservation and climate change mitigation[18], and LIFE Andros Park project[19], which includes work on the assessment of fungal diversity and conservation through the protection and restoration of alder habitats in the Aegean Islands.

While the European Union faces a notable shortfall in macrofungi mapping efforts, there are valuable resources available to address this gap. In the USA, the **Fungal Conservation Tracker[20]** developed by the Fungi Foundation provides a platform for monitoring fungal conservation efforts. Additionally, the **Micheli Guide to Fungal Conservation[21]**, maintained by the International Society for Fungal Conservation, evaluates national biodiversity action plans and reports from a fungal

[16] https://fun-dive.eu/
[17] https://cinea.ec.europa.eu/programmes/life_en
[18] https://lifeforestco2.eu/life-forest-co2-project/?lang=en
[19] http://www.life-androspark.gr/en/
[20] https://fungalconservationtracker.ffungi.org/
[21] http://www.fungal-conservation.org/micheli.htm

perspective, covering many European countries. These tools can serve as models or support for enhancing fungal conservation initiatives within the EU.

Despite their ecological significance, fungi have historically received less attention in conservation planning compared to plants and animals. This gap highlights the need for dedicated mapping and conservation initiatives for macrofungi to ensure their protection and to integrate them more fully into broader biodiversity conservation strategies. Efforts such as the ECCF (European Council for the Conservation of Fungi) Mapping Programme (Fraiture & Otto, 2015) are pivotal, but more comprehensive mapping and targeted conservation actions are urgently needed.

European Council for the Conservation of Fungi (ECCF)

The European Council for the Conservation of Fungi (ECCF) was founded in 1985 at the 9th Congress of European Mycologists in Oslo, Norway, in response to concerns among mycologists about the decline of certain fungal species on the continent. In 2003, the ECCF became the conservation body of the European Mycological Association (EMA) and was recognised by the International Mycological Association (IMA) as the fungal conservation representative for Europe. Notable ECCF efforts included the preparation of a list of 33 fungi for inclusion in the Bern Convention (without success, unfortunately), the mapping programme that resulted in the study of the distribution of 51 species, as well as their ecology and conservation status in Europe (Fraiture & Otto, 2015), and the European Red List of Fungi initiative in collaboration with IUCN (ongoing). From 2020, the ECCF acts as the European hub for the IUCN SSC Fungal Conservation Committee[22]. As an informal network of volunteers, the ECCF relies on the engagement of its members and is currently more active around Red List activities and workshops.

European Mycological Association (EMA)

The European Mycological Association (EMA) is a regional not-for-profit and non-party political association of individuals (amateur or professional) and organisations (public or private) with an interest in European fungi, including local, national and regional mycological groups and societies[23]. The EMA organises the Congresses of European Mycologists and serves as the Committee for Fungi in Europe within the International Mycological Association. The EMA works within Europe for the following objectives: to promote the study of fungi; to disseminate knowledge and information about fungi; to promote the conservation of fungi (for example through the ECCF); to promote socially responsible handling of fungi (for example in medicine, plant and animal pathology, quarantine and pharmaceutical research); to establish and foster relations between those working towards such objectives, through meetings, electronic media, publications, and by promoting personal contacts, collaboration and the exchange of ideas and information; to improve the infrastructure of mycology within Europe; to provide European-level input to the International Mycological Association, and other international bodies and initiatives.

[22] https://www.iucn-fungi.org/
[23] http://www.euromould.org/

JoNeF – Join Network for wild Fungi

JoNeF is an IMPEL Network project established to create a collaborative network of professional mycologists across European countries. This initiative focuses on disseminating information to decision-makers and policymakers while promoting conservation actions to protect fungi in their natural habitats (Figure 16). JoNeF produces comprehensive reports and organises events and activities that engage mycologists, researchers, and policymakers in fungal conservation efforts. These events serve as valuable platforms for knowledge exchange and collaboration, strengthening the network of fungal conservation advocates across Europe. By highlighting the ecological roles and benefits of fungi, JoNeF raises awareness of their importance and the urgent need for their protection.

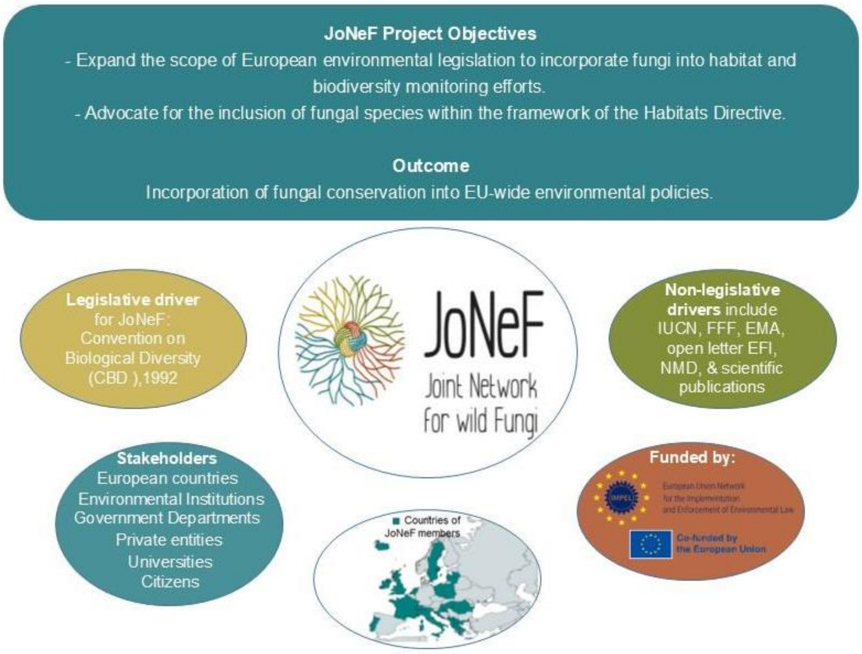

Figure 16. Schematic representation of the JoNeF project

Case Studies of Successful Conservation Projects

Several successful conservation projects across Europe highlight the effectiveness of targeted efforts to protect fungi.

One notable example is the conservation of the wood-decay fungus *Fomitopsis rosea* in Finland. This project involved habitat restoration, the creation of deadwood structures, and the protection of old-growth forests, resulting in a significant increase in the species' population (Komonen et al., 2021).

Another case is the Lost and Found Fungi (LAFF) Project in the UK where 100 rarely recorded species were selected for targeted survey through citizen science engagement. This project led to approximately 1400 records for around 80 LAFF species including the rediscovery of several species not seen in more than 50 years, the description of species new to science, as well as targeted management advice to landowners. As a result of the rediscovery of *Hypocreopsis lichenoides* in Scotland, efforts are underway to conserve the species. These projects demonstrate the importance of habitat management, research, and community involvement in fungal conservation.

Data Collection and Monitoring Efforts Around Macrofungi

Robust data collection and monitoring efforts are crucial for understanding the status and trends of macrofungi populations. In Europe, various initiatives are in place to gather data on fungal diversity and distribution. This topic will be discussed extensively explicitly in chapter 3 of this guidance.

Stakeholders and Communities Engagement

Engaging stakeholders and local communities are vital for the success of fungal conservation initiatives. Effective engagement involves raising awareness about the ecological roles of fungi, the threats they face, and the benefits of their conservation. Educational programs, citizen science projects, and community-led monitoring initiatives are effective ways to involve the public. For example, the Danish Fungal Atlas project engages volunteers in recording fungal occurrences, contributing valuable data for conservation planning. Collaboration with landowners, forestry managers, and policymakers ensures that conservation measures are practical and widely supported (Heilmann-Clausen et al., 2021).

The Italian Network for the study of mycological diversity

In February 2021 the Italian Institute for Environmental Protection and Research (ISPRA)[24] launched the Network for the study of mycological diversity (NMD)[25] with the goal of compiling, organising, and publishing surveys, samples, and data on fungal species found in Italian habitats into a single national database.

The NMD operates as a network system that integrates human and technological resources to conduct a nationwide census and monitoring of macromycetes, focusing on:

- Advancing research, data collection, analysis, and communication on the protection of mycological biodiversity through innovative management solutions under an open science initiative

- Providing tools for collaboration among participants in the network and establishing shared scientific standards for operation

- Offering stakeholders a unified national knowledge base to guide policy making for the protection and conservation of fungal communities, especially in light of climate change and its impacts.

Integration of fungal conservation into ecosystem management

Integrating fungal conservation into broader ecosystem management practices is essential for holistic biodiversity conservation.

Fungi play critical roles in nutrient cycling, soil health, and plant symbiosis, making their conservation integral to ecosystem functioning. Approaches such as sustainable forestry, habitat restoration, and protected area management should incorporate fungal conservation considerations. For instance, leaving deadwood in managed forests supports saproxylic fungi, while protecting mycorrhizal fungi is crucial for forest health. A recent study in Greece showed that fungal diversity of saprotrophic and xylotrophic fungi is significantly higher in undisturbed sites (such as sacred) because of the old trees they hold compared to the managed coppice forests; moreover, the study indicated that mycorrhizal fungi show remarkable incidence in both sacred (undisturbed)

[24] https://www.isprambiente.gov.it/en/istitute
[25] https://ndm.isprambiente.it/en/homepage-english/

and managed coppice forests (Diamandis et al., 2021). Ecosystem-based management strategies that consider the needs of fungi alongside other biota contribute to resilient and functioning ecosystems.

2.4. Priorities for the conservation of macrofungi

According to the Kew's State of the World Plant and Fungi[26], "*all yet undiscovered fungi should be considered as threatened*". This statement drives the directions and the priorities which are essential for advancing macrofungi conservation in Europe. These include:

- **Enhanced Research and Monitoring**: Continuing investment in research to fill knowledge gaps about fungal diversity, ecology, and threats. Improving monitoring programs to track population trends and the effectiveness of conservation measures.
- **Policy Integration**: Strengthening the integration of fungi into national and international conservation policies and frameworks. Advocating for the inclusion of fungi in biodiversity assessments and conservation funding.
- **Climate Change Adaptation**: Addressing the impacts of climate change on fungal habitats and populations through adaptive management strategies.
- **Habitat Protection and Restoration**: Prioritising the protection and restoration of critical fungal habitats, including old-growth forests, grasslands, and wetlands.
- **Public Engagement and Education**: Expanding public engagement efforts to build a broader base of support for fungal conservation. Promoting citizen science and community involvement in monitoring and conservation activities.
- **Collaborative Networks**: Strengthening collaboration among mycologists, conservationists, policymakers, and stakeholders across Europe to share knowledge and resources and coordinate conservation efforts.

These directions will ensure that fungal conservation becomes an integral part of biodiversity conservation efforts in Europe, safeguarding these vital organisms for our planet and future generations.

JoNeF has initiated this collaborative effort to unite individuals working with macrofungi across Europe to achieve common conservation goals. This approach is crucial for implementing effective conservation actions for macrofungi throughout the continent.

The following Focus Box 1 explores the Bern Convention's historical gap in addressing fungal conservation, highlighting initiatives like the European Charter on Fungi-Gathering and Biodiversity and the role of projects in promoting fungi conservation practices and addressing legislative shortfalls.

[26] https://www.kew.org/science/state-of-the-worlds-plants-and-fungi

Focus Box 1: From the Bern Convention to European Fungi Conservation Initiatives

Authors: Panagiotis Madesis, Dheeraj Singh Rathore, Eleni Topalidou

Affiliations: see Annex I

The Bern Convention, formally known as the Convention on the Conservation of European Wildlife and Natural Habitats, stands as a crucial international treaty aimed at safeguarding Europe's biodiversity[27]. Enforced since 1982, the convention focuses on protecting wild flora and fauna, with a particular focus on endangered and vulnerable species, including their habitats, across its member states[28]. It emphasises the need for international cooperation in the conservation of species and their habitats across national borders.

Under the Bern Convention fungi are no longer treated as an obscure subset of "lower plants" but recognised as their own kingdom with an extraordinary diversity[29]; however, fungal species have been historically overlooked, in both the appendices of the Bern Convention and other key legislation, such as the **Council Directive 92/43/EEC** on the conservation of natural habitats and wild fauna and flora (Habitats Directive).

The **European Charter on Fungi-Gathering and Biodiversity[30]**, building on the Bern Convention, seeks to fill this gap by promoting sustainable fungi gathering practices and raising awareness about the ecological importance of fungi. Although no fungal species are currently listed under the Bern Convention, the European Council for the Conservation of Fungi (ECCF) has played a key role in addressing this oversight. In 2007, the ECCF reviewed the status and threats of 33 species, listed by the IUCN as endangered, in a report for the Standing Committee. The findings of this review helped shape **Recommendation No. 132 (2007)**, which urged member states to implement stronger conservation measures for fungi in Europe.

Despite fungi being historically underrepresented in conservation actions due to insufficient knowledge of their ecology, taxonomy, and conservation status, awareness of declining fungal populations has grown significantly in recent decades. Habitat loss, degradation, and nitrification are major threats to fungal biodiversity in Europe. The **"Declaration of Cordoba"** (World Fungi 2007[31]) and the **"Guidance for the Conservation of Mushroom in Europe"** (Senn-Irlet et al., 2007) have been instrumental in promoting better protection and management of fungal species, laying the groundwork for the **European Charter on Fungi-Gathering and Biodiversity** (Brainerd & Doornbos 2013). This Charter provides practical guidance to ensure that the gathering of fungi is conducted sustainably, balancing human use with the protection of fungal habitats and biodiversity. Projects like JoNeF are critical in this context, as this highlights the lack of legal frameworks and conservation efforts for fungi, addressing their ecological importance and the need for focused, sustainable conservation strategies.

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[27] https://www.coe.int/en/web/bern-convention
[28] https://www.coe.int/en/web/conventions/full-list?module=treaty-detail&treatynum=104
[29] https://www.coe.int/en/web/bern-convention/on-the-conservation-of-plants
[30] https://rm.coe.int/1680746764
[31] World Fungi 2007 is the 1st World Conference on the Conservation and Sustainable Use of Wild Fungi (Cordoba, Spain, 10-16 December 2007): http://www.cybertruffle.org.uk/whitbymycosynod/decofcor.pdf

3. Macrofungal Monitoring and Assessment Initiatives in Europe

Authors: Stephen Mifsud, Francesca Floccia, Livia Kisne Fodor, Katerina Rusevska, Celeste Santos-Silva, Susana Gonçalves, Izabela Kałucka

Affiliations: see Annex I

"FUNGI ARE THE FIRMAMENT OF LIFE ON EARTH. THEY MAKE SYSTEMS ECOSYSTEMS."

Giuliana Furci, founder and director of Fungi Foundation

Monitoring and assessment are indispensable for ensuring that strategies for species conservation are effective, responsive, and sustainable. They provide the feedback necessary to adapt and improve conservation practices, leading to better protection and preservation of biodiversity and natural ecosystems.

There are many definitions of monitoring, depending on the area of interest. Particularly, concerning environmental protection, United Nations Economic Commission for Europe (2016) define it as "Environmental monitoring is a tool to assess environmental conditions and trends, support policy development and its implementation, and develop information for reporting to national policymakers, international forums and the public"[32].

Macrofungal monitoring and assessment initiatives in Europe are critical for understanding and conserving the diverse and ecologically significant fungal species found across the continent. In addition, the conservation of macrofungi is more crucial since they are often neglected in conservation compared to plants and animals, as discussed below. These initiatives are usually driven by a combination of national programs, research institutions, and citizen efforts, and are essential for tracking the health of ecosystems and informing conservation policies.

The JoNeF survey was primarily carried out in European countries, with questions focused on national and subnational (local and regional) levels.

In the field of conservation and data collection, local initiatives are often focused on specific species and habitats, instead, regional ones aim to manage ecosystems. On the other hand, national programs prioritise policy development and comprehensive conservation planning, and, at least, global initiatives address transboundary issues and large-scale environmental change.

[32] https://unece.org/environmental-monitoring#:~:text=Environmental%20monitoring%20is%20a%20tool,international%20forums%20and%20the%20public

This chapter focuses primarily on national initiatives, whereas sub-national ones are also documented in the JoNeF Survey Report (IMPEL, 2024).

3.1. National data resources: data collection surveys, monitoring initiatives and fungaria

Biodiversity plays an important role on Earth, for healthy ecosystems and everyday human life. Fungi are a diverse group of organisms that play crucial environmental functions, but also have numerous human applications. Therefore, the knowledge of fungi and mycodiversity is of particular importance for the sustainability of healthy ecosystems, as well as for human life.

In the framework of JoNeF project, a survey concerning the most important questions for the knowledge of mycodiversity, fungaria, databases, monitoring etc. from approximately 30 countries (number varies slightly depending on questions) was performed.

There are several types of institutions specialised in the conservation and data collection of fungi in countries from Europe, such as universities, institutes, governmental institutions, associations or NGOs.

National data resources on macrofungi are crucial for the inventory and effective conservation of fungi. They provide the essential information needed to understand fungal diversity, monitor population trends, identify threatened species, support habitat conservation, and develop informed conservation strategies. Investment and utilisation of these resources enhance the protection of fungal species and the critical roles they play in maintaining healthy ecosystems and associated ecosystem services.

Fungi are among the most diverse groups of organisms where some 2.5 to 5 million species are estimated to occur on Earth (Niskanen et al., 2023, Gautam et al., 2022), yet they are often underrepresented in biodiversity studies and only a fraction are described. National data resources help catalogue and document the wide range of fungal species present across different countries and ecosystems.

Monitoring initiatives and long-term surveys are vital for gathering data on the population trends of fungal species. By tracking changes in population sizes, distributions, host associations and threats over time, scientists can identify species that are in decline, whether due to habitat loss, pollution, climate change, or other threats, especially of anthropogenic origin.

Comprehensive data collection through national macrofungal resources also helps identify species that are rare, declining rapidly and restricted to a small geographical area (sometimes endemic), which may require targeted conservation measures to prevent extinction. Fungaria, which are repositories of preserved specimens, also play a key role by providing physical evidence and reference material for species identification and occurrences, hence further aid in conservation assessments including habitat restorations.

Fungi often have specific habitat requirements - sometimes host-specific, and their qualitative and quantitative occurrences can indicate the health of natural environments, from a specific natural habitat to an entire ecosystem. By using national data resources to map fungal distributions, conservation scientists and stakeholders can identify key habitats that need protection. Protecting these habitats not only conserves the fungi themselves but also the broader ecosystem services they support.

It is important to note that accurate and comprehensive fungal data are essential for developing effective conservation strategies. This data provides the scientific foundation needed to design conservation plans, set priorities, and allocate resources effectively.

According to the JoNeF Survey Report (IMPEL, 2024), several countries have national-level data collection initiatives for fungi (see Figure 17). These programs vary in scope, with some concentrating exclusively on fungi, others integrating fungal data within broader information systems that manage various types of biotic data. Specific programs collect data on all macrofungal species and are employed to create checklists, while others focus on specific groups, such as protected or endangered species, and are used to compile Red Lists. However, it is important to note that the respondents to the survey did not always provide precise or exhaustive information on such programs, which may affect the completeness of the reported maps.

Specifically, in Greece, which is noted as "NA" in Figure 17, several collection initiatives focusing exclusively on macrofungi have been (or are currently being) implemented. These include activities in protected areas such as the National Parks of Samaria and Western Crete, the Prespes area in NW Greece, the Aegean islands, and elsewhere, notably within the framework of the 'FunDive' project.

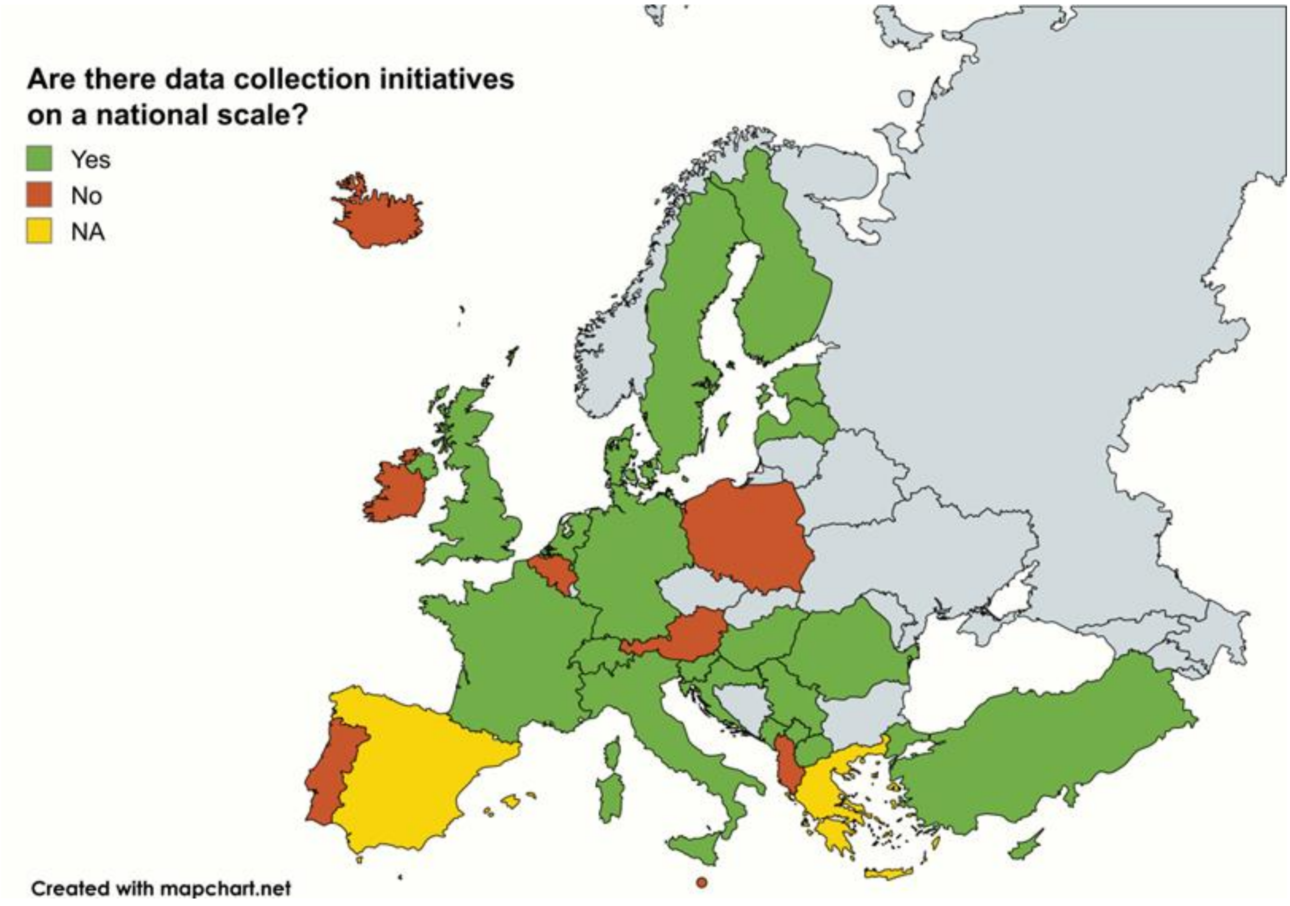

Figure 17. Map of countries with reported national-scale data collection initiatives and/or projects on fungi (source: IMPEL, 2024).

Data collection programs initiated by associations play a crucial role in fungal conservation. Data collection programs and initiatives are present in most responding countries and are driven by volunteer-based citizen science, with 84% of surveyed countries reporting active citizen science-based data collection on fungi.

Associations and groups often lead local efforts that fill critical knowledge gaps, particularly in underrepresented regions or habitats. These projects foster collaboration among scientists, conservationists, policymakers, and the public, enhancing conservation efforts and building a strong network of fungal conservation advocates.

3.2. National data recording and storage

Concerning best practices in data collecting and sharing for mycodiversity observations, several principles guide effective and ethical data management. These principles are particularly relevant for Europe, where biodiversity data is increasingly made open source through collaborative platforms. The JoNeF Survey Report (IMPEL, 2024) outlines several of those practices and summarises their enforcement in several European countries.

The essential key points are:

1) **Standardised Protocols**: The presence of official and/or national protocols for data collection ensures more reliable and high-quality information. Only nine countries reported having such protocols, which are essential for maintaining consistency and accuracy in data collection (Figure 18).

2) **Citizen Science Initiatives**: Public engagement through citizen science projects has proven effective for data recording: 84% of responding countries indicate the existence of citizen science programs for fungal data collection, however not all countries have national-level initiatives.

3) **Centralised Databases**: Centralised databases or information systems for organising fungi data facilitate better data sharing and accessibility. Thirteen countries reported having such systems, but only ten utilize fungal indicators to evaluate habitat quality and conservation status.

4) **Online Accessibility**: Making databases available online is crucial for enhancing transparency and collaboration in conservation efforts. Only five countries have a national checklist freely accessible to the public online. Although, there are several regional macrofungal lists for many European countries, available in online journal articles.

Notable examples of open-source databases including fungi are the Global Biodiversity Information Facility[33] (GBIF), one of the largest open-access biodiversity repositories and databases in the world, including significant fungal data from European sources. It aggregates data from various sources (research institutions, museums, mycological publications, etc.), and citizen science projects, like the Research Grade observations from iNaturalist[34], the largest citizen science platform for biodiversity recording around the world.

[33] https://www.gbif.org/
[34] https://www.inaturalist.org/

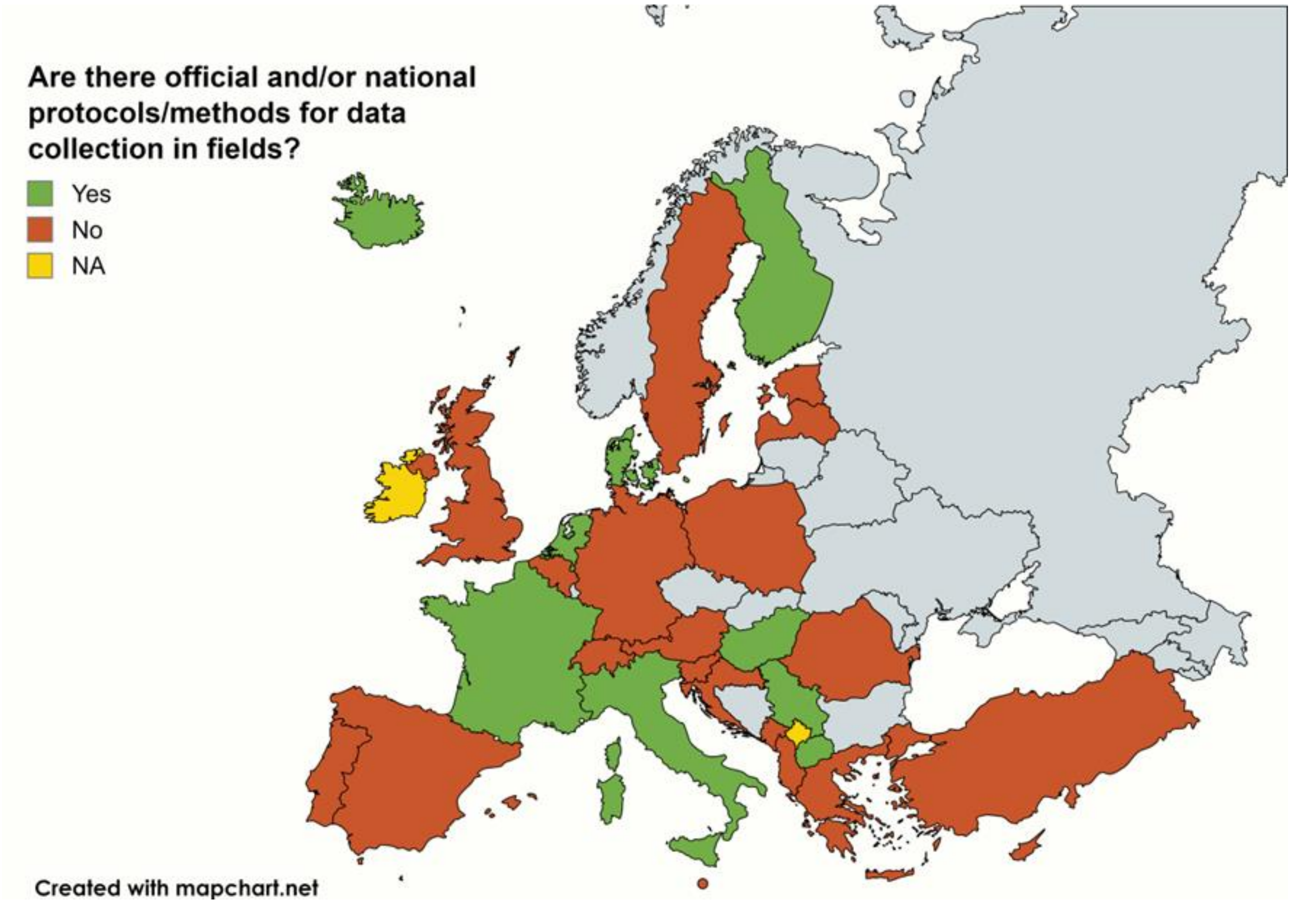

Figure 18. Map of countries reporting official and/or national protocols or methods for field data collection (source: IMPEL, 2024).

MycoBank[35] maintains a comprehensive database on fungi, focusing on nomenclature and species descriptions. Similarly, Species Fungorum Plus[36] is a project to produce an effectively complete global checklist of organisms belonging to the kingdom Fungi and organisms that were previously included in the fungi but are now classified in other branches of the tree of life; it is built on top of the global fungal nomenclator Index Fungorum, which is also a major source of names for the GBIF taxonomy backbone. These databases are essential for taxonomic research on fungi. Observation.org[37] is a platform designed for registering biodiversity observations, including fungi, across Europe; linked to the app ObsMapp (available on Android and iOS), it has a strong focus on European species and offers offline recording capabilities. PlutoF[38] is a cloud-based platform used by researchers to manage, analyse, and share biodiversity data, with a strong emphasis on mycology. Its associated App, called PlutofGo, allows easy data entry. An example of an open, curated, national-scale fungal database operating on a voluntary basis is Atlas grzybów [Mushrooms and Fungi of Poland][39]. Apart from descriptions, photographs and notes on most of the macromycetes found in Poland, it contains the system of gathering new records of protected and

[35] https://www.mycobank.org/
[36] The Catalogue of Life Partnership: Species Fungorum Plus http://www.catalogueoflife.org/ ; https://www.speciesfungorum.org/
[37] https://observation.org/
[38] https://plutof.ut.ee/
[39] https://www.grzyby.pl/index.html

threatened fungi reported by citizen scientists, with exact locations, pictures and identification of fungal species confirmed by mycologists and documented with fungarium voucher collections.

To summarise, best practices in fungi data collection and sharing in Europe emphasise free access, standardisation, and collaboration between citizen scientists and researchers. Several European countries lead by example with platforms and databases that ensure data is accessible, high-quality, and widely used for biodiversity conservation. Apps like iNaturalist and Observation.org that feed into GBIF play central roles in democratising fungi data accessibility across the continent.

3.3. Assessment of data: maps, indicators, trends

The assessment of data on fungi through maps, indicators, and trends provides essential insights into their distribution, roles in ecosystems, and responses to environmental change. While significant progress has been made in understanding fungal biodiversity and its impacts, ongoing research and technological innovations are crucial for improving the ability to monitor and manage fungi, particularly in the face of climate change and global biodiversity loss.

Mapping the distribution of fungi is essential for understanding their ecological roles and biogeography. Maps are usually generated from field surveys, satellite imagery, and herbarium records and are essential to provide spatial information about fungal species across different ecosystems. For instance, the mapping and recording database operated by GBIF is the main source for IUCN assessments to categorise species' Red lists.

Based on the JoNeF Survey Report (IMPEL, 2024), about half of the 32 countries that answered the survey have a central database and/or an information system for organising the data concerning fungi. In the other half there is an effort to make it or use some other options, like using data from GBIF[40] or iNaturalist[41] (see Figure 19). Fungi can act as indicators of ecosystem health.

In the JoNeF Survey Report, 10 out of 32 countries reported using fungal indicators to analyse the quality and conservation status of a habitat or area. Some indicators are not official or are included in other documents (such as the National Biodiversity Strategy or the Natura 2000 system); others have been developed for selected habitats. For example, the proportion of protected species and the proportion of red-listed species are instruments that can help support the expert judgement regarding the conservation status (Figures 20, 21).

In Hungary, in the monitoring protocols there are used several indicators like trends in species number, fruit bodies number (abundance), diversity indexes, functional spectrum, proportion of protected species, proportion of red-listed species.

[40] GBIF is the Global Biodiversity Information Facility: https://www.gbif.org/
[41] iNaturalist is a Community for Naturalists: https://www.inaturalist.org/

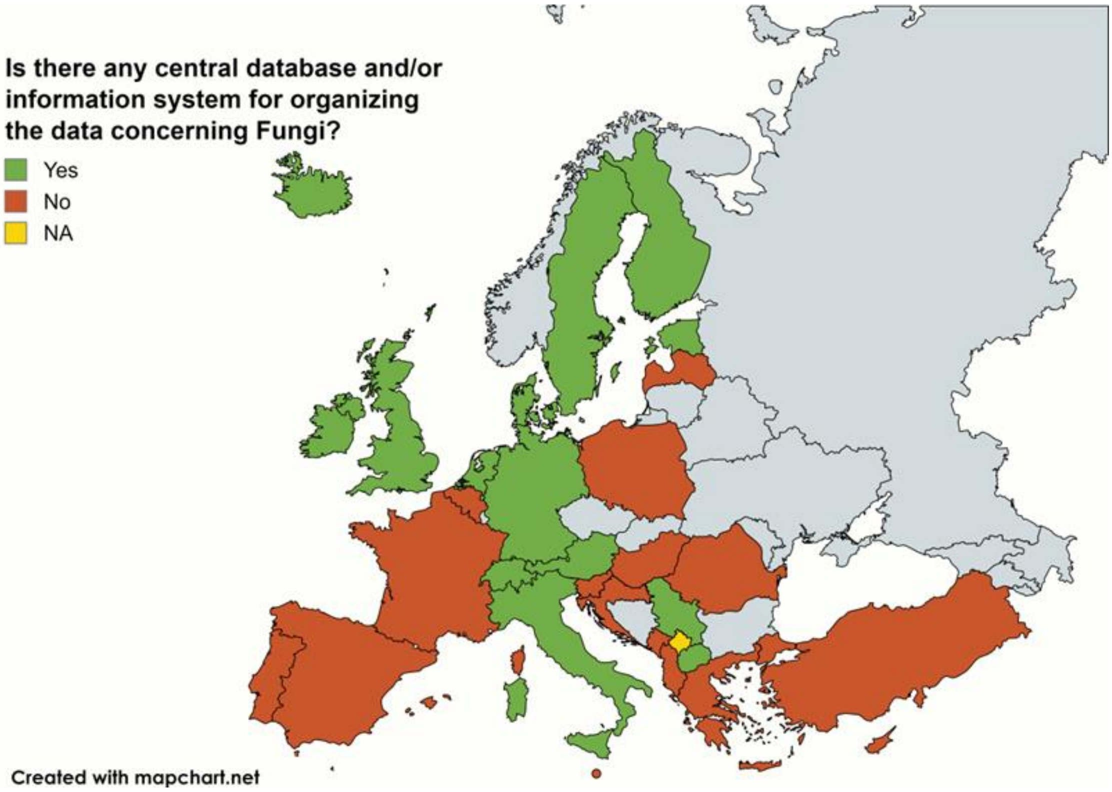

Figure 19. Map of countries with a central database and/or information system for organizing fungal data (source: IMPEL, 2024).

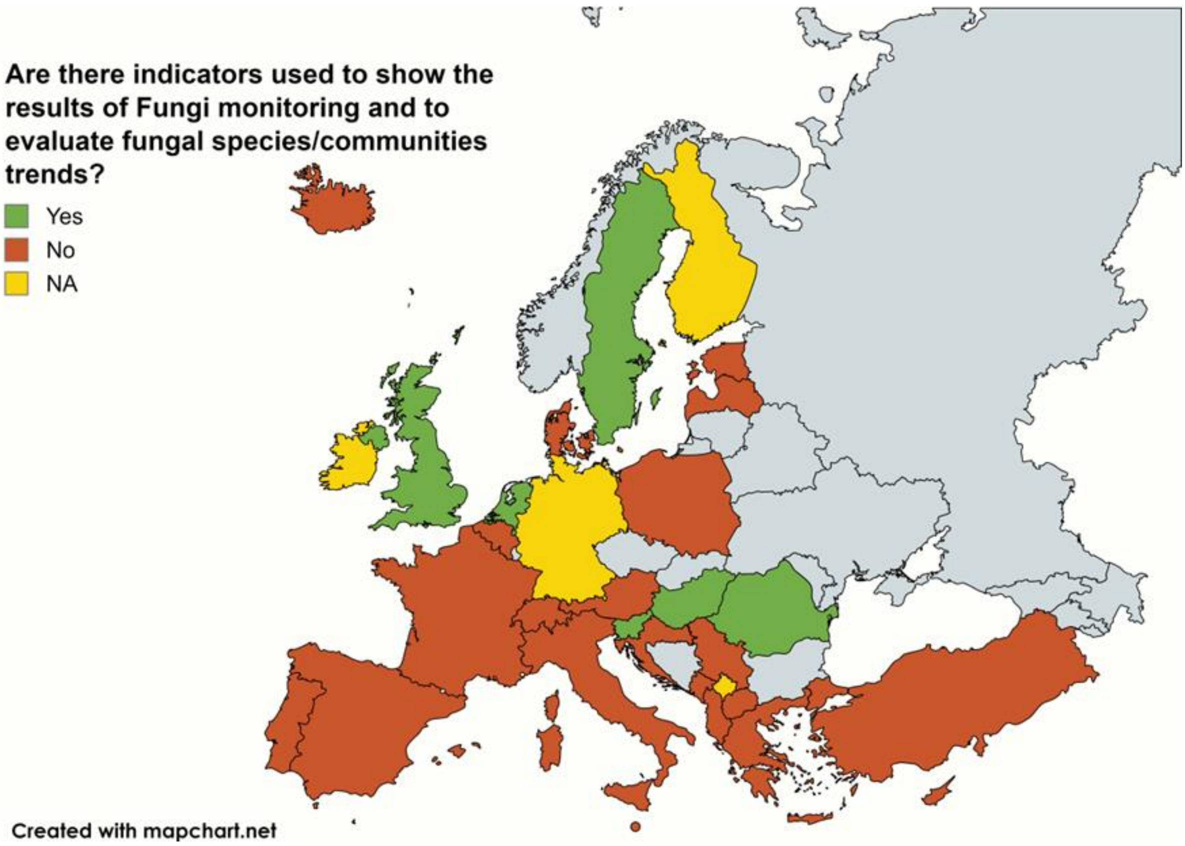

Figure 20. Map of countries reporting the use of indicators to display fungi monitoring results and evaluate trends in fungal species and communities (source: IMPEL, 2024).

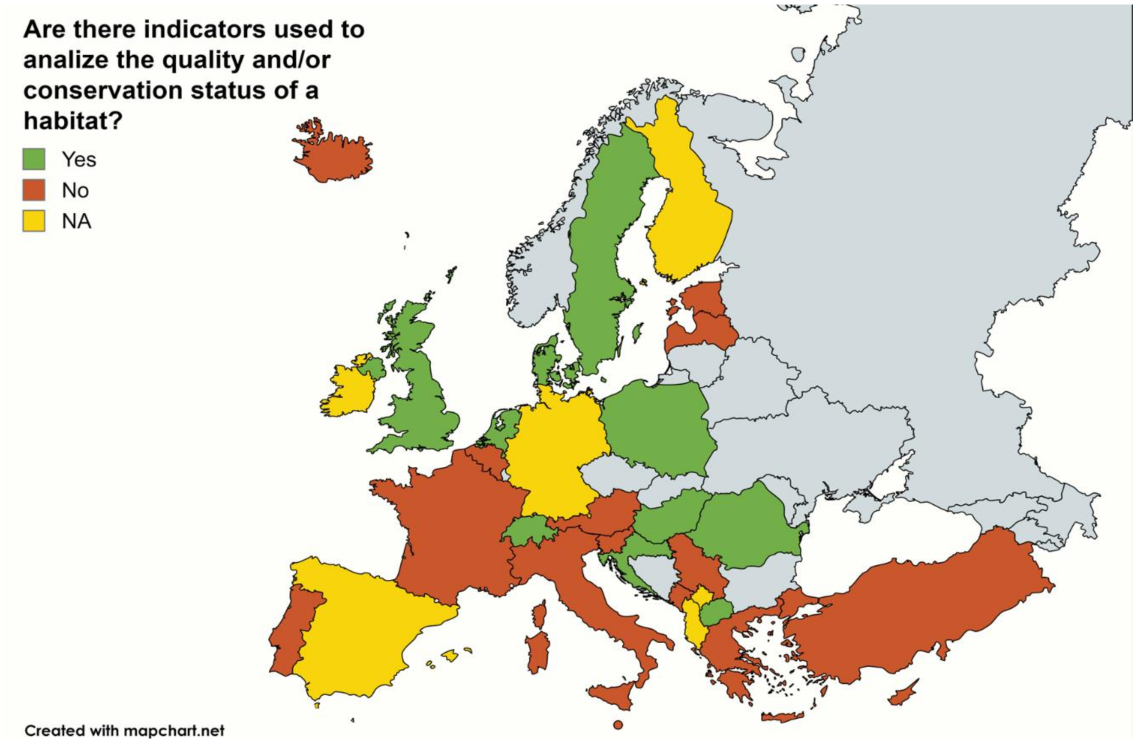

Figure 21. Map of countries reporting the use of indicators to assess the quality and/or conservation status of habitats or areas (source: IMPEL, 2024).

As fungal populations are often highly sensitive to environmental fluctuations, long-term monitoring of species and communities is key to identifying trends related to climate change, land-use changes, and human activities.

Despite the growing availability of data on fungi, several challenges remain because fungal diversity is vast and poorly documented compared to other kingdoms like plants and animals. Moreover, many fungi are cryptic or have life stages that are difficult to detect, making field surveys challenging. Plus, some species do not produce fruiting bodies every year. Finally, the lack of standardised protocols for collecting and reporting fungal data hinders the ability to compare studies across different regions and time periods.

3.4. Application of data: national checklists and Red Lists

Accurate scientific understanding of biodiversity distribution is crucial for effective nature conservation and the sustainable management of natural resources. Species checklists are important tools for taxonomy and ecology and are necessary for distribution research and making conservation plans. They also serve as a foundation for legislation concerning protected species. Due to their dynamic nature, checklists require continuous updates as new species are discovered, or changes in the species distribution occur, or some taxa need to be updated or corrected according to new research and taxonomical reviews. Fungal checklists are essential for understanding national mycobiota. Preparing complete national fungal checklists is still a challenge in many countries due to several factors, like their huge diversity, identification difficulties, and cryptic nature (e.g. fungi producing very small fruitbodies or hypogeous fruitbodies), the increasing need to perform molecular analysis for determination, and the small number of mycologists, as well as, citizen scientists when compared to those who study plants and animals. Several initiatives such as GBIF[42], iNaturalist[43], Biodiversa+[44] and FunDive[45] are fundamental in the process of creating checklists and providing distribution data for Red List assessments.

Considering the current state of national fungi checklists that are based on the JoNeF survey report, only 18 of 31 European countries have published checklists for macrofungi, four of which are provided on online database platforms (Figure 22). Some of the lists are not updated and there is a difference in the content of selected species/groups. During the period of the questionnaire, Latvia and Iceland remarked that their checklist is in preparation, although the latter has published the checklist of Latvian macrofungi in 2024[46].

Red Lists rely heavily on regional and national species checklists, which serve as their foundation. Since only a limited number of countries have comprehensive checklists, the status of Red Lists reflects a similar pattern. Currently, 19 countries have Red Lists; however, many are outdated, with some remaining unrevised for over 20–30 years. Furthermore, only 10 countries have compiled their Red Lists following IUCN criteria. It is important to highlight the significant variation in the number of species evaluated across these national Red Lists.

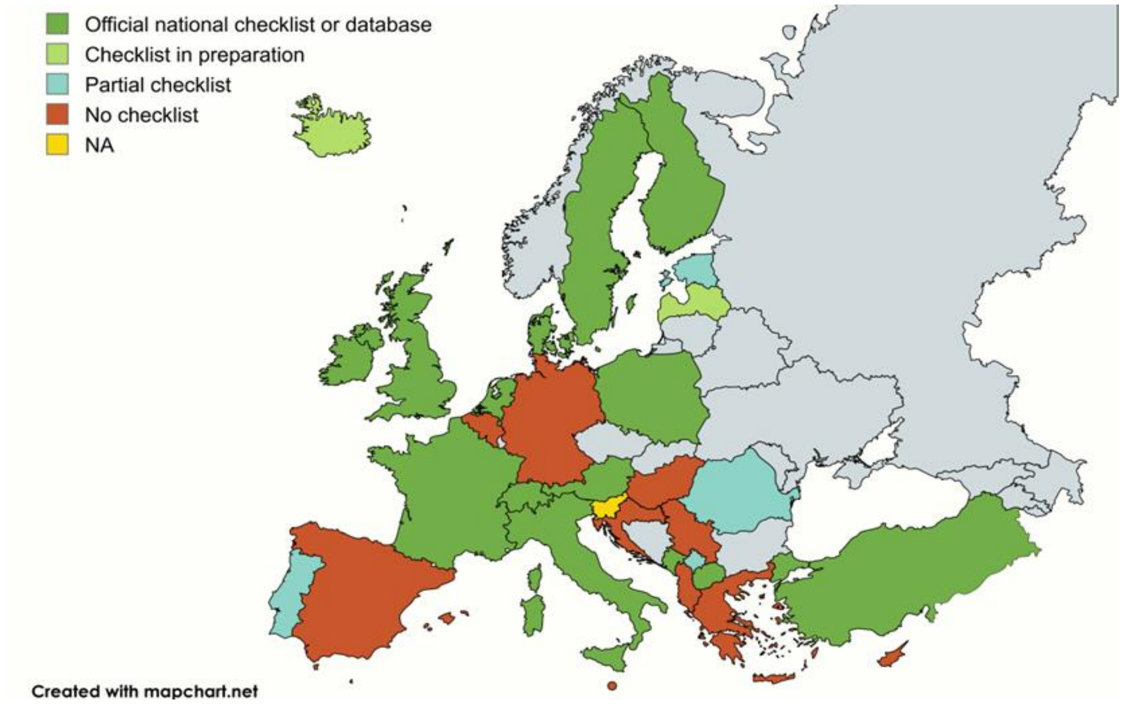

Figure 22. Availability and status of national fungal checklists in Europe (source: IMPEL, 2024)[47].

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[42] GBIF—the Global Biodiversity Information Facility: https://www.gbif.org/
[43] https://www.inaturalist.org/
[44] https://www.biodiversa.eu/
[45] https://fun-dive.eu/
[46] https://www.silava.lv/images/articles/Latvijas-Vegetacija/2024-34/2024-LatVeg-34.pdf
[47] Note on Figure 23: Figure 23 is not accurate with respect to Greece. There are published checklists for macrofungi (Basidiomycota and Ascomycota), such as Zervakis, G., Dimou, D., and Balis, C. (1998). A checklist of the Greek macrofungi, including hosts and biogeographic distribution: I. Basidiomycotina. Mycotaxon 66, 273–336, and Zervakis, G., Lizon, P., Dimou, D., and Polemis, E. (1999). Annotated checklist of the Greek macrofungi: II. Ascomycotina. Mycotaxon 72, 487–506. In addition, an updated national checklist is currently under preparation, highlighting ongoing efforts in fungal biodiversity documentation in Greece.

3.5. Towards establishing a European Fungi Monitoring Network

3.5.1. Biodiversity monitoring

Monitoring is essential for understanding biodiversity trends and guiding conservation actions. While meaningful results require consistent, long-term data collection, fungal monitoring faces practical challenges such as ensuring continuity, stable funding, and institutional support.

The "general indicator" theory (Juhász-Nagy, 1986) underpins biodiversity monitoring, stating that living organisms and their attributes, as occurrence, abundance, and interrelationships, reflect environmental limiting factors. Trend monitoring identifies population and community dynamics, providing baselines for detecting anomalies. Early detection enables more effective and cost-efficient interventions.

Reliable comparisons across time and space require standardized methods for data sampling, analysis, and assessment. Biodiversity monitoring informs decision-makers and the public, offering a foundation for conservation and sustainable management by tracking species, habitats, and threats over time.

3.5.2. Biodiversity monitoring requirements in EU legislation and in other international agreements for nature conservation

Monitoring and long-term observation of biodiversity is not only a requirement of the Convention on Biological Diversity but also a priority task in the European Union. The implementation of the nature directives, including the Directive on the Conservation of Wild Birds (79/409/EEC), and the Directive on the Conservation of Natural Habitats and of Wild Flora and Fauna (92/43/EC), aim to preserve the natural heritage and biological diversity of Europe through the conservation of species and habitats of Community importance. Under Article 17 of the Habitats Directive, the conservation status of species (lichens, mosses, higher plants, animals) and habitats of community importance must be continuously monitored and reported every six years to the European Commission.

Fungi are not explicitly mentioned in these Directives, highlighting that their conservation is not being given importance. Yet, as mentioned above, they play an essential role in ecosystem processes.

In 2003, on behalf of the ECCF, Sweden proposed 33 fungi species to Annex I of the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats). However, the proposal was withdrawn as it did not receive the backing of most of the European Union States (Report of Standing Committee, 2003). The main reason was that the Annex included commercial species and species which were frequent in some regions[48]. In 2007, the Bern Convention released a recommendation [No. 132 (2007)] on the conservation of fungi in Europe [Senn-Irlet et al., 2007, T-PVS (2003) 24[49]]. Later, the convention released another document concerning fungi, about the gathering of macrofungi under the title: European Charter on fungi-gathering and biodiversity (Brainerd & Doornbos 2013).

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[48] CONVENTION ON THE CONSERVATION OF EUROPEAN WILDLIFE AND NATURAL HABITATS. Standing Committee 23rd meeting. Strasbourg, 1st-4 December 2003. Comments on the proposal to include 33 fungi species to the Appendix I.

[49] T-PVS (2003) 24 is the report of the 23rd meeting of the Standing Committee of the Bern Convention, held from 1 to 4 December 2003: https://rm.coe.int/0900001680928e73

3.5.3. Challenges and opportunities in monitoring of Fungi

Monitoring fungi presents significant challenges due to difficulties in detecting them in the field and accurately identifying them at the species level. The special lifeform, the small size of sporocarps (fruiting bodies) of many species, the ephemeral occurrence (often just a few days) due to their weather-dependence and the difficulties in the examination of material all contribute to some challenges that naturalists and collectors face during monitoring in the field. The sporocarps of ink-cap fungi last a few hours to a few days; bonnet mushrooms and some genera of cup-fungi are less than 5mm wide; truffles grow underground in the soil; and some bracket fungi are located high on trees. These are only a few examples to demonstrate the difficulties in monitoring macrofungi, which traditionally are identified on gross morphology and using powerful microscopes with special staining techniques. In addition, species may not fruit every year depending on nutrient availability and climate conditions. Without fruiting, these species can remain hidden for decades.

In the last few decades, accurate identification of fungi has been assisted by molecular analysis, which provides a more representative picture of the fungal community present. However, this approach requires funds and resources which are rarely accessible to all data collectors, e.g. citizen scientists. Hence, it is not feasible to conduct molecular surveys on a large scale, and identification of sporocarps by classical means for now remains the most viable method of monitoring that requires reasonable effort and can be conducted to encompass most fruiting species within large areas. Furthermore, fruiting and production of spores are important for the long-term survival of fungal species as they represent the sexual reproductive structures of the species. Thus, sporocarp surveys over time are suitable to evaluate the reproductive fitness of fungal populations (Senn-Irlet et al., 2007). For the purpose of assessing species' extinction risk, sporocarps are considered functional individuals, aligning with the IUCN Red List concept of mature individuals (Dahlberg & Mueller, 2011).

However, recent advancements offer promising opportunities. Over the past decades, molecular techniques have revolutionized fungal identification, enabling a more comprehensive and accurate picture of fungal communities. While mycologists working on fungal diversity, taxonomy, and phylogenetics generally possess both the necessary skills and strong interest in their field, the main challenges lie in their relatively low numbers and the limited resources allocated to mycological research and conservation. Additionally, the absence of established conservation protocols for fungi in the EU often redirects emerging scientists toward other branches of biodiversity, such as marine, plant, or zoological studies, where funding opportunities and career prospects are more abundant. This creates a negative feedback loop, further marginalizing fungi in conservation efforts at both political and national levels.

In conclusion, while challenges persist, technological advancements, growing public interest, and collaborative approaches offer significant potential to improve fungal monitoring. By building on these opportunities, fungal conservation can gain greater visibility and contribute to broader biodiversity strategies at national and European levels.

3.5.4. Species and habitat monitoring

Species monitoring is important to follow trends in population sizes and distribution areas. The conservation status of a species, whether it has been red-listed and evaluated as threatened or covered by legal protection, is important for nature conservation concerns, as some respondents mentioned in the questionnaire. However, the species can be selected for monitoring also by their indicator characteristics.

There is a strong tradition in northern Europe of using selected species of fungi (both macrofungi and lichens), insects, mosses and other plants as indicators of habitat quality, especially in grasslands and old-growth forests rich in dead wood (Heilmann-Clausen & Vesterholt, 2008).

Macrofungi are very suitable indicators of dead wood continuity (decomposition quotient) and the well-being of nature in general. This is especially true at the landscape scale, and indicator species are used as one of several tools in selecting forest reserves and/or woodland key habitats in several countries. In Denmark, Finland, and Sweden, wood-inhabiting macrofungi have been included in the Natura 2000 programme for forests to assess favourable conservation status (Senn-Irlet et al., 2007).

3.5.5. Lesson learned from JoNeF questionnaire regarding monitoring of fungi

In the JoNeF questionnaire several questions were about collecting information on monitoring activities concerning fungi. Based on the answers, there are very different approaches to the concept of monitoring, and because of the short answers in the questionnaire, it is not possible to analyse the details. For most respondents, monitoring means mainly to collect the data on selected fungi species, and only two cases mentioned to regularly survey the fungal diversity (fungi/habitat association) of a given area (IMPEL, 2024). Only some respondents stated that monitoring means long-term observation with standardised methods. Hence one of the roles of this guidance is to ask policymakers to provide common protocols to achieve a shared approach.

About half of the countries reported developing macrofungal indicators for monitoring and analysing the quality and conservation status of a habitat/area. In the future, it is expected that the assessment of the state of nature, vulnerability and linked measures are based on databases (IMPEL, 2024).

The answers of the JoNeF questionnaire highlighted that most of the countries are willing to have fungi monitoring initiatives. Internationally harmonised monitoring activities could give a higher level of conclusions.

3.5.6. Towards a harmonised system for monitoring fungi in Europe

Harmonisation of monitoring activities could work based on a well-planned and improved coordination, synchronisation and standardisation of monitoring protocols for sampling, analyses, databasing and archiving.

Investing funds in data sharing mechanisms, data analysis and management is needed. In addition, raising modelling efforts and using new technologies could be partly the possible solution to the above difficulties (Moersberger et al., 2022).

Several good practices and experiences emerged from the JoNeF survey, but it also revealed that the related documents and detailed guidelines are mainly written in national languages, highlighting a basic impediment to sharing the knowledge and working methods. After analysing the data from the questionnaire and spotting several lacunas in the monitoring of macrofungi, the following needs, key activities and tasks are highlighted:

- **Sharing Best Practices**: Promoting effective approaches for monitoring fungi, with a focus on both species and habitat monitoring.
- **Standardised Methods for Data Comparability**: Ensuring consistency over time and across regions by implementing standardised methods for data collection and analysis, and guidelines for selecting ecological and conservation fungal indicators respecting biogeographical diversity.
- **Data Management Solutions**: Exploring and analysing options for data management to determine whether existing systems can be utilised or if a new information system is required.
- **Citizen Science Engagement**: Developing best practices to demonstrate how citizen science participation can enhance fungi monitoring efforts and expand capacity.
- **Educational Initiatives**: Planning training programs and educational activities to support fieldwork, data analysis, and the development of effective networks.

4. Recommendations for Implementing Macrofungi Conservation in Europe

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Introduction

“FUNGI ARE LIKE A CANARY IN A COAL MINE, ACTING AS BIOINDICATORS FOR ENVIRONMENTAL CHANGES.”

Seraiah Alexander, November 27, 2023

Fungi play a crucial role in ecosystems, contributing to organic matter decomposition and nutrient cycling, soil formation, primary production, and overall ecosystem health. By incorporating fungi into environmental policies, we can contribute to protect crucial elements of our environment, as well as ecosystem services, to protect soils, to detect environmental stress, monitor habitat quality and much more.

Indeed, fungi are sensitive indicators of environmental changes like pollution and climate shifts, offering valuable insight into habitat quality. Their vast biodiversity, ecological importance and potential role in climate adaptation make them essential to ecosystem resilience. Including fungi in conservation efforts can also safeguard rare and endangered species and complement other biodiversity indicators, leading to more informed environmental management decisions.

In recent years, fungi have received growing attention from academics, scientists and the public, driven by a deeper understanding of their essential roles in ecosystems and the awareness that many fungal species are yet to be discovered, while others are at risk of extinction.

The JoNeF survey (IMPEL, 2024) examined existing legislation and actions regarding macrofungi across Europe. While it revealed a strong interest in fungal data collection and conservation, with varying approaches among European countries, it also highlighted a general lack of legislation specifically focused on the conservation of wild fungi.

This chapter outlines **four key recommendations** (listed below) to advance the conservation of macrofungi and their integration into biodiversity policy, conservation frameworks and management practices.

Recommendation 1

- ***Inclusion of Macrofungi Among 'Typical Species' of Annex 1 Habitat Types***
- Macrofungi should be recognized as essential indicators of habitat structure and quality, particularly those protected by Annex 1 of the Habitats Directive. Their inclusion in the official list of typical species in the framework of the Reporting under Article 17, ensures a more comprehensive approach to the habitat conservation status assessment.

Recommendation 2

- ***Enhancing the Inclusion of Fungi in Natura 2000 Standard Data Forms***
- Fungal species should be systematically incorporated into the Standard Data Forms used for collecting data on Natura 2000 sites, reflecting their critical role in ecosystem functioning and biodiversity conservation.

Recommendation 3

- ***Development of Habitat-Specific Fungal Species Lists and Their Integration into Monitoring Plans***
- Lists of fungal species tailored to specific habitats should be developed and used as indicators for monitoring their health and quality, and to guide conservation actions.

Recommendation 4

- ***Integration of Macrofungi into National and International Environmental Legislation and Conservation Strategies***
- Macrofungi must be formally recognized within legal and policy frameworks, both nationally and internationally, to ensure their protection and sustainable management as part of broader biodiversity goals.

The recommendations are supported by **focus boxes** on related issues authored by members of the JoNeF team and external experts. These case studies provide real-world examples, best practices and proposals.

Recommendation 1: Inclusion of Macrofungi Among 'Typical Species' of Annex 1 Habitat Types

Context: reporting under article 17 of the Habitats Directive 92/43/EEC.

Purpose: use of macrofungi in the assessment of conservation status of the habitats in Annex 1 of the Directive 92/43/EEC.

Target: this proposal is aimed at people involved in reporting under Article 17 of the Habitats Directive at various levels, including researchers, experts and technicians from **Ministries** and **environmental agencies**.

WE ENCOURAGE THE ADOPTION OF MACROFUNGAL SPECIES AS TYPICAL SPECIES FOR THE ASSESSMENT OF THE CONSERVATION STATUS OF THE HABITATS IN ANNEX 1 OF THE HABITATS DIRECTIVE.

Article 17 of the Habitats Directive requires a national report to be sent to the European Commission every six years by Member States. The core of the national reporting is the assessment of conservation status of all the habitat types and the fauna and flora species included in the annexes of the Directive which are found in the national territory of the Member State. The reporting requires the use of standard methodology and common formats throughout Europe.

The assessment of the conservation status is related to the concept of Favourable Conservation Status (FCS), defined in Article 1 of the Directive. The conservation status of a habitat is considered "favourable" when:

- its natural range and areas cover within that range are stable or increasing, and
- the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future, and
- the conservation status of its typical species is favourable (as defined in the same article).

The method for the evaluation of the conservation status of a habitat type includes four parameters to be assessed separately: *Range*, *Area*, *Structure and functions (including typical species)*, *Future prospects.* These four assessments need to be combined through a specific evaluation matrix (shown in the Reporting format, PART E) to give the overall assessment of the conservation status of each habitat type in every biogeographical region of a Member State (for the distribution of biogeographical regions see Figure 23). One habitat type can be assessed in Favourable Conservation Status only if the parameter *Structures and functions (including typical species)* is evaluated in good condition and without significant deteriorations and/or pressures.

The list of typical species for each habitat type must be provided by Member States together with the national report, following the official formats which require some additional information (e.g. biogeographical region, habitat code, update, species scientific name). Member States can optionally provide information on the method used for assessing typical species, and, if needed, can update the lists of typical species in every reporting cycle.

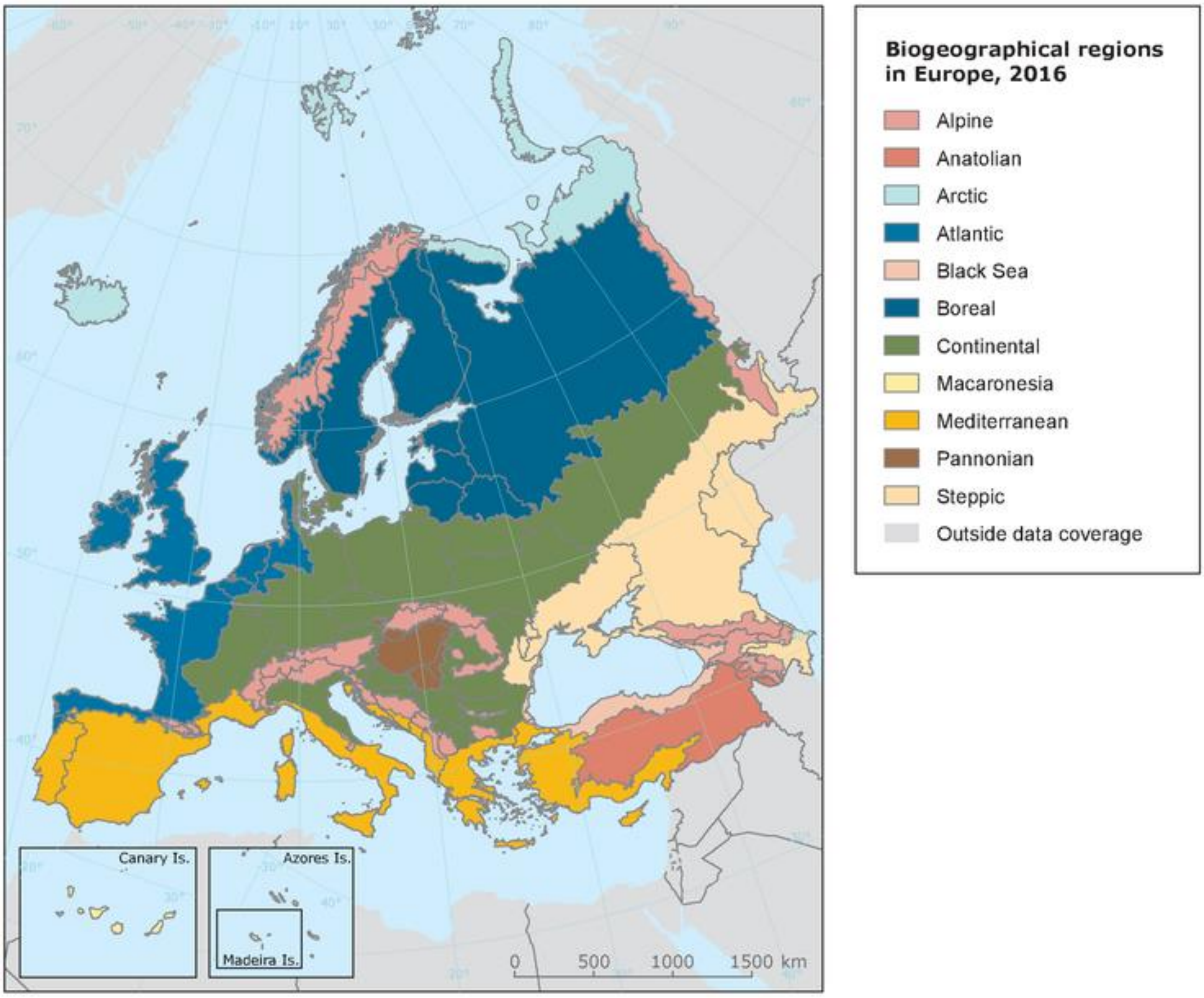

Figure 23. Distribution of the biogeographical regions in Europe[50].

The most recent European Guidelines for reporting[51] (DG Environment, 2023) indicate the following factors when selecting typical species:

• "typical species" should be species which occur regularly at a high constancy (i.e. are "characteristic") in a habitat type or at least in a major subtype or variant of a habitat type

• "typical species" should include species which are good indicators of favourable habitat quality, e.g. by indicating the presence of a wider group of species with specific habitat requirements. They should include species sensitive to changes in the condition of the habitat ("early warning indicator species")

• "typical species" should include species which can be monitored easily by non-destructive and/or inexpensive means should be favoured.

[50] Source: EEA, https://www.eea.europa.eu/en/analysis/maps-and-charts/biogeographical-regions-in-europe-2
[51] https://cdr.eionet.europa.eu/help/habitats_art17

Typical species can be selected among different groups based on the relation with the habitat type: inseparable from the habitat (whose ecological requirements are met only by the habitat in question, representing the ideal), consistently present but not restricted, characteristic, keystone-species (which significantly influence the habitat structure and functions), etc.

Characteristic species listed in the Interpretation Manual of European Union Habitats (European Commission, 2013) may be used as typical species if they meet one or more of the criteria mentioned above.

The Guidelines indicate that «typical species may be drawn from any species group and, although most species noted in the 2001–2006 and 2007–2012 reporting rounds were vascular plants, consideration should be given to also selecting lichens, mosses, **fungi**, and animals, including birds.» (DG Environment, 2023).

For further information on the Article 17 Reporting and typical species it is possible to consult the Reference Portal provided by Eionet (European Environment Information and Observation Network) at the following link: https://cdr.eionet.europa.eu/help/habitats_art17.

Considering their ecological functions, macrofungi could play an important role in the assessment of the conservation status of the Annex 1 habitat types.

Despite some authors (Ellwanger et al., 2018) highlight that the exclusion of fungi, as well as of animal species, is a notable weakness in the habitat monitoring frameworks of nearly all Member States, it is noteworthy that some of them (Spain, Finland, France, Lithuania, Latvia, the Netherlands, Sweden) have already integrated fungi among typical species in the habitat assessment for the article 17 reporting periods 2007-2012 and 2013-2018[52] (see boxes 2 and 3).

The selection of macrofungi as typical species requires deep biological and ecological knowledge of this taxonomic group, but also a good understanding of the reporting system and methods. Thus experts, such as ecologists, mycologists, and conservation biologists should collaborate with people officially involved in compiling the national Article 17 reports for the Member State, such as technicians of environmental agencies and ministries.

The following focus boxes (from 2 to 7) illustrate application cases and proposals related to the use of macrofungi as typical species of some Annex 1 habitat types.

[52] https://cdr.eionet.europa.eu/help/habitats_art17

Focus Box 2: Macrofungi as Typical Species in the Art.17 Habitat Assessment in Europe: a Brief Survey

Authors: Francesca Floccia, Valeria Giacanelli

Affiliation: see Annex I

The official lists of typical species used in the previous reporting periods (2008-2012 and 2013-2018; file downloadable from the reference portal for reporting under Article 17 of the Habitats Directive[53]) show that some countries have already integrated fungi in the habitat assessment for the Article 17 national reports.

Spain, Finland, France, Lithuania, Latvia, the Netherlands and Sweden have already integrated fungi among typical species in the assessment of the habitat conservation status: an overall number of 93 fungal species belonging to 32 Families are reported in the official list. The number of fungal species considered by each country is shown in Figure 24.

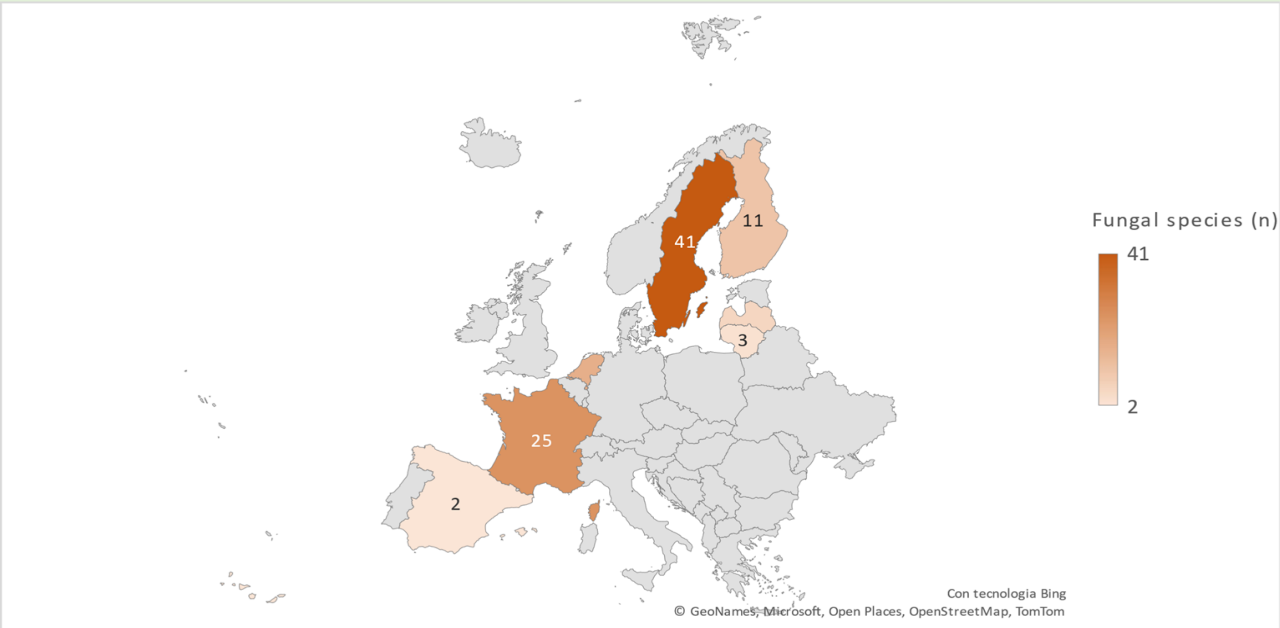

Figure 24. Number of fungal species used in art. 17 habitat assessment

[53] https://cdr.eionet.europa.eu/help/habitats_art17 ; excel file "The compilation of typical species used by Member States to assess the parameter 'Specific structure and functions (including typical species)' for the reporting periods 2008-2012 and 2013-2018".

Out of the 93 fungal species, 21 species (22,51%) are mycorrhizal fungi forming symbiotic relationships with trees and shrub roots, 47 (50,54%) are saprotrophic fungi, 25 (26,88%) are both parasitic and saprotrophic species (Figure 25).

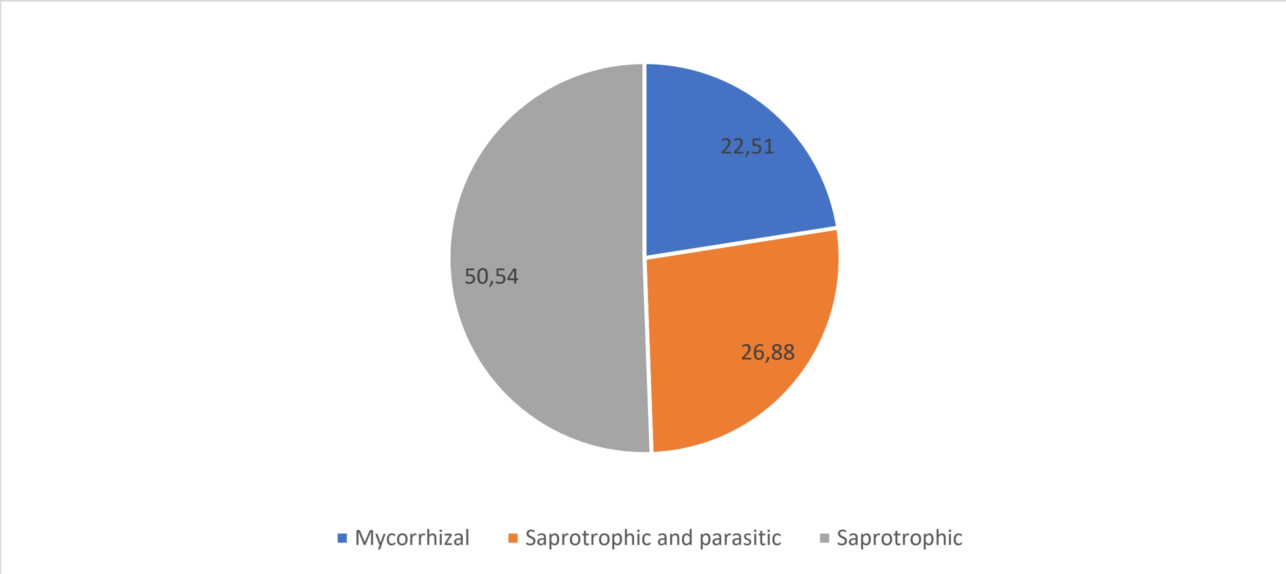

Figure 25. Percentage distribution of fungal typical species in each trophic group

The habitat types assessed using macrofungi are in total 26 and include different formations distributed in 5 biogeographical regions: Alpine, Atlantic, Boreal, Continental, Mediterranean. Most of them belong to broad-leaved (beech and oak woods) and coniferous (e.g. Taiga) forest formations, but grasslands, humid environments and coastal habitats are also represented (Table 1).

Table 1. The 26 Annex I habitat types (identified by codes) assessed using fungi as typical species, with formations and habitat categories based on the Interpretation Manual of European Union Habitats (European Commission, 2013).

type of formations	habitat category	habitat codes
FORESTS	Forests of temperate Europe	9110, 9120, 9130, 9150, 9160, 9190, 91D0
	Forests of Boreal Europe	9010, 9020, 9030, 9050, 9060, 9070
	Temperate mountainous coniferous forests	9430
SCLEROPHYLLOUS SCRUB (MATORRAL)	Sub-Mediterranean and temperate scrub	5130
NATURAL AND SEMI-NATURAL GRASSLAND	Semi-natural dry grasslands and scrubland facies	6210, 6230
	Natural grasslands	6170
	Mesophile grasslands	6530
RAISED BOGS AND MIRES AND FENS	Sphagnum acid bogs	7110, 7140, 7150
COASTAL AND HALOPHYTIC HABITATS	Atlantic and continental salt marshes and salt meadows	1340
COASTAL SAND DUNES AND INLAND DUNES	Sea dunes of the Atlantic, North Sea and Baltic coasts	2120, 2180
	Sea dunes of the Mediterranean coast	2260

France is the country with the largest overall number of habitat types assessed using fungi among typical species (12), followed by Sweden (7), Finland (5), The Netherlands (4), Latvia (3), Spain (2) and Lithuania (1). As the same habitat type can occur in more than one biogeographical region of a country, the number of assessments per Member State can be larger (see Figure 26).

So far, the use of fungi as indicator in the Article 17 habitat assessment is more developed in Northern Europe, both regarding number of countries and for number of fungal species considered. Different habitat types are involved with a prevalence of forest formations.

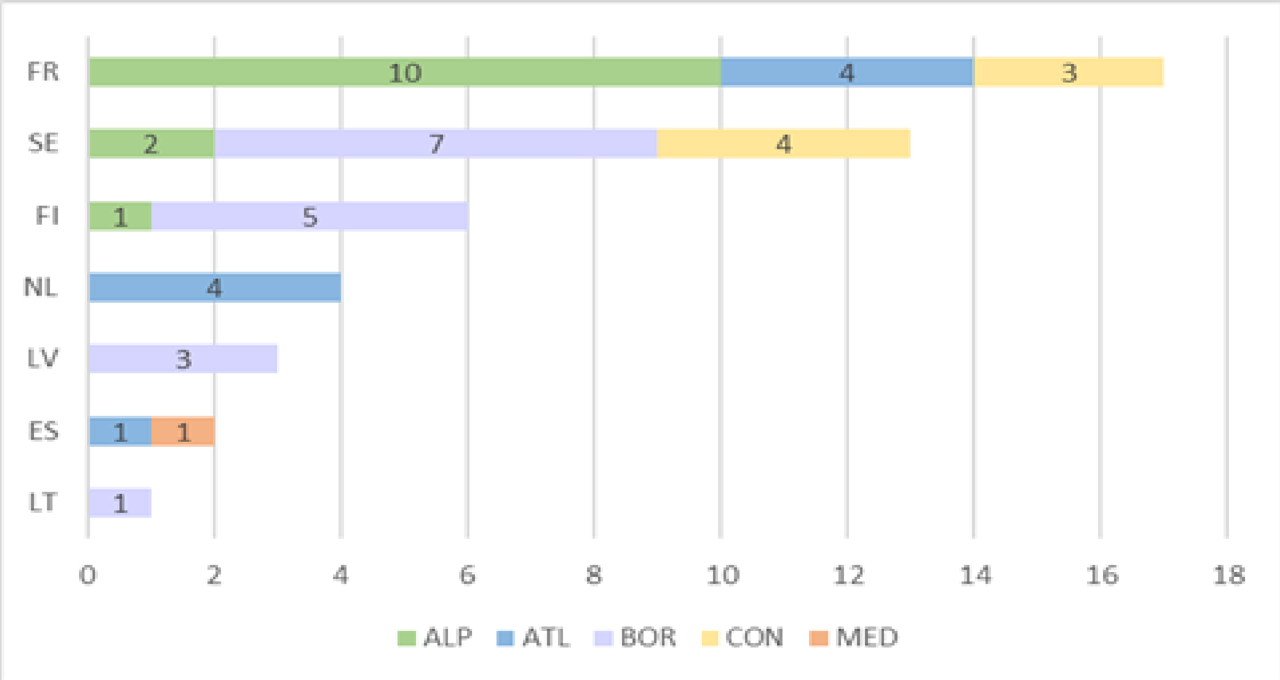

Figure 26. Number of habitat types assessed using fungi in each biogeographical region per country[54].

References

DG Environment, 2023. Reporting under Article 17 of the Habitats Directive: Guidelines on concepts and definitions – Article 17 of Directive 92/43/EEC, Reporting period 2019-2024. Brussels. Pp 104.

European Commission, 2013. Interpretation Manual of European Union habitats (EUR28). http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf

[54] Note that the same habitat type can be present in more than one biogeographical region of a country.

Focus Box 3: Fungi as Typical Species in the Dutch Implementation of the Habitats Directive

Authors: Inge Somhorst, Wim Ozinga, Pier Hoekstra

Affiliations: *I. Somhorst*, *P. Hoekstra* - see Annex I; *W. Ozinga* - Team Vegetation and Landscape Ecology, Wageningen Environmental Research, Wageningen - The Netherlands

The Netherlands have a long tradition of mycological research but nevertheless fungi were largely neglected in nature policy and nature management in the Netherlands over the past decades. With the implementation of Habitats Directive, however this changed slightly in a positive way. The Habitats Directive requires the Member States to report every six years on the conservation status of habitats listed in Annex I, to evaluate the effectiveness of their policies in terms of biodiversity conservation (DG Environment 2017). Although there are no fungal species included in these annexes, fungi can indirectly play a role in the monitoring and conservation at the level of habitat types. In this box we describe the use of fungi in the Dutch implementation of the Habitats Directive and the monitoring network that is used.

The assessment of habitats in the periodic report is regulated by Article 17 of the directive, which suggests the use of "typical species" to assess the conservation status of habitat. These typical species are characteristic of a given habitat type and at the same time they should be indicative of a "good conservation status". Among other criteria the conservation status of a habitat type will be considered as 'favourable' when the conservation status of its typical species is favourable. So, inclusion of fungi as typical species can be an important way to raise the importance of fungi in nature policy. From the start onwards, the Dutch list included species from a broad spectrum of species groups, including 18 fungal species. The conservation status of these typical species is assessed based on their Red List status complemented with more detailed monitoring data.

In practice, however, it appeared that the role of fungi in nature policy and management remained limited. For the periodic reporting on the conservation status of habitat types it turned out that the number of species for a given habitat type was often too small to allow reliable assessments at the level of habitat types and some species were in hindsight less suitable for monitoring. Moreover, for management plans of Natura 2000 sites, fungi were often not considered.

A Dutch guidance document on fungi in nature policy and management

Managers of nature areas are often willing to take more account of fungi, but the knowledge of habitat requirements of fungi and therefore the options to provide 'fungus-friendly' management is very scattered and difficult to access. Various Dutch stakeholders indicated that with better access to such information there is probably much to be gained for the conservation and restoration of fungal diversity. Therefore, a project has been conducted by a group of Dutch mycologists that aimed to facilitate this process and to provide a guidance document for the Netherlands. This resulted in a publication (in Dutch with English summary) entitled 'Macrofungi in conservation management' (Ozinga et al., 2013). It gives an overview of important habitats for fungi and opportunities for the sustainable conservation and restoration of fungal diversity (Figure 27).

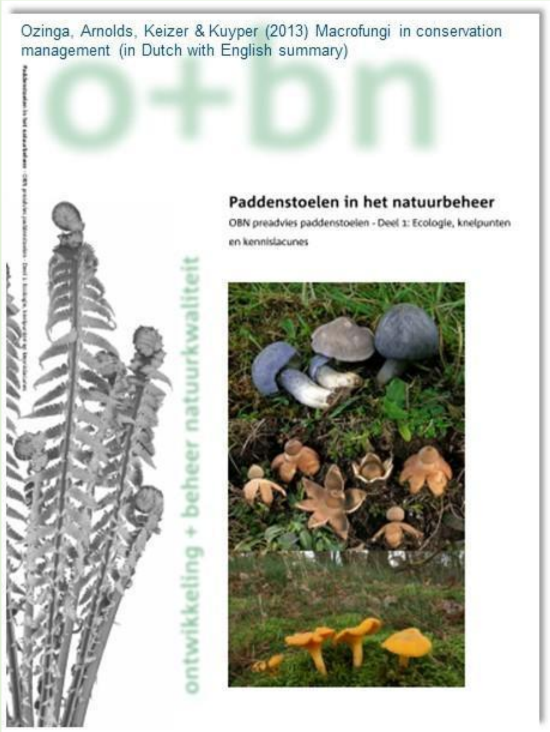

Figure 27. Cover of the Dutch guidance document on fungi in nature policy and management (Ozinga et al. 2013).

The publication consists of two parts: (1) a volume with general information on the ecology of functional groups of fungi, the main threats to fungal diversity and an overview of knowledge gaps and recommendations for future research, and (2) a separate volume with information on the funga of the main Dutch habitat types with recommendations on their management.

The second part is also intended to stimulate the use of fungi in nature policy, including the Habitats Directive. For each habitat type, a table with characteristic fungal species is given and for most Natura 2000 habitat types' species were identified for which the presence in an area can be taken as a sign of habitat quality ('quality indicators'). A selection of these species might in a later stage be added to the Dutch list of typical species, but even without such a formal registration, the list of characteristic fungal species can be useful in assessing the conservation status of habitat types. Importantly, the use of fungi in the evaluation of habitat quality across sites requires reliable data on occurrences and trends.

Monitoring in the Netherlands

Three monitoring projects, based on 17 typical fungal species of the Habitats Directive, are set up in forests on sandy soil (deciduous, mixed and coniferous), in fens and bogs (sphagnum vegetations and transitions to grasslands or heathlands), and in white and grey dunes. In Table 2 an overview of these networks is given with the habitat-codes as used in the Habitats Directive. One other species, *Kavinia alboviridus,* is assigned as a typical species for Juniper scrubs (H5130), but this species is not monitored because it is very rare and hard to find.

Species are monitored by volunteers on fixed routes within a square kilometre, one or several times a year, according to the habitat. Date, location, duration of the survey are noted, and for each species habitat and number of growing places: fruiting bodies of soil inhabiting species growing within 10 metres are assigned to one growing place. For wood inhabiting species every colonised piece of wood that has not been connected to other colonised pieces is considered as a separate growing place. Every year collected data from the 3 projects are analysed by Statistic Netherlands CBS. Data is corrected for observer effort. Although the number of monitoring plots is quite high, improvements are still possible. A point of attention for the future for example, is the spatial coverage of Natura 2000 sites across the country.

Table 2. Overview of the characteristics of the three monitoring networks on fungi in The Netherlands.

	forests	**fens, bogs**	**dunes**
habitatcode	H9190	H7140	H2120
		H7110	
		H7120	
		H91D0	
typical species	4	7	6
additional species	136	40	18
start year	(1998) 2017	2017	2014
visits per year	3	1-2	2
volunteers 2023	99	10	23
# km2 2023	214	36	82
# records 2023	19392	536	2535
total # records	84712	4349	17344

Some results

Statistic Netherlands calculates distribution trends based on the monitoring data and validated opportunistic data from the National Database Flora and Fauna, NDFF. In the forest-project we found a clear correlation between the occurrence of nitrophobic ectomycorrhizal species (36) and the nitrogen deposition in the Netherlands, which is extremely high (Van Strien et al. 2018, see Figure 28). Nitrotolerant ectomycorrhizal species (9) only showed a weak fluctuation (note the differences in scale on the y-axis) in the same period. From the 1950's nitrogen deposition was extremely high in the Netherlands and nitrophobic species declined rapidly, the most sensitive species disappeared. In the late 1990s measures were taken to reduce nitrogen deposition, and many species restored partially. Reduction came to a halt in 2010, after which the nitrophobic ectomycorrhizal species as a group showed a decline. The rapid response of the nitrophobic species to the nitrogen deposition is remarkable. Climatological changes and the increasing number of dry hot summers should be considered.

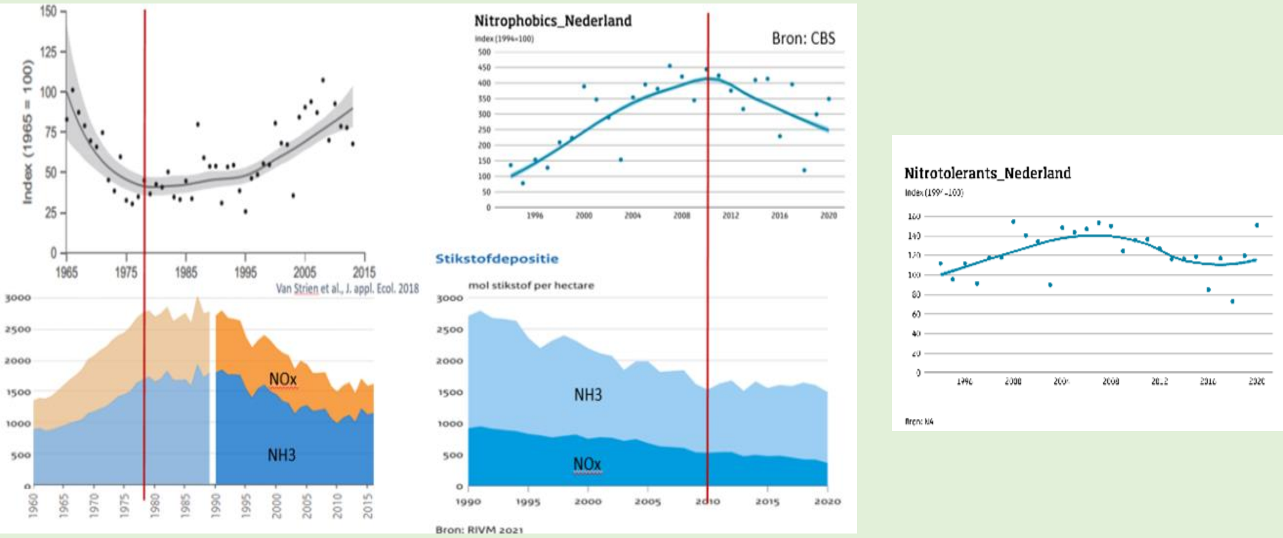

Figure 28. Results from the forest monitoring network, showing trends in nitrogen deposition (bottom), the long-term trend of ectomycorrhizal species (top left), and the trend of ectomycorrhizal species with low and high sensitivity to nitrogen (top right)[55].

Reference s

CBS, PBL & Wageningen UR., 2016. Eutrophying deposition, 1990-2015; indicator 0189, version 15, 20 December 2016). Retrieved from http://www.clo.nl/nl0189

DG Environment, 2017. Reporting under Article 17 of the Habitats Directive: Explanatory notes and guidelines for the period 2013–2018. Brussels. 188 pp.

Ozinga W.A., E. Arnolds, P.J. Keizer, T.W. Kuyper, 2013. Macrofungi in conservation management. OBN report. Ministry of Economic Affairs, Den Haag, The Netherlands. 410 pp.

van Strien A.J., Boomsluit M., Noordeloos M.E., Verweij R.J.T., Kuyper T.W., 2018. Woodland ectomycorrhizal fungi benefit from large-scale reduction in nitrogen deposition in the Netherlands. Journal of Applied Ecology 55: 290-298.

[55] see Van Strien et al., 2018, for further details

Focus Box 4: Typical Species of Fungi in Italian Forests Dominated by *Quercus ilex*: Applying a Method for Effective Proposals

Authors: Carolina Elena Girometta[1], Claudia Perini[2], Paola Angelini[3], Mirca Zotti[4], Marco Leonardi[5], Maria Letizia Gargano[6], Giuseppe Venturella[7], Marco Floriani[8], Anna Maria Persiani[9]

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Introduction

With concern to The European Guidelines for the reporting period 2019-2024 (DG Environment, 2023), “typical species” and “characteristic species” are only partially overlapping concepts. The latter relies on solid statistical and analytic support starting from an extensive, updated and peer-reviewed database over a certain time span. Above all, such a database should be built up in a homogeneous framework where surveyors have been contributing for years through standard protocols. Similar initiatives are in progress in Italy primed by Società Botanica Italiana – Working Group Micologia and involving several contributors from the most regions of Italy. Noteworthy, this initiative has involved 8 Universities, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), MUSE (Museo delle Scienze – Trento) and 5 different mycological associations. Until now, the database including fungal species (macromycetes) recorded in holm oak woodlands is the most valuable example which meets the main requirements to be associated with selected habitat(s) in Annex 1, despite still lacking a strict standardisation. A team of mycologists has been working on this topic for 5 years to collect, analyse and format checklists covering almost all the Italian Regions.

Holm oak woodlands in Italy include *Quercus ilex* L. only, that is vicariant to *Q. rotundifolia* Lam.[56] A major part of holm oak woodlands can be included in Habitat 9340 *Quercus ilex* and *Quercus rotundifoli*a forests in Annex 1. In turn, Italian woodlands in Habitat 9340 can be mainly referred to either the sub-type 45.31 - Meso-Mediterranean holm-oak forests (i.e. thermophilic) or 45.32 - Supra-Mediterranean holm-oak forests (i.e. mesophilic)[57]. Due to the remarkable environmental complexity of the Italian territory, such a categorization has been well assessed in peninsular as well as Sicilian woodlands (Northern ones obviously fall into mesophilic category), whereas Sardinian ones apparently escape this frame and probably need further investigation (Biondi et al., 2003). It should be highlighted that Italy in fact includes 3 biogeographical regions (Alpine, Continental and Mediterranean) according to the European Union reference (2016). Further on, based on the elaboration of studies such as Blasi et al. (2014), the Italian responsible Ministry (Ministero dell’Ambiente e della Sicurezza Energetica) currently recognizes 28 different phytoclimates[58]. Such a complexity suggests pursuing the highest coverage as possible of different areas in Italy with

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[56] https://dryades.units.it/floritaly/index.php ; https://powo.science.kew.org/
[57] http://vnr.unipg.it/habitat/
[58] http://www.pcn.minambiente.it/viewer/

concern to holm oak woodlands too: very different physiognomy, structure, dynamics frame as well as phytocoenosis can be found (Biondi & Blasi, 2017[59]).

Based on the "typical species" concept described in the European Guidelines for the reporting period 2019-2024 (DG Environment, 2023), the aim of the work was to select a small set of fungal species representing Habitat 9340 in Italy.

Materials and Methods

Data collection and database structure

A database was created to include the widest number of records of macromycetes growing in *Q. ilex* in woodlands reasonably fitting the definition of Habitat 9340. Consistently, all the records such as single trees, tree grows in agricultural and urban landscape were discarded. Hypogeous species and broadly defined micromycetes were excluded *a priori*, whereas anamorphs of broadly defined macromycetes were potentially included. Only data recorded since 2000 were considered.

Starting from an initiative primed by Società Botanica Italiana – Working Group of Mycology was divided into different macro-areas up to different academic institutions[60] as in Table 3.

Table 3. Reference scheme for the collection of local databases from Italian Habitat 9340.

Reference Institution	**Administrative Region(s) or Province**	**Biogeographical region including Habitat 9340**	**Other contributors**
University of Pavia	Lombardia, Emilia-Romagna, Veneto, Friuli-Venezia Giulia, Provincia Autonoma di Trento (Trentino)	continental	MUSE (Museo delle Scienze – Trento), AMB (Associazione Micologica Bresadola), dr. Annarosa Bernicchia
University of Genova	Liguria	Mediterranean	C.A.M.P.A.L. (Coordinamento delle Associazioni Micologiche Piemontesi, Aostane e Liguri)
	Piemonte	continental	no data from this Region
University of Siena	Toscana	continental / Mediterranean	A.G.M.T. Associazione Gruppi Micologici Toscani
University of Perugia	Umbria, Marche	continental	AMI UMBRIA (Coordinamento Associazioni Micologiche Umbre)
University of L'Aquila	Abruzzo, Molise	continental	-
University of Roma La Sapienza	Lazio, Campania	Mediterranean	A.M.E.R. Associazione Micologica ed Ecologica Romana
University of Bari	Puglia, Basilicata, Calabria	Mediterranean	-
University of Palermo	Sicilia, Sardegna	Mediterranean	MUSE (Museo delle Scienze – Trento), dr. Annarosa Bernicchia

[59] https://www.prodromo-vegetazione-italia.org/
[60] http://www.pcn.minambiente.it/viewer/

Valle d'Aosta/Vallée d'Aoste and Provincia Autonoma di Bolzano/Bozen were the only administrative areas excluded *a priori* since no native holm oaks are present there[61].

The role of academic institutions was to collect, share and analyse data achieved by different contributors, including both scholars and amateurs.

The comprehensive database achieved was set to univocally associate each record to the indicators described in Table 4.

Table 4. Main indicators adopted to analyse the comprehensive database of fungal diversity in holm oak woodlands.

Indicator	Reference/description
Source	Contributor(s) who legit and/or determinavit
Date	Collection and/or survey
Updated species name	Based on Index Fungorum (www.indexfungorum.org)
Trophism	Mycorrhizal/soil saprotroph/wood decayer/other
Administrative region and municipality	As represented in http://www.pcn.minambiente.it/viewer/
Locality	Local toponym, either reported on maps or not
Coordinates and reference system	East – north; etrs89/Utm33n (epsg25833)
Syntaxonomy and dynamics	Based on https://www.prodromo-vegetazione-italia.org/ and Blasi et Rosati (2010)
Main represented physionomy	Shrub, tree, small tree
Woodland composition	Monospecific / mixed population

With concern to the latter indicator, it should be noticed that holm oak woodlands are meant to be "dominated" by *Q. ilex* in the diagnostic phrase of Italian Habitat 9340, although several other tree and shrub species are also present mixed to *Q. ilex* itself (http://vnr.unipg.it/). This sometimes made it difficult to discern the putative host or symbiont.

Data analysis and selection workflow

Based on the "typical species" concept described in the *European Guidelines for the reporting period 2019-2024 (DG Environment, 2023)*, the following criteria were pursued: species which occur regularly at a high constancy in the selected habitat; species which are good indicators of favourable habitat quality; species which can be monitored easily. This meant to select species showing the following features: widespread in the habitat distribution and not limited to few localities; common enough to allow at least presence/absence listing within 1–2-decade monitoring; easy enough to identify, i.e. non-cryptic and ideally monophyletic in the habitat; highly related to the examined habitat with respect to other habitats and/or hosts.

To account for the above-described complexity of Italian Habitat 9340, the basic workflow in Figure 29 was adopted.

As shown in Figure 29, a major critical step is included in this workflow: how to discern species which are more related to holm oak woodlands (Habitat 9340) than to other habitats? The following literature references (not exhaustive list) were considered for instance: Onofri et al., (2003); Boccardo et al. (2008), Bernicchia et Gorjón (2010); Angelini et al. (2017); Bernicchia et Gorjón (2020); Ferraro et al. (2022), Gargano et al. (2021), Pardi et al. (2022).

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[61] https://dryades.units.it/floritaly/index.php

In order to harmonise local lists and reduce the sampling error, as well as to cross-check literature references, the expert-based approach was also adopted by consulting researchers who had devoted significant efforts in investigating fungal diversity in holm oak woodlands.

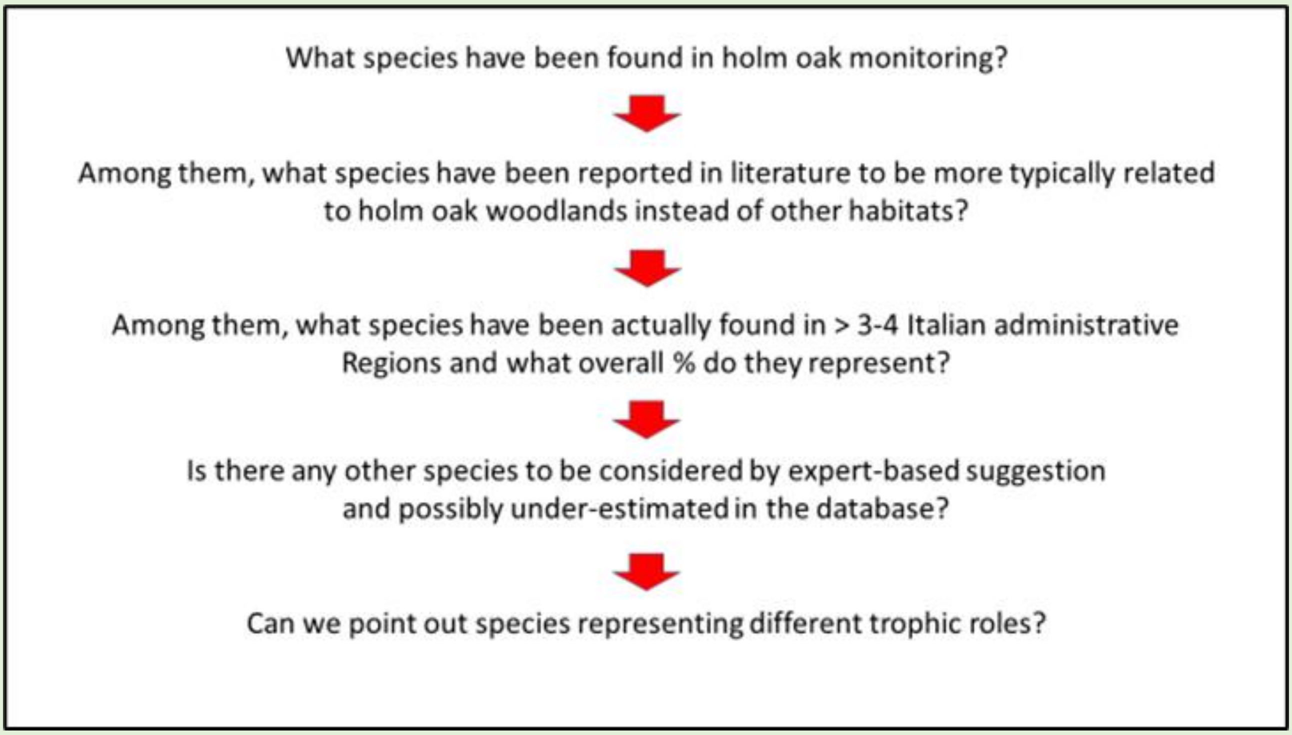

Figure 29. Workflow for the selection of typical fungal species in holm oak woodlands.

Results and discussion

Starting from the comprehensive collection of local databases, most species are not expected to be highly related to Habitat 9340 nor to holm oak as a host species. Moreover, many species are apparently represented in few localities only and are not shared with other sampling sites in Italy. This obviously implies a sampling error due to both the human surveyor and environmental contingency, including weather conditions.

Analogously, some species may be related to local features in holm oak woodlands and may therefore suggest they are “characteristic” of that peculiar context instead of “typical” of Habitat 9340 as a whole (further statistical analysis is needed to disentangle these aspects).

Based on the available data, administrative Regions are represented quite proportionally to the current area occupied by Habitat 9340; however, the cumulative records per Region highly depend on the sampling and monitoring effort (Figure 30).

It should be noticed that *Q. ilex* is a “winner species” in the post-glacial environments of the Mediterranean basin, and a resilient one with respect to human activities since ancient times (Biondi & Blasi, 2017). Therefore, it has colonized remarkable areas Northward and is by far the most represented evergreen oak in Italy and peninsular areas especially (such as Toscana) even out of the Mediterranean biogeographical region (until Trentino, almost at the edge of the Alpine region).

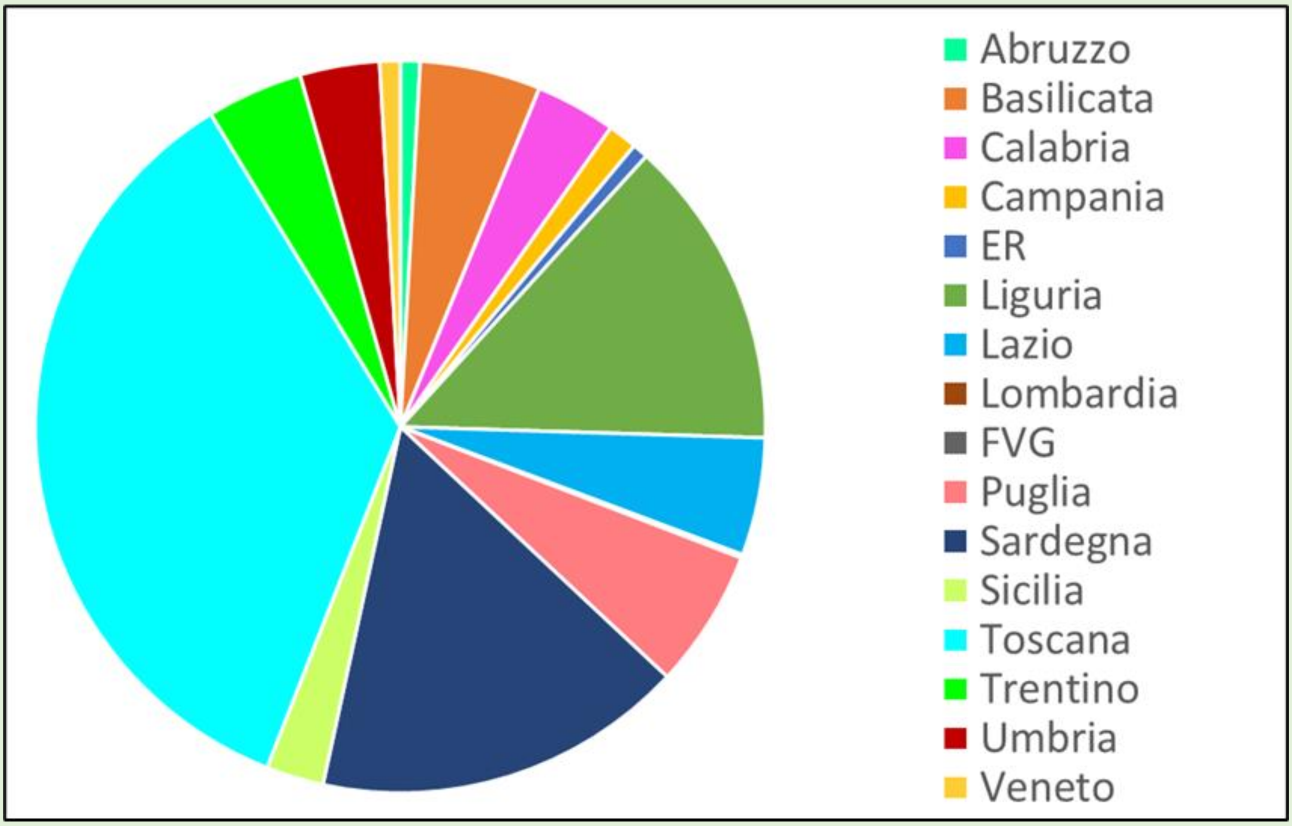

Figure 30. Cumulative records of macromycetes per region. Please note that each species was counted only once per locality.

Consistently, a major part of Habitat 9340 belongs to the 45.32 (mesophilic) sub-type, that is both represented in the Mediterranean and the continental biogeographical regions. From a mycological perspective, mesophilic holm oak woodlands are subjected to a rainier pluviometric regime, which expands the suitable period for sporocarps development and survey.

Moving step by step along the above-described workflow, the top-range of fungal species selected as "typical" of Habitat 9340 is reported in Figure 31.

It should be noticed that not all the Regions hosting Habitat 9340 (18/20 administrative Regions) are reported in Figure 31; no data are in fact available from Piemonte, Marche and Molise, whereas data from Emilia-Romagna were discarded since formally too old (recorded before 2000). Notwithstanding, the sampled Habitat 9340 is for sure still preserved in Emilia-Romagna in Bosco della Mesola Natural Reserve, also including a strict reserve portion[62].

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[62] https://www.parcodeltapo.it/

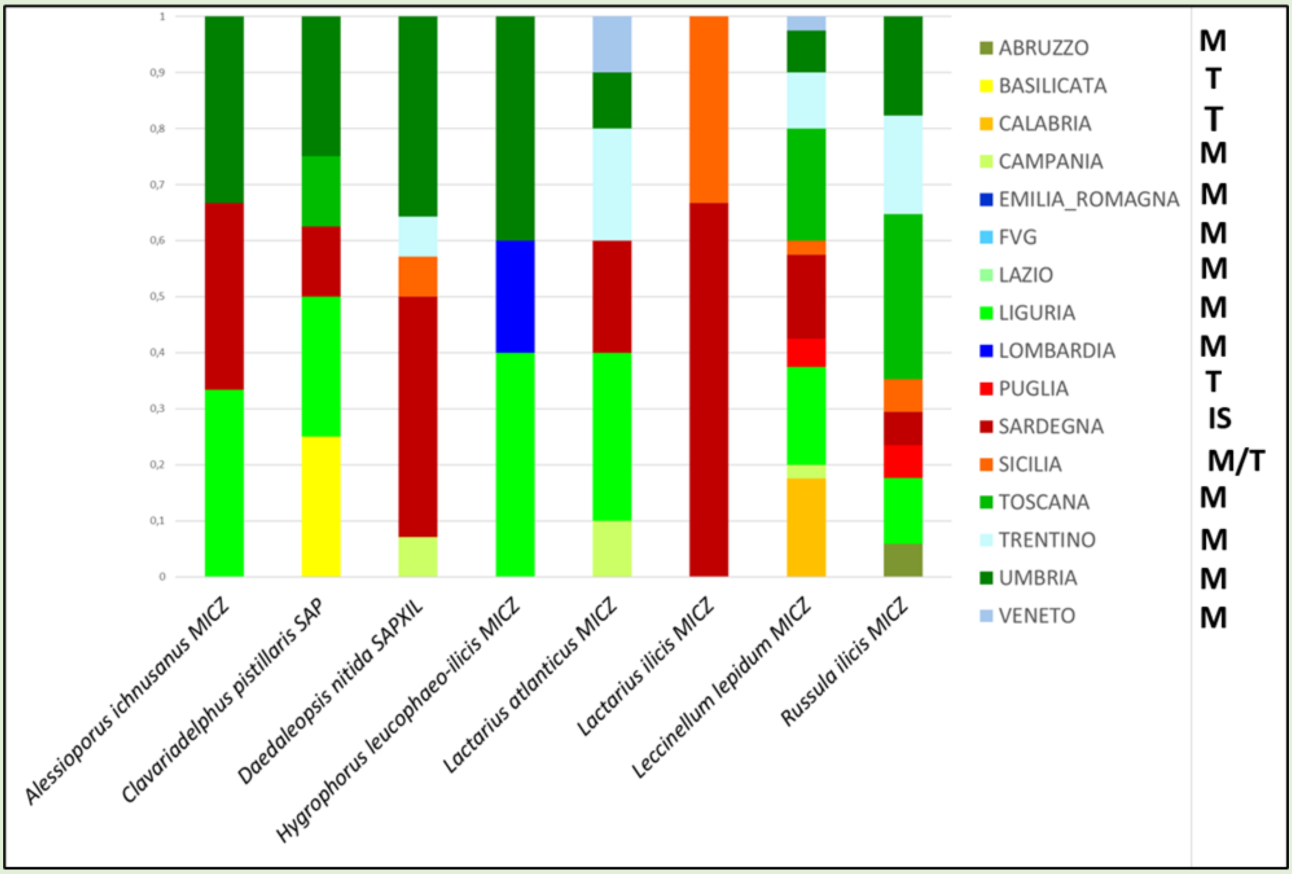

Figure 31. Top-range of macrofungi species selected as "typical" of Habitat 9340.

The proportion is based on Municipality units. MICZ = mycorrhizal; SAP = soil saprotroph; SAPXIL = wood decayer. T = thermophilic forest (45.31 sub-type of Habitat 9340); M = mesophilic (45.32 sub-type); IS = incertae sedis. Blue and light light blue colours indicate continental (mesophilic) areas, green colours indicate peninsular mesophilic areas, whereas yellow-orange-red-reddish colours indicate Mediterranean peninsular and insular areas, which can be either mesophilic or thermophilic.

Based on the drafted protocol some species in the top-range selection, such as *Lactarius ilicis* (2 Regions), *Alessioporus ichnusanus* and *Hygrophorus leucophaeo-ilicis* (3 Regions each), appear poorly represented across different areas. However, expert-based evaluation suggests they may have been underestimated and deserve to be monitored as featuring species in Habitat 9340.

Consistently with the original aim of the work, different trophic roles were valorized in the selection process. As shown in Figure 31, 6 out of 8 selected species are mycorrhizal, but only two fully encompass the variability of Italian Habitat 9340: *Leccinellum lepidum* and *Russula ilicis* were in fact recorded in 10 and 8 administrative Regions respectively; each species is moreover represented in both continental and Mediterranean biogeographical regions, and the latter in both mesophilic, thermophilic and *incertae sedis* (Sardinian) sub-types. Besides these mycorrhizal species, analogous consideration concerns the saproxylic (saprotrophic wood-decayer) *Daedaleopsis nitida*, whose monitoring is made easier by its very peculiar hymenial morphology and persistent basidiomata (annual but taking a long time to be degraded). Finally, the soil saprotroph *Clavariadelphus pistillaris* is apparently missing in continental holm oak woodlands, although represented in peninsular mesophilics and Sardinian *incertae sedis* ones.

In conclusion, the methodology above described resulted in the selection of a small set of fungal species to be listed as typical of the Italian Habitat 9340 *Quercus ilex* and *Q. rotundifolia* forests: *L. lepidum*; *R. ilicis*; *D. nitida* and *C. pistillaris*.

References

Angelini P., Arcangeli A., Bistocchi G., Rubini A., Venanzoni R., Perini C., 2017. Current knowledge of Umbrian macrofungi (central Italy). Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 151(5): 915-923.

Bernicchia A., Gorjón S., 2010. Corticiaceae sl. Corticiaceae sl. Candusso Edizioni, Alassio (SV).

Bernicchia A., Gorjón S., 2020. Polypores of the Mediterranean region. Romar Edizioni.

Biondi E., Casavecchia S., Gigante D., 2003. Contribution to the syntaxonomic knowledge of the Quercus ilex L. woods of the Central European Mediterranean Basin. Fitosociologia, 40(1): 129-156.

Blasi C., Biondi E., 2017. La flora in Italia. Ministero dell'Ambiente e della Tutela del Territorio e del Mare, pp. 704. Sapienza Università Editrice, Roma.

Blasi C., Rosati L., 2010. La Vegetazione d'Italia e la Carta delle Serie di vegetazione. In: Blasi C. (ed.). La Vegetazione d'Italia. Palombi & Partner Srl, Roma. ISBN: 8860602904. Pp. 9-15

Blasi C., Capotorti G., Copiz R., Guida D., Mollo B., Smiraglia D., Zavattero L., 2014. Classification and mapping of the ecoregions of Italy. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 148(6): 1255-1345.

Boccardo F., Traverso M., Vizzini A., Zotti M., 2008. Funghi d'Italia. Zanichelli Ed.

DG Environment, 2023. Reporting under Article 17 of the Habitats Directive: Guidelines on concepts and definitions – Article 17 of Directive 92/43/EEC, Reporting period 2019-2024. Brussels. Pp 104.

Ferraro V., Venturella G., Cirlincione F., Mirabile G., Gargano M.L., Colasuonno P., 2022. The checklist of Sicilian macrofungi. Journal of Fungi, 8(6): 566.

Onofri S., Bernicchia A., Filipello Marchisio V., Perini C., Venturella G., Zucconi L., Ripa C., 2003. The Check-list of Italian Fungi, Part I (Basidiomycetes, Basidiomycota). Bocconea, 16(2): 1083-1089.

Gargano M.L., Di Gristina E., Domina G., Venturella G. 2021. Trees and shrubs in the city of Bari (Italy). Fl. Medit. 31: 23-30. https://doi.org/10.7320/FlMedit31.023

Pardi R., Venturella G., Cirlincione F., Mirabile G., Di Gristina E., Gargano M.L., 2022. Forest ecosystems in the Monti Sicani Park (Sicily). Flora Mediterranea, 32: 5-16. https://doi.org/10.7320/FlMedit32.005

Websites

Geoportale Nazionale, Nuovo Visualizzatore. http://www.pcn.minambiente.it/viewer/ Last accessed Nov. 10th, 2024

Habitat Italia. https://vnr.unipg.it/habitat/ Last accessed Nov. 10th 2024

Parco Delta del Po Emilia Romagna. https://www.parcodeltapo.it/ Last accessed Nov 11th 2024.

Plants of the World Online. https://powo.science.kew.org/ Last accessed Nov. 10th 2024.

Portale della Flora d'Italia. https://dryades.units.it/floritaly/index.php Last accessed Nov. 10th 2024

Prodromo della Vegetazione d'Italia. https://www.prodromo-vegetazione-italia.org/ Last accessed Nov. 10th 2024

Focus Box 5: *Montagnea candollei*: a Typical Species of Sand Dunes Habitats of the Mediterranean Region

Author: Stephen Misfud

Affiliation: see Annex I

Fungi are perceived as organisms growing in humid woodlands or damp shaded areas, but there are a few exceptional species that grow in desert-like conditions amongst the various habitats they can grow (Webster & Webster, 2007). In Europe, such xerophilous species are found in sand dunes and can withstand extreme conditions such as aridity, wind and sea spray, which are normally extremely adverse conditions for most fungi. One example that is infrequent in some sandy beaches in the Mediterranean Region is the species *Montagnea candollei*, which for long was known under the synonymous taxon of *Montagnea arenaria* (DC.) Zeller) and commonly known as the Desert Inkcap (Figure 32).

It is a globally widespread species found from the tropics up to warm regions of the temperate zone and is a common fungus in some regions (Kreisel, 2001). According to GBIF (2024) and iNaturalist (2024), it is particularly common in Australia and SW of the United States (e.g. California), but it is less frequent in the Mediterranean region, especially the central region.

Figure 32. Montagnea candollei from Ramla l-Ħamra, Xagħra, Gozo (Malta) (Photo by S. Mifsud)

This species dwells in vegetated sand dunes, with typical arenophilous vegetation, including *Juniperus* spp. and *Tamarix* spp. (Stasinska & Prajs, 2002; Jorjadze et al., 2022). It is a saprotroph, decomposing organic debris of plants, shrubs and tree litter present in sand dunes, hence typically in habitat 1210 (Annual vegetation of drift lines); and more commonly in Habitat 2110 (Embryonic shifting sand dunes) and 2220 (Dunes with *Euphorbia terracina*). As a result, the presence of this species can act as a bioindicator of healthy and biodiversity-rich sand dunes, since the detritus of a profuse sand-dune vegetation provides the substrate for the Desert Inkcap fungus to grow.

In fact, taking Malta as an example, *Montagnea candollei* is only found in the best preserved and least degraded sand dune in the Maltese Islands, which is called ir-Ramla l-Ħamra (Briffa & Lanfranco, 1986; Mifsud & Mifsud, 2023), located at the northern coast of Gozo. This fungus has so far not been recorded from any other sand dune within the Maltese Islands, presumably because the state of conservation is not of the level or Ramla sand dune. A similar bio indicative relationship between this specific macrofungus or other species may be found in well-preserved sand dunes within the Mediterranean Region.

References

Briffa M., Lanfranco E., 1986. The Macrofungi of the Maltese Islands: Additions and Notes. The Central Mediterranean Naturalist, 1(4): 69–79. https://www.um.edu.mt/library/oar/handle/123456789/14542

GBIF Secretariat, 2024. GBIF Backbone Taxonomy. [Checklist dataset for *Montagnea arenaria*]. Retrieved on 26 September 2024 from https://www.gbif.org/occurrence/search?taxon_key=2535286

INaturalist, 2024. Observations for Desert Inkcap (*Montagnea arenaria*). Retrieved on 26 September 2024 from https://www.inaturalist.org/taxa/351592-Montagnea-arenaria

Jorjadze A., Kvelashvili A., Batsatsashvili K., 2022. New localities of *Montagnea arenaria* (DC.) Zeller in Georgia. Annals of Agrarian Science 20: 180–183

Kreisel H., 2001. Checklist of the gasteral and secotioid Basidiomycetes of Europe, Africa, and the Middle East. Österreichische Zeitschrift für Pilzkunde. 10: 213–313.

Stasinska M., Prajs, B. 2002. New record of *Montagnea arenaria* (Fungi, Agaricales) and its distribution in Poland. Polish Botanical Journal 47(2): 211–213.

Mifsud S., Mifsud D., 2023. The macrofungi of Gozo (Maltese Islands): an annotated checklist. Borziana 4: 51-94 https://doi.org/10.7320/Borziana.004.051

Webster J., Weber R., 2007. Introduction to Fungi. Cambridge University Press.

Focus Box 6: *Russula* spp. as a Typical Fungi Species in Montados/Dehesas

Author: Celeste Santos-Silva

Affiliation: see Annex I

Russula spp. are commonly associated with oak woodlands, particularly in ecosystems like *Quercus suber* (cork oak) and *Q. rotundifolia*/*Q. ilex* (holm oak) Montados/Dehesas (Figure 33). These systems, prevalent in Mediterranean regions, such as the Iberian Peninsula, are complex agro-silvo-pastoral landscapes where trees, livestock, and crops coexist. *Russula* spp. play a key role in these ecosystems, especially in terms of their mycorrhizal relationships with *Quercus* trees and Mediterranean shrub species, contributing to natural regeneration success and tree health[63].

Russula species form symbiotic mutualistic relationships with the roots of oak trees and various shrubs, facilitating nutrient exchange. In exchange for carbon, the fungi assist with the uptake of nutrients, like phosphorus and nitrogen, and water from the soil, which benefits the growth and resilience of the trees.

Russula is the most species-rich genus in healthy Montados/Dehesas (Andrade et al., 2016; Santos-Silva et al., 2024) and can be considered a typical species in the natural habitats 9330 and 9340[64], contributing with 25 to 50% to the overall mycorrhizal abundance (Andrade et al., 2016; Reis et al., 2018) Those fungi contribute to the resilience of cork and holm oak trees by improving nutrient availability and enhancing resistance to drought (Richard et al., 2025) and other environmental stresses. The fungal networks help stabilise soils and improve water retention, which is crucial in the arid conditions typical of Mediterranean ecosystems.

Overgrazing, deforestation, and changes in land use practices can negatively affect the diversity of *Russula* spp. and other mycorrhizal fungi in these systems (Santos-Silva & Louro, 2016). Sustainable land management practices that maintain tree cover and promote fungal diversity are essential for the long-term health of cork and holm oak ecosystems (Santos-Silva et al., 2011). Fungal diversity, particularly mycorrhizal diversity, is also an indicator of the ecological health of these silvo-pastoral systems, and e.g., abundance of *Russula praetervisa* are statistically inversely correlated to tree defoliation caused by *Phytophthora* spp. (Ruiz Gómez et al., 2019).

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[63] Biological indicators of the natural regeneration of cork oak and holm oak: *Russulaceae*, assessment of the diversity of macrofungi of the *Russulaceae* family in montado areas with different types of tree and shrub cover. 2012-2013. Project partially funded by MED&CHANGE (Mediterranean Institute for Agriculture, Environment and Development and Global Change and Sustainability Institute) and Science and Tecnology Fundation.

[64] 9330 - *Quercus suber* forests and 9340 - Forests of *Q. ilex* and *Q. rotundifolia* - Natural habitats of community interest listed in Annex I of the Habitats Directive.

Figure 33. Agro-silvo-pastoral landscape: Montado/Dehesa (Photo: Celeste Santos-Silva)

Moreover, *Russula* spp. provides numerous ecosystem services such as: Nutrient cycling and soil formation, as *Russula* spp. help plants access essential nutrients by breaking down organic matter in the soil (Smith & Read, 2008); carbon sequestration, as mycorrhizal fungi like *Russula* spp. can improve the ability of trees to capture and store atmospheric carbon dioxide in biomass and soil, which is crucial for mitigating climate change (Clemmensen et al., 2013); soil structure and health, as *Russula* spp. produce mycelial networks that bind soil particles, improving soil structure, and enhancing soil aeration and water retention, which are crucial for plant health and forest sustainability (Rillig & Mummey, 2006); biodiversity support, as *Russula* spp. support biodiversity through their role in the food web, being a food source for various fungivores (e.g., small mammals, insects, and invertebrates); additionally, by promoting tree health, they contribute to overall ecosystem diversity (Simard et al., 1997); cultural and recreational value, as some species of *Russula* are edible and are harvested for culinary purposes, contributing to local economies and food culture; in regions where foraging is popular, the presence of *Russula* spp. can also have recreational value (Boa, 2004).

In Montados/Dehesas some of the most common and abundant *Russula* species are the edible and medicinal ones, such as: Charcoal burner (*R. cyanoxantha*, Figure 34), the Motley brittlegill, (*R. amoenicolor,* Figure 35) and the Bypassed brittlegill (*R. praetervisa,* Figure 36).

In conclusion, *Russula* spp. are vital components of the Montados/Dehesas' ecosystems, significantly contributing to the health and resilience of cork and holm oak trees. As the most diverse genus in these environments, *Russula* spp. not only support tree health but also play a crucial role in soil stability, nutrient cycling, carbon sequestration, and overall biodiversity. However, their diversity and ecological functions are threatened by unsustainable land use practices, such as overgrazing and deforestation. Therefore, implementing sustainable land management practices that preserve tree cover and promote fungal diversity are essential for ensuring that these unique ecosystems continue to provide vital ecosystem services and cultural values for future generations.

Figure 34. Russula cyanoxantha *(Photo: José Andrade)*

Figure 35. Russula amoenicolor *(Photo: José Andrade)*

Figure 36. Russula praetervisa *(Photo: José Andrade)*

References

Andrade J., Louro R., Santos-Silva C., 2016. *Russula* and *Lactarius* diversity in montado - Canopy cover and fruiting patterns. Proceedings of the World Congress Silvo-Pastoral Systems, 27 to 30 de September, Évora, Portugal.

Boa E., 2004. Wild Edible Fungi: A Global Overview of Their Use and Importance to People. FAO Non-Wood Forest Products Series, No. 17. Food and Agriculture Organization of the United Nations (FAO).

Clemmensen K.E., Bahr A., Ovaskainen O., Dahlberg A., Ekblad A., Wallander H., Stenlid J., Finlay R.D., Wardle D.A., Lindahl B.D., 2013. Roots and associated fungi drive long-term carbon sequestration in boreal forest. Science, 339(6127): 1615-1618. https://doi.org/10.1126/science.1231923

Reis F., Valdiviesso T., Varela C., Tavares R., Baptista P., Lino-Neto T., 2018. Ectomycorrhizal fungal diversity and community structure associated with cork oak in different landscapes. Mycorrhiza, 28: 357–368. https://doi.org/10.1007/s00572-018-0832-1

Richard F., Millot S., Gardes M., Selosse MA., 2005. Diversity and specificity of ectomycorrhizal fungi retrieved from an old-growth Mediterranean forest dominated by *Quercus ilex*. New Phytol., 166(3): 1011-23. https://doi.org/10.1111/j.1469-8137.2005.01382.x

Rillig M.C., Mummey D.L. 2006. Mycorrhizas and soil structure. New Phytologist, 171(1): 41-53. https://doi.org/10.1111/j.1469-8137.2006.01750.x

Ruiz Gómez F.J., Navarro-Cerrillo R.M., Pérez-de-Luque A., Oβwald W., Vannini A., Morales-Rodríguez C., 2019. Assessment of functional and structural changes of soil fungal and oomycete communities in holm oak declined dehesas through metabarcoding analysis. Sci Rep 9, 5315. https://doi.org/10.1038/s41598-019-41804-y

Santos-Silva C., Gonçalves A., Louro R., 2011. Canopy cover influence on macrofungal richness and sporocarp production in Montado ecosystems. Agroforestry Systems, 82(2): 149-159. https://doi.org/10.1007/s10457-011-9374-7

Santos-Silva C., Louro R., 2016. Assessment of the diversity of epigeous Basidiomycota under different soil-management systems in a Montado ecosystem: a case study conducted in Alentejo. Agroforestry Systems, 90(1): 117-126. https://doi.org/10.1007/S10457-015-9800-3

Santos-Silva C., Louro R., Raposo J., 2024. Margens do Sol Posto e Sol Nascente Homestead– Micological Diversity. University of Évora Ed., 38 pp. ISBN 978-972-778-380-9.

Simard S.W., Perry D.A., Jones M.D., Myrold D.D., Durall D.M., Molina R. 1997. Net transfer of carbon between ectomycorrhizal tree species in the field. Nature, 388(6642): 579-582. https://doi.org/10.1038/41557

Smith S.E., Read D.J., 2008. Mycorrhizal Symbiosis. Academic Press.

Focus Box 7: *Pyrofomes demidoffii* and *Antrodia juniperina*: Two Typical Species of Grecian Juniper Forests

Author: Mitko Karadelev and Katerina Rusevska

Affiliations: *M. Karadelev* - Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University in Skopje, North Macedonia; *K. Rusevska* - see Annex I.

The Grecian juniper (*Juniperus excelsa*) is a tall shrub or tree up to 20 m tall, with a trunk as large as 2 m in diameter. Concerning the general distribution, the Grecian juniper forests extend from Iran and Lebanon through Asia Minor and Crimea to the Balkan Peninsula. As an East Mediterranean element, it can be found in the sub-mediterranean regions of southern Europe (Albania, North Macedonia, Bulgaria, and Greece). The western and northern edge of its distribution is North Macedonia, where it grows on limestone gravel, serpentine and other types of bedrocks supporting shallow soils in warm habitats at altitudes of 100–1200 m.

Grecian juniper forests are considered as a priority habitat in the Habitats Directive under the code 9560 - *Endemic forests with *Juniperus* spp. and 42.A3 of the Pal. Class.: Grecian juniper woods (*Juniperetum excelsae*) – forest formations dominated by *Juniperus excelsa*.

The Grecian juniper is known as a very resistant wood to the development of lignicolous fungi, where approximately thirty species are known. Of these, the most significant conservation value and species suitable for monitoring are: *Antrodia juniperina* (Murrill) Niemelä & Ryvarden[65] and *Pyrofomes demidoffii* (Lév.) Kotl. & Pouzar. Both species are endangered [EN B2ab(i,ii,iv)] according to the Bulgarian Red List of Fungi (Gyosheva et al. 2006) and vulnerable (VU –B1ab (iii,iv) + 2ab(iii,iv); D1) according to the North Macedonian Red List of Fungi (Karadelev et. al. 2021/22).

Figure 37. Grecian juniper forest on the island Golem Grad, Prespa Lake, Macedonia (left) with well-developed trees (right). Photo: Macedonian Ecological Society (left), Mitko Karadelev (right).

[65] According to both Mycobank and Index Fungorum, this is a synonym of the currently accepted name: *Fomitopsis juniperina* (Murrill) Spirin & Vlasák

Pyrofomes demidoffii is a parasitic species on various juniper trees in East Africa and North America (Ryvarden & Johansen, 1980; Gilbertson & Ryvarden, 1986-1987; Ryvarden & Gilbertson, 1993). Is known from Caucasus, Uzbekistan, Siberia, and Crimea mostly on *Juniperus* spp. (Bondartsev, 1971). The species exclusively occurs as a parasite on old juniper trees. In Europe it is known only from Balkan countries (North Macedonia, Bulgaria and Albania), always on the Grecian juniper. It is a rare species in Europe with a restricted area of distribution following the host distribution. It is known from five localities in North Macedonia, one in Albania and two in Bulgaria. The species is a parasite on old juniper trees usually present in well-developed forests.

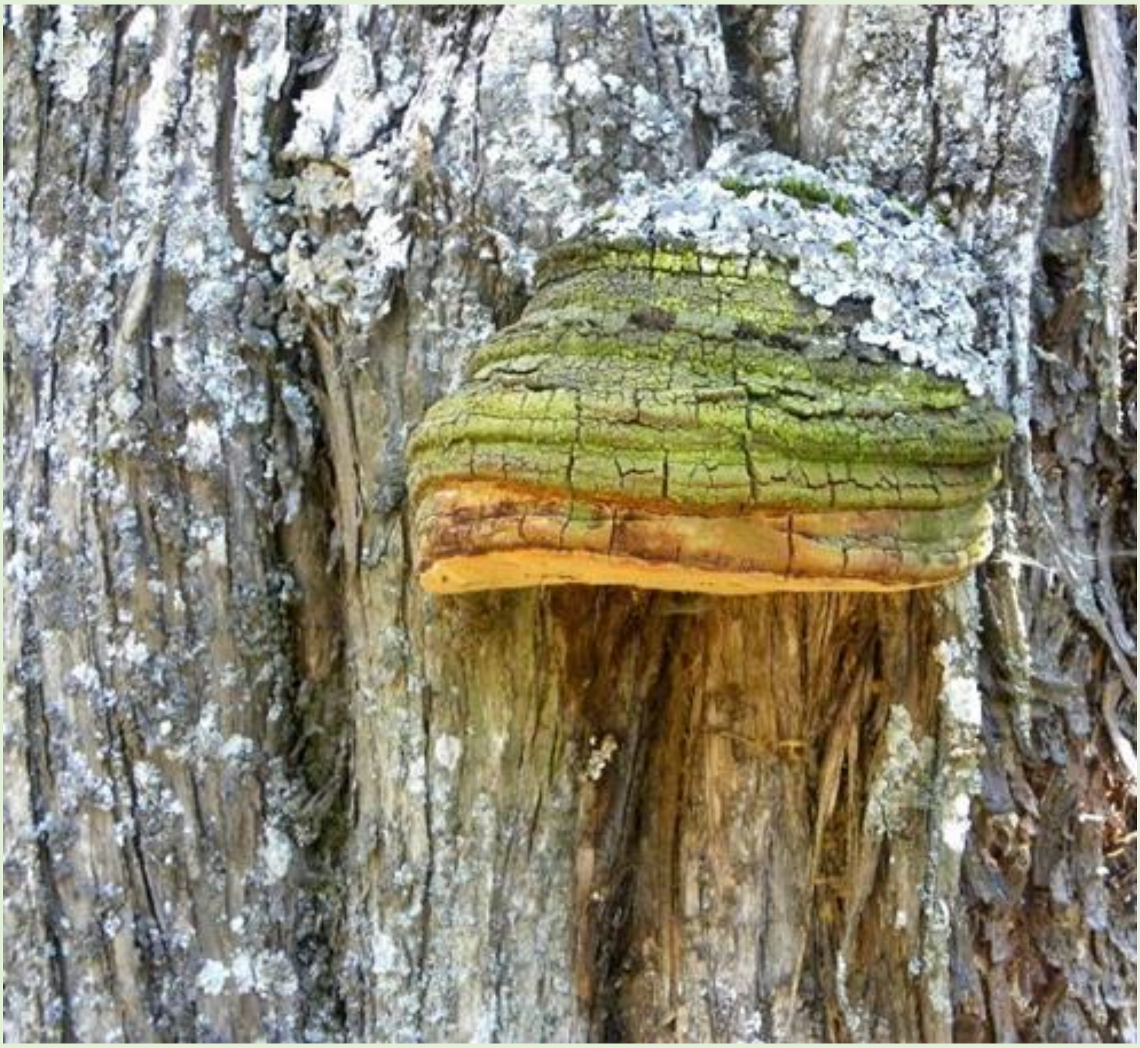

Figure 38. Pyrofomes demidoffii, island Golem Grad (Prespa Lake, Macedonia). Photo: Mitko Karadelev

Antrodia juniperina is known in East Africa (Niemelä & Ryvarden, 1975; Ryvarden & Johansen, 1980) as a parasite and saprobe on thick trunks of *Juniperus procera*; in the USA (Gilbertson & Ryvarden, 1986-1987) it grows on J. *deppeana, J. monosperma, J. osteosperm*a and *J. virginiana* while in Europe it is known from Spain on *J. thurifera* (Garcia-Manjon & Moreno, 1981), and from the Balkans and Turkey where it grows as a saprobe, rarely as a parasite on old trunks of *J. excelsa* and *J. foetidissima* (Karadelev, 2001; Dogan & Karadelev 2006). In the Balkan countries (Albania, North Macedonia and Bulgaria) the species has been spotted on rotten wood of Grecian juniper. It is a rare species, occurring with different abundance at all localities where the host is present, but it is more common in the well-developed Grecian juniper communities, particularly if there are old trunks around. The highest number of specimens has been observed at localities with well-developed Grecian juniper communities.

Figure 39. Antrodia juniperina, Kozhle village, Macedonia. Photo: Matthias Theiss

The impact of both species is manifested by host habitat degradation and/or fragmentation since those species are strictly bound to a single host. Immediate impact upon the species has not been ascertained. The threat manifests differently and it depends on the community site. Reduced amount of habitat should be the main cause of the decline. Main reason for that is the uncontrolled wood cutting and logging for using the wood (burning) for production of burnt lime. The potential danger of juniper forests' fires is quite significant.

Protection of old host trees is the key conservation action for protection of the species; study of the population number and range; interpretation of species status by means of reinforced understanding of the species biology and ecology; habitat conservation; study of the trends via monitoring.

References

Karadelev M., Tofilovska S., K. Rusevska, 2021–2022. National red list of fungi (2021): Focusing on Critically Endangered Species. CONTRIBUTIONS, Section of Natural, Mathematical and Biotechnical Sciences, MASA, 42-43 (1-2): 37-43. DOI: https://doi.org/10.20903/masa/nmbsci.2021.42.9

Gyosheva M.M., Denchev C.M., Dimitrova E.G., Assyov B., Petrova R.D., Stoichev G.T., 2006. Red List of fungi in Bulgaria. Mycologia Balcanica 3: 81-87.

Bondartsev A.S., 1971. The Polyporaceae of the European USSR and Caucasia. Jerusalem. Pp 896.

Dogan H.H., Karadelev M., 2006. Ecology and distribution of two parasitic fungal species (*Pyrofomes demidoffii* and *Antrodia juniperina*) on scale-leaf juniper trees in Turkey. Cryptogamie Mycologie 27 27(1): 35-43.

Garcia-Manjon J.L., Moreno G., 1981. Estudios sobre Aphyllophorales I. Fructificaciones sobre *Juniperus*. Ann. Jard. Bot. Gard. Madrid 37(2): 407-416.

Gilbertson R., Ryvarden L., 1986-1987. North American Polypores (Part 1-2). Fungiflora. Oslo: 1-885.

Karadelev M., 2001. Distribution of lignicolous macromycetes, parasites and saprophytes on *Juniperus* spp. (*J. excelsa*, *J. foetidissima*, *J. sabina*, *J. communis* & *J. oxycedrus*) in the Balkan Peninsula. La Deuxieme Colloque International "Le Genevrier thurifere et le forets d'altitude dans les Montagnes du Pourtour Mediteraneen": 125-131. Marrakech, Morocco.

Niemelä, T., Ryvarden L., 1975. Studies in the aphyllophorales of africa IV: *Antrodia juniperina*, new for east Africa. Transactions of the British Mycological Society 65(3): 427-432.

Ryvarden L., Gilbertson R., 1993. European Polypores (Part 1-2). Fungiflora. Oslo. Pp. 743.

Ryvarden L., Johansen I., 1980. A Preliminary Polypore Flora of East Africa. Fungiflora. Oslo. Pp 636.

Recommendation 2: Enhancing the Inclusion of Fungi in Natura 2000 Standard Data Forms

Context: Natura 2000 Standard Data Forms developed under the framework of the Habitats Directive 92/43/EEC.

Purpose: integrate macrofungal species in the Nature 2000 Standard Data Forms.

Target: the target audience includes biodiversity and conservation professionals involved in the management of Natura 2000 sites. This may encompass **managing bodies, Ministries and authorities**, who are responsible for managing Natura 2000 sites; **researchers and scientists**, who may contribute to species monitoring and knowledge; **technical staff and consultants** assisting in the completion and updating of Standard Data Forms (SDFs); finally, **policy makers and decision makers**, who oversee the implementation of the Habitats Directive.

WE ENCOURAGE STAKEHOLDERS INVOLVED IN MANAGING THE STANDARD DATA FORM TO INCLUDE MACROFUNGAL SPECIES THAT MEET THE CRITERIA OUTLINED IN SUBSECTION 3.3. THIS INCLUDES SPECIES LISTED IN NATIONAL RED LISTS, EU RED LISTS, GLOBAL RED LISTS, AND ENDEMIC SPECIES.

The Habitats Directive together with the Birds Directive, collectively known as the Nature Directives, established the Natura 2000 network, the largest coordinated network of protected areas globally. Its primary goal is to "*maintain and restore, at a favourable conservation status, natural habitats and species of wild fauna and flora of Community interest*".

While the Natura 2000 framework has been instrumental in protecting many species and habitats, fungi remain underrepresented.

Related to Nature 2000, the European Commission adopted a Standard Data Form (SDF) to collect and record detailed information about sites[66].

Section 3 of the SDF, called "*Ecological Information*", provides details on species present in the site.

Subsection 3.3, which is optional, allows Member States to report "*Other important species of flora and fauna*" not covered by the Nature Directives, but relevant for conservation and management of the site. This subsection explicitly includes fungi as a category alongside plants, lichens, and other groups.

However, the optional nature of this subsection has often led to the omission of fungi, despite their critical ecological roles as decomposers, mutualists, and indicators of habitat quality.

Information required on species included in subsection 3.3 is shown in Table 5.

We encourage Member States to systematically include in section 3.3 important fungal species relevant for site management and conservation. This ensures fungi are recognized as integral components of the site's ecological value.

An example of the inclusion of a macrofungal species in the subsection 3.3 of the SDF concerning a Natura 2000 site in Italy is reported in the focus box 8.

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[66] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L_202302806

Table 5. Section 3.3 of the Standard Data Form

3.3	**Other important species of flora and fauna (optional)**		
3.3.1	Species group	If the species belongs to one of the species groups on the code-list available on the Natura 2000 reference portal use the respective code from this list; otherwise leave the field empty (blank).	
3.3.2	Species code	If the species is on the code-lists on the Natura 2000 reference portal that are used in field 3.2.2, please use that code, otherwise leave this field empty.	
3.3.3	Scientific name	If relevant, insert the scientific name as used in the code lists on the Natura 2000 reference portal that are used in field 3.2.2.	
3.3.4	Sensitivity of species data	Indicate in case of sensitive species data	
3.3.5	Non-presence	Indicate if the species is no-longer present in the site	
3.3.6	Population size and unit		
3.3.6.1	Population size	Minimum and maximum population size	
3.3.6.2	Population unit	Code-list (see Natura 2000 reference portal)	
3.3.7	Abundance category	Pre-defined options:	
		☐	Common
		☐	Rare
		☐	Very rare
		☐	Present
3.3.8	Motivation	Pre-defined options:	
		☐	Species of Annex II of the Habitats Directive in a SPA
		☐	Species of Annex IV of the Habitats Directive
		☐	Species of Annex V of the Habitats Directive
		☐	Bird species of Annex I of the Birds Directive in a pSCI, SCI, SAC
		☐	Migratory bird species in a pSCI, SCI, SAC
		☐	Prohibited species of Annex I of the Technical Measures Regulation under the common fisheries policy (EU Regulation 2019/1241) which are not already protected by the Annexes of the Habitats Directive
		☐	Species listed in National Red Lists
		☐	Species listed in EU Red Lists
		☐	Species listed in Global Red Lists
		☐	Endemic species
		☐	Species listed/protected under international Conventions such as the Bern convention and the Convention on the Conservation of Migratory Species of Wild Animals or the Convention of Biological Diversity (CBD)
		☐	Typical species of Annex I habitat types
		☐	Crop Wild Relatives (CWR) / Forest Genetic Resources (FGR)
		☐	Invasive alien species of Union concern as referred to in the EU Regulation 1143/2014 on invasive alien species (IAS)
		☐	Other reasons

Focus Box 8: The Inclusion of *Pleurotus nebrodensis* in the Natura 2000 Network

Author: Giuseppe Venturella

Affiliation: University of Palermo, Department of Agricultural, Food and Forestry Sciences

The inclusion of *Pleurotus nebrodensis* within the Natura 2000 network underscores its significance as a species of high conservation concern due to its restricted distribution and the specific threats it faces, particularly in Sicily.

Listed as critically endangered, *P. nebrodensis* is the focus of targeted conservation actions under Natura 2000, which aim to preserve its natural habitat and ensure its survival.

Efforts include habitat protection, regulated harvesting, and cultivation to reduce anthropogenic pressure on wild populations, contributing to both conservation and sustainable use.

Scientific name

Pleurotus nebrodensis (Inzenga) Quél., Enchir. fung.: 148 (1886). See Figure 40.

Figure 40. Pleurotus nebrodensis (Inzenga) Quél.

Taxonomy and significance

The basidiomycete *Pleurotus nebrodensis* is a rare endemic fungus in Italy and Europe, notable for its antibacterial and anti-cancer properties, making it a potential medicinal mushroom. It is found primarily in the Madonie mountains of Sicily, growing on dead roots of *Prangos ferulacea*, an herbaceous plant native to the Mediterranean Basin.

Historical background

Described in 1863 by Giuseppe Inzenga as *Agaricus nebrodensis*, this species was later reclassified as *Pleurotus nebrodensis*. It was praised by early mycologists, including Ferdinando Alfonso Spagna, for its exceptional culinary qualities.

Conservation status

Despite its significance, *P. nebrodensis* and its habitat lack protection under international conservation laws.

It is, however, previously listed as Critically Endangered (CR) by the IUCN and included in the TOP 50 Mediterranean Island Plants list. After the finding of populations in Greece the new assigned category is EN (Endangered) according to IUCN Red List Criteria: B2ab(iv, v)c(iii, iv).

Its population is highly fragmented and declining, necessitating both in situ and ex situ conservation strategies.

In situ conservation

In situ conservation focuses on protecting *P. nebrodensis* within its natural habitat in the Madonie Mountains, where its collection is regulated. Specific zones within Madonie Park prohibit harvesting, while others restrict it to mature specimens only. Despite these measures, inadequate enforcement has led to continued overharvesting, further endangering the species.

Ex situ conservation

Ex situ conservation efforts include cultivating *P. nebrodensis* in controlled environments to reduce harvesting pressure on wild populations. The "PLEURÒN" project, initiated by the Sicilian Administrative Region, aims to cultivate this species on a pilot scale for both culinary and medicinal purposes. This approach not only aids in conservation but also makes the mushroom more accessible to consumers by lowering its market price.

Public awareness and participation

To enhance conservation efforts, it is crucial to involve citizens and raise awareness about the environmental and economic importance of *P. nebrodensis*. Promoting its medicinal potential can further engage public interest, contributing to the protection, cultivation and sustainable use of this valuable species.

Nature 2000 Network

The Sicilian subpopulation of *P. nebrodensis* falls within the following Italian Natura 2000 sites (see Figure 41):

- ITA020004 "M. San Salvatore, M. Catarineci, Vallone Mandarini, ambienti umidi"
- ITA020016 "Monte Quacella, Monte dei Cervi, Pizzo. Carbonara, Monte Ferro, Pizzo Otiero".

P. nebrodensis was originally thought to occur only in Sicily. However, its presence was recently also confirmed from mainland Greece.

Greek subpopulation of *P. nebrodensis* falls within the following Natura 2000 sites:

- GR2410002 "Oros Parnassos"
- GR2530001 "Koryfes Orous Kyllini (Ziria) kai Charadra Flampouritsa"
- GR2320008 "Oros Erymanthos"
- GR2320002 "Oros Chelmos kai Ydata Stygos".

Figure 41. Presence of Pleurotus nebrodensis populations

References

Pasta S., Perez-Graber A., Fazan L. and Montmollin B. de (Eds), 2017. The Top 50 Mediterranean Island Plants UPDATE 2017. IUCN/SSC/Mediterranean Plant Specialist Group. Neuchâtel (Switzerland). E-book and online. 141 pp. https://top50.iucn-mpsg.org/species/39

Gargano M.L., Saitta A., Zervakis G., Venturella G., 2011. Building the jigsaw puzzle of the critically endangered *Pleurotus nebrodensis*: Historical collection sites and an emended description. Mycotaxon 115: 107–114. http://mail.ithaca-ny.com/journal-PDF/vol115/s13.pdf

Gargano M.L., Venturella G., Balenzano G., Ferraro V., Cirlincione F., Mirabile G., 2024. *Pleurotus nebrodensis* (Basidiomycota), a rare endemic mushroom of Sicily: current and future issues. Italian Botanist 17: 55–68. https://doi.org/10.3897/italianbotanist.17.123048

Zervakis G.I., Ntougias S., Gargano M.L., Besi M.I., Polemis E., Typas M.A., Venturella G., 2014. A reappraisal of the *Pleurotus eryngii* complex – New species and taxonomic combinations based on the application of a polyphasic approach, and an identification key to Pleurotus taxa associated with Apiaceae plants. Fungal Biology 118, 814–834.

Recommendation 3: Development of Habitat-Specific Fungal Species Lists and Their Integration into Monitoring Plans

Context: Habitats Directive 92/43/EEC, Interpretation Manual of European Union habitat types listed in Annex I (EC 2013).

Purpose: Inclusion of macrofungal species in the Interpretation Manual of EU habitat types and Habitat Fact Sheets.

Target: This recommendation is directed to the **European Commission** who is responsible for overseeing the implementation of the Habitats Directive across EU Member States and the developed of the documentations (including guidelines and Interpretation Manuals); the **European Environment Agency** (EEA) who works in collaboration with the Commission and other expert bodies to ensure the Manual and guidelines is used consistently across Member States; **national environmental authorities and competent agencies** involved in implementing habitat monitoring programs; **research institutes, universities, and conservation organisations** which often play a significant role in interpreting and applying the Manual, conduct field surveys, identify habitat types in Natura 2000 areas, and carry out monitoring and reporting.

WE RECOMMEND THE INCLUSION OF MACROFUNGAL SPECIES IN THE MANUAL OF INTERPRETATION OF THE HABITATS DIRECTIVE AND THE ASSOCIATED HABITAT FACT SHEETS FOR HABITATS IN WHICH FUNGI ARE ECOLOGICALLY IMPORTANT AND PLAY A CENTRAL ROLE IN NUTRIENT CYCLING, PLANT HEALTH, AND BIODIVERSITY MAINTENANCE (E.G., FORESTS, GRASSLANDS, BOGS, AND FENS).

In May 1992 the Scientific Working Group established by the Habitats Committee recognized the need for a manual to interpret the habitat types listed in Annex I of the Habitats Directive, i.e. "*Natural habitat types of community interest whose conservation requires the designation of special areas of conservation*".

The resulting document is known as the "Interpretation Manual of European Union Habitats"[67]. It provides standardised definitions of habitat types applicable across all EU Member States.

The manual has undergone several revisions, with the most recent version, EUR28, being adopted by the Habitats Committee on 25 April 2013.

The Interpretation Manual and the habitat Fact Sheets provide essential guidance for the identification and management of protected habitats and species, but fungi are not adequately addressed within these documents.

Each habitat Fact Sheet is divided into five sections, as shown in Figure 42. In Section 2 a list of characteristic animal and plant species for each habitat type is reported. A *characteristic* species is defined as one that helps identify a habitat type, with its presence strongly associated with specific ecological factors of that habitat (Müller-Kroehling, 2019).

[67] https://eunis.eea.europa.eu/references/2435

The Interpretation Manual should incorporate **key fungal species or fungal guilds** that are vital to the ecological processes within specific habitats. This would include:

- threatened or rare fungal species that require conservation attention due to habitat loss or degradation
- mycorrhizal fungi that form symbiotic relationships with plants in forest, grassland and heathland ecosystems
- saprotrophic fungi which are responsible for decomposition in terrestrial ecosystems, contributing to nutrient recycling.

Regular monitoring of key fungal species and their populations will provide a clearer understanding of the overall health of ecosystems.

In the following focus boxes (from 9 to 12), examples of macrofungal species included in national habitat Fact Sheets are presented.

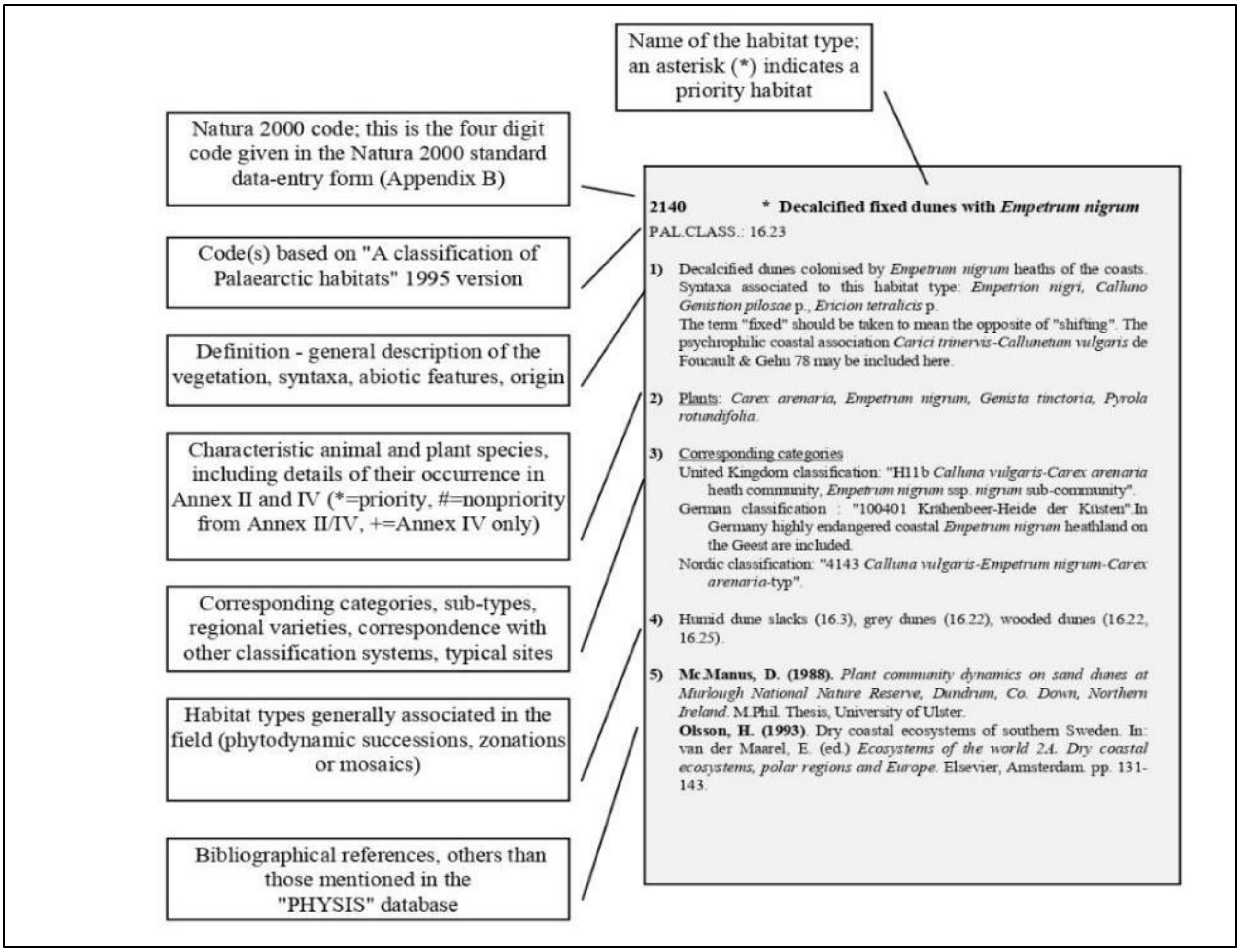

Figure 42. Sections of the fact sheet

Focus Box 9: Macrofungi Included in Habitat Descriptive Sheets of the Interpretation Manual of EU habitats

Author: Francesca Floccia

Affiliation: see Annex I

Among the habitat types described in the Interpretation Manual of European Union habitats (European Commission, 2013), there are three for which fungi are explicitly mentioned among the characteristic species, within the "Plants" group (see Figure 43).

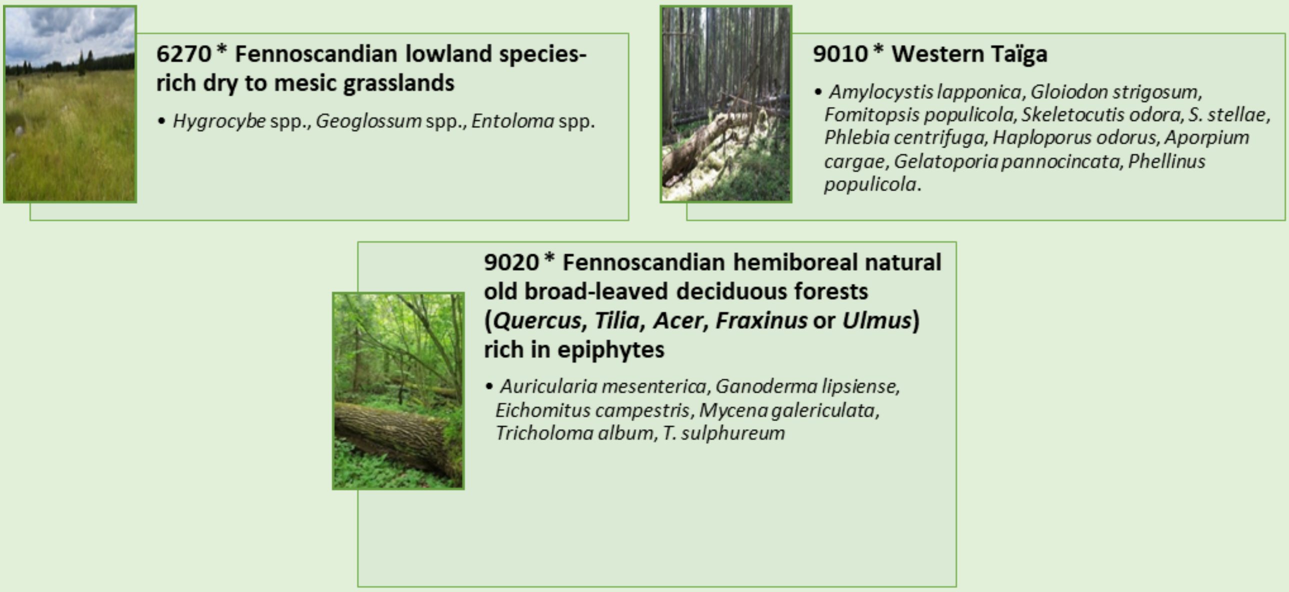

Figure 43. Macrofungi among the characteristic species of habitat types in the Interpretation Manual of European Union Habitats.

The **habitat type 6270** (Fennoscandian lowland species-rich dry to mesic grasslands) includes three fungal genera playing a vital role in nutrient cycling and overall biodiversity.

In **habitat type 9010** (Western Taiga), 10 fungal species are mentioned. This boreal forest habitat is rich in deadwood, which creates ideal conditions for various fungi, particularly wood-decaying ones. Fungi in these ecosystems are critical for decomposition and nutrient cycling, enhancing the biodiversity and functionality of the forest.

Similarly, **habitat type 9020** (Fennoscandian hemiboreal natural old broad-leaved deciduous forests) includes 12 fungal species. These forests are biodiversity hotspots, particularly for species associated with deadwood and decomposing materials. The presence of fungi is vital for maintaining forest integrity, especially in association with old trees and decaying wood.

References

European Commission, 2013. Interpretation Manual of European Union Habitats (EUR 28). https://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf

Focus Box 10: The Latvian Fungi Included in National Habitat Types

Authors: Inita Daniele, Gita Strode

Affiliations: *I. Daniele*: see Annex I; *G. Strode*: Nature Conservation Agency, Director of Nature Conservation Department

Fungi play a crucial role in various habitat types across Latvia, contributing to biodiversity and ecosystem stability. In Latvian ecosystems, macrofungi are significant due to their involvement in nutrient cycling, decomposition, and symbiotic relationships with plants (mycorrhiza). These fungi are found in a wide range of habitats, from forests and grasslands to wetlands and coastal areas.

The Latvian Nature Conservation Agency[68] employs fact sheets for habitat mapping and monitoring. These fact sheets are used by experts during field inspections to verify the presence of species in various habitats. This hands-on approach ensures that accurate and up-to-date information is collected for habitat conservation and management.

Monitoring fact sheets with species names are reported in the web site of the Nature Conservation Agency Republic of Latvia, section “Biotope mapping methodologies”[69].

More information about each habitat type and species are reported in the Interpretation manual of European Union protected habitats in Latvia”[70].

Key habitat types in Latvia involving fungi are shown in Figure 44.

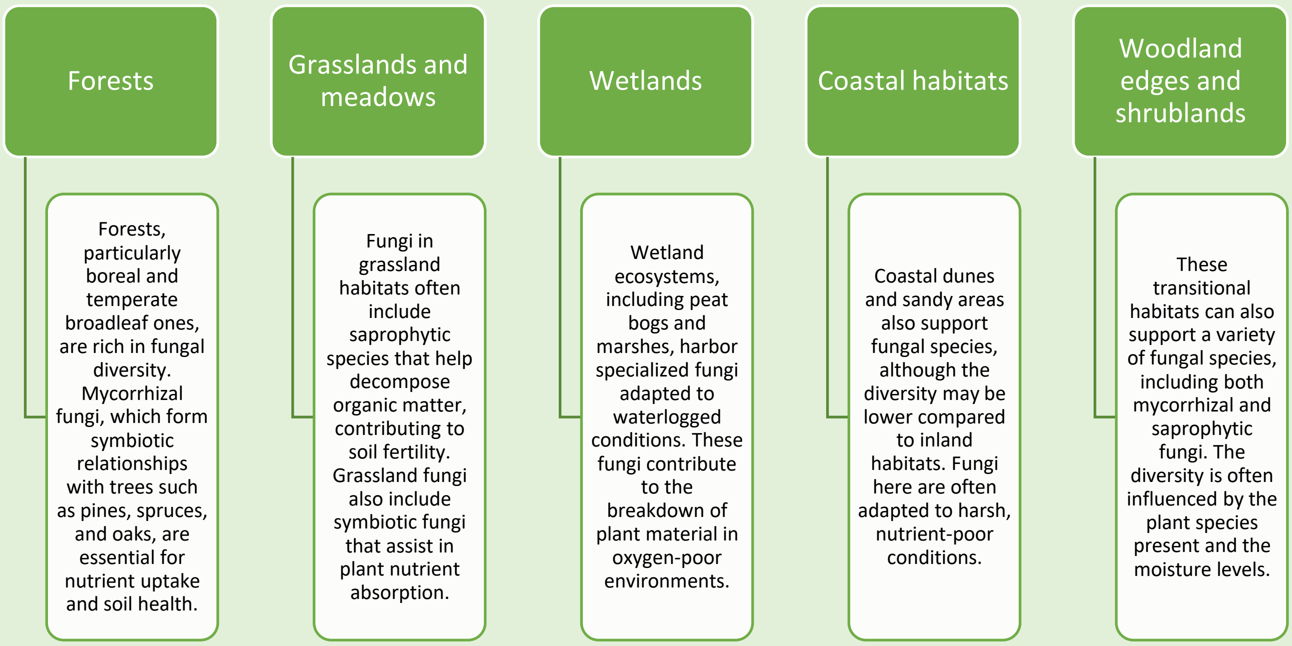

Figure 44. Key habitat types in Latvia involving fungi

68 https://www.daba.gov.lv/lv/biotopu-kartesanas-metodikas-0
69 https://www.daba.gov.lv/lv/biotopu-kartesanas-metodikas-0
70 https://www.daba.gov.lv/lv/media/5945/download?attachment

Forests

Common forest fungi in Latvia include species from genera such as *Boletus, Russula, Cortinarius,* and *Amanita.*

Most of the threatened mushroom species are associated with forests, mainly old and deciduous forests. Mycorrhizal species of oaks (*Quercus*) are endangered in nemoral (broad-leaved) forests, which can be explained by the small area of natural oak forests, for example the species *Amanita ceciliae, Entoloma sinuatum, Gyroporus castaneus*. On the other hand, such species as *Pseudoinonotus dryadeus, Fistulina hepatica, Urnula craterium* and others are associated with dead oak wood in these forests. In particular, *Rhodotus palmatus can* be found on *Ulmus* wood. Latvia is a country of giant oaks and *Hapalopilus croceus* and *Xylobolus frustulatus* are associated with old, often solitary oaks.

Several endangered mushroom species are associated with boreal (coniferous) forests. Rare mycorrhizal fungi (*Tricholoma apium, Ramaria boreimaxima, Boletopsis grisea*), xylotrophs (*Bondarzewia mesenterica*) and partial parasites (*Sparassis crispa* growing at the base of old pines) can be found in *Pinus silvestris* forests.

In Picea abies forests, we can find both mycorrhizal fungi (Gomphus clavatus, Hydnellum suaveolens) and xylotrophs (Pycnoporellus alboluteus, Phellopilus nigrolimitatus, etc.)

Coniferous mycorrhizal fungi Hydnellum aurantiacum, Hydnellum caeruleum are found in various boreal forests; xylotrophs Erastia salmonicolor, Pleurocybella porrigens, Gyromitra sphaerospora, dead ground cover saprotrophs Clavariadelphus truncatus, Marasmius wynneae and Sarcosoma globosum.

Grasslands and meadows

Species such as *Clavaria, Geoglossum, and Entoloma* are often associated with semi-natural grasslands in Latvia.

Clavaria zollingeri can be found in natural, unfertilized meadows, pastures, woodlands and other grassy areas, as well as several rare *Hygrocybe* spp. species. The main threats to the fungi inhabiting grasslands are changes in meadow management, disappearance of pastures, fertilisation of meadows, use of herbicides, overgrowth of meadows, ploughing or afforestation.

Wetlands

Fungi like *Sphagnum* specialists (associated with peat moss) are common in these habitats.

Pseudoboletus parasiticus, a mycotrophic fungus growing on *Scleroderma*, is found in wet mixed forests, while *Mitrula paludosa* is found in forest ditches and swamps on fallen forest litter. Xylotrophs *Ionomidotis irregularis*, *Rigidoporus crocatus* are also found in wet forests, as well as on *Salix* spp. growing *Trametes suaveolens*.

Lentinus tigrinus is found in wet places and often grows on slopes over which water washes. *Desarmillaria ectypa*, a species of herbotrophic and bryotrophic fungi associated with different types of bogs. The main threat to various wetland fungi is drainage and changes in the moisture regime.

Coastal habitats

Coastal dunes and sandy areas also support fungal species, although the diversity may be lower compared to inland habitats. Fungi here are often adapted to harsh, nutrient-poor conditions.

Species such as *Psathyrella* and other sand-dwelling fungi can be found in Latvia's coastal regions.

Agaricus devoniensis, Phallus hadriani, Peziza ammophila are found in the seaside dunes. The main threats are the impact of tourism and recreation on dunes and coastal forest habitats.

Several rare mushroom species are also found in man-made habitats - parks and gardens. *Quercus* mycorrhizal fungi *Amanita strobiliformis*, *Caloboletus calopus, Cyanoboletus pulverulentus* are found in old country parks, but as xylotrophs *Bulgaria inquinans, Holwaya mucida, Volvariella bombycina*. *Sarcodontia crocea* is sometimes found on apple trees in old orchards. Due to intensive fruit cultivation, such old orchards are endangered all over the world.

Focus Box 11: Environmental Monitoring of Fungi in Sweden

Box edited by experts from Swedish Environmental Protection Agency, Swedish National Forest Inventory, Swedish Forest Soil Inventory

The Swedish National Forest Inventory (NFI) has been conducting extensive surveys of trees, shrubs, and ground vegetation since 1923. Over the years, the methods have evolved to meet increasing demands for data related to biodiversity, climate change, and ecosystem services. This focus box aims to showcase the contributions of NFI surveys, providing examples of data analysis. These surveys cover a wide variety of plant species and groups, including trees, shrubs, vascular plants, mosses, lichens, and fungi. The methods used vary depending on the species and the objective of each survey, with results highlighting changes in vegetation cover and species distribution over time, especially for species like bilberry and reindeer lichen.

Data analysis from these surveys reveal trends in species abundance and distribution, which are crucial for habitat classification and environmental monitoring. The NFI's efforts provide valuable insights into forest ecosystems and support informed decision-making in areas like forestry, biodiversity conservation, and climate change mitigation. The fungi monitored by NFI include species such as: *Phellinus chrysoloma, Fomitopsis pinicola*, *Climacocystis borealis*, *Fomes fomentarius*, *Phellinus pini*, *Phellinus igniarius*.

Some of the results, based on NFI's registration of fungal sporocarps, are shown in Figure 45.

In addition, the Swedish Forest Soil Inventory has been collecting humus samples from approximately 350 forests annually since 2015, in collaboration with the NFI, to analyse fungal eDNA. This research provides a comprehensive understanding of the dominant and frequent fungal species in various Swedish forest types, highlighting important mycorrhizal and decomposer fungi. However, rarer species are less likely to be detected, given the small sample size.

The inventories are conducted on permanent plots (314 m²) shared with the NFI and organised into square clusters, with denser sampling towards southern Sweden. Fieldwork is carried out in the summer by trained staff. Soil samples are collected from up to five soil layers, and a separate sample is taken for eDNA-based analysis of fungal biodiversity. Several chemical properties of the soil are also measured, such as carbon, nitrogen, base cations, aluminium, and acidity.

The results of the Swedish Forest Soil Inventory are used to monitor national environmental quality objectives, report carbon stocks within the LULUCF sector (under the UNFCCC), and support research, education, and public information. Fungal community analysis is based on eDNA extracted from humus samples, with species identified using ITS2 (Internal Transcribed Spacer 2) markers. These DNA sequences are analysed through PacBio SMRT sequencing in collaboration with SciLifeLab NGI in Uppsala. Species composition is identified by comparing the sequences with the UNITE reference database, which is based on DNA from identified fungal sporocarps and mycelial cultures.

To ensure accuracy, a species is considered present in a sample only if it constitutes more than 1% of the total fungal ITS2 markers in that sample. This threshold minimises the risk of identifying species based on fungal spores or contamination during sample preparation. It also prioritises precise taxonomic identification over reporting a larger number of observations.

For additional information on typical species per habitat, visit Sök arter - Artfakta from SLU Artdatabanken[71].

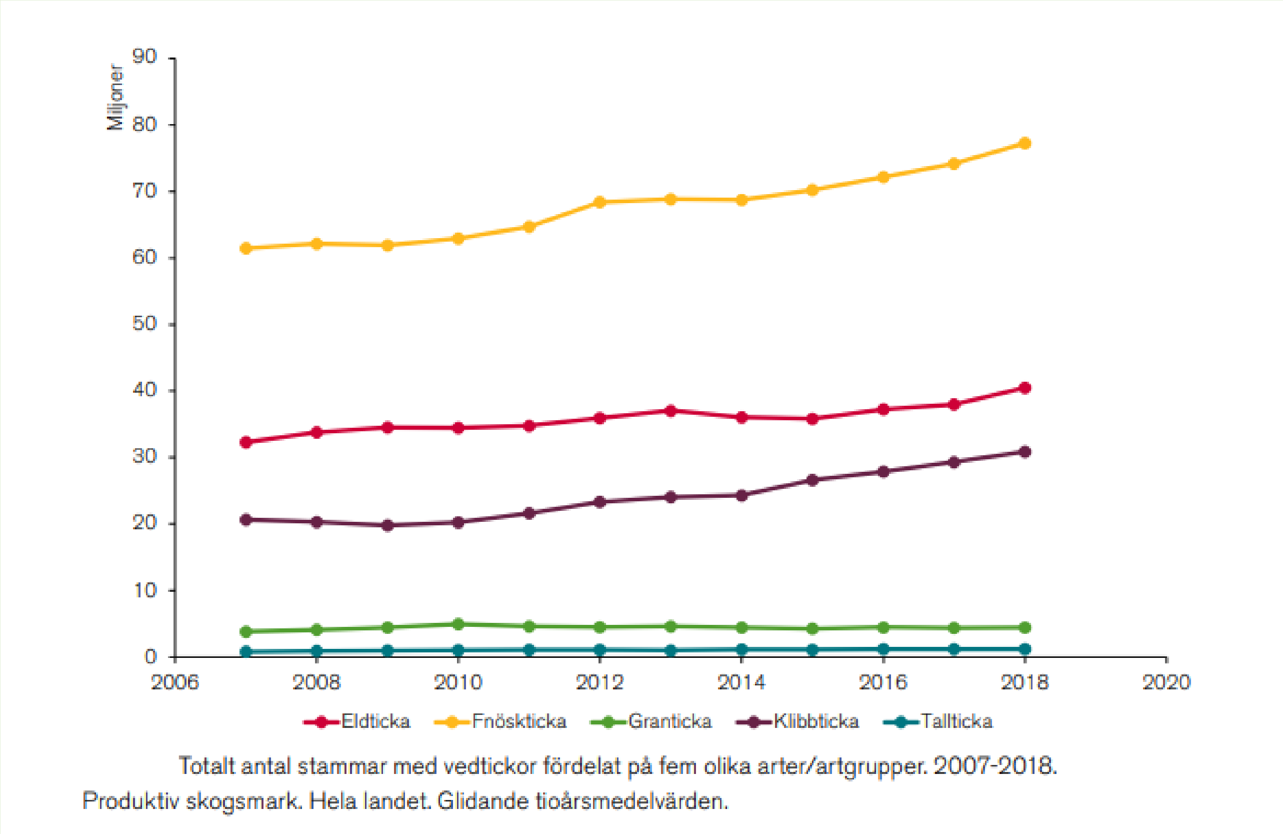

Figure 45. Total number of logs, categorized into five different species or species groups, recorded from 2007 to 2018.

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[71] https://www.artfakta.se

Focus Box 12: Development of Plant and Fungal Species Lists for Habitats to be Proposed for Protection in France

Authors: Yann Sellier, Francis Martin, Frédéric Vincq

Affiliations: *Y. Sellier* - National Nature Reserve, RNN du Pinail, France, Conservation, Research officer; *F. Martin* - see Annex I; *F. Vincq* - Direction de l'eau et de la biodiversité, Ministère de la transition écologique et de la cohésion des territoires

In response to the expectations of biodiversity management and conservation stakeholders, and to contribute to the objective of the National Biodiversity Strategy on species protection, the Flora, Fungi, Natural Habitats, and National Botanical Conservatories Working Group (FFH-CBN WG) of the National Council for Nature Protection (CNPN) reactivated, at the beginning of 2023, the coordinated effort to update lists of protected species of vascular plants for mainland France and overseas territories and to develop such lists for non-vascular plants and fungi. Upon the proposal of its president, the CNPN validated on 20 December 2023 the document "Guidelines for the Development of Plant and Fungal Species Lists for Terrestrial, Aquatic, and Coastal Habitats to be proposed for Protection." This document, resulting from a collaborative effort (involving numerous French institutions and associations, including the National Botanical Conservatories), was initiated in February 2023 by the FFH-CBN WG. This work continues the momentum started during the group's previous mandate (2017-2022), following junior engineer internship work on the Revision of the Regulatory Framework for Flora Protection at the national level that took place in 2017 at the Water and Biodiversity Directorate (DEB) of the French Ministry of Environment, Energy, and the Sea. Work commenced in early 2024, with nearly one hundred experts from various organisations being mobilised to form National Working Groups (GTNs) for the three areas: Vascular Flora, Non-vascular Flora (algae, bryophytes), and Lichenised fungi. These GTNs are expected, at first, to translate the above-mentioned guidelines into finalised methodologies for each taxonomic group by the end of 2024, and then, on the basis of these methodologies, identify lists of species to be proposed for protection by the end of 2025. The political and validation phases will predece the publication of the species protection decrees.

Répondant à l'attente des acteurs de la gestion et de la conservation de la biodiversité, et pour contribuer à l'objectif fixé dans la Stratégie Nationale Biodiversité 2030 en matière de protection des espèces, le Groupe de travail Flore, Fonge, Habitats naturels et Conservatoires botaniques nationaux du Conseil National de Protection de la Nature (GT FFH-CBN du CNPN) a réactivé début 2023 la dynamique concertée d'actualisation des listes d'espèces protégées de flore vasculaire pour la métropole et les outre-mer, et d'élaboration de listes pour la flore non vasculaire et la fonge. Sur proposition de son président, le CNPN a validé le 20 décembre 2023 le document « lignes directrices pour l'élaboration de listes d'espèces végétales et fongiques des milieux terrestres, aquatiques et littoraux à proposer à la protection » issu d'un travail concerté (participation de nombreuses institutions, dont les Conservatoires botaniques nationaux, associations françaises) entrepris en février 2023 par le GT FFH-CBN. Ce travail s'inscrit dans la continuation de la dynamique initiée lors de son précédent mandat (2017-2022), à la suite d'un stage d'élève ingénieur portant sur la Révision du cadre de protection réglementaire de la flore sur le territoire national organisé en 2017 au sein de la Direction de l'eau et de la biodiversité (DEB) du Ministère de l'Environnement, de l'Énergie et de la Mer. Après la validation des lignes directrices par le CNPN, près d'une centaine d'experts de tous organismes ont été mobilisés pour constituer des Groupes de Travail Nationaux (GTN) pour les 3 groupes taxonomiques: Flore vasculaire, Flore non vasculaire (algues, bryophytes) et Fonge (champignons, lichens). Dans un premier temps, ces GTN déclinent en méthodologies les lignes directrices pour chacun des groupes taxonomiques (pour fin 2024), ils identifieront ensuite, sur la base de ces méthodologies, des listes d'espèces à proposer à la protection (pour fin 2025). Il s'ensuivra un temps politique et de validation avant la parution des arrêtés de protection des espèces.

Recommendation 4: Integration of Macrofungi into National and International Environmental Legislation and Conservation Strategies

Context: Biodiversity conservation laws and strategies at national and international scale.

Purpose: integrate macrofungi into environmental legislation and biodiversity conservation frameworks.

Target: this recommendation is for **National Governments and Ministries** which can incorporate macrofungi into the National Conservation Strategies, propose legislation that explicitly includes the protection of fungal species, and promote the inclusion of fungi in the application of international Agreements, such as Convention on Biological Diversity (CBD), and biodiversity monitoring frameworks.

It is also intended for the **European Environment Agency** (EEA), which could advance fungal conservation efforts at the EU level; and for **environmental NGOs** and **conservation organisations**, such as the International Union for Conservation of Nature (IUCN) and the IUCN Global Fungal Red List Initiative, which can advocate for legislative changes by providing scientific data and policy recommendations. Among these, the **IMPEL Network** could expand its efforts to include fungi.

Finally, it is intended for **Academia and mycologists**, who can play a crucial role in raising awareness about fungi providing scientific data and evidence on the extinction risks and importance of fungal species, biodiversity assessments and recommendations.

WE RECOMMEND THAT ALL STAKEHOLDERS TAKE THE ACTIONS TO FULLY INTEGRATE FUNGI INTO ENVIRONMENTAL AND BIODIVERSITY CONSERVATION FRAMEWORKS.

WE CALL FOR COLLABORATION AMONG GOVERNMENTS, INTERNATIONAL ORGANIZATIONS, NGOS, SCIENTISTS, AND THE PUBLIC TO ENSURE THAT FUNGI RECEIVE THE LEGAL PROTECTIONS NECESSARY TO SAFEGUARD THEIR SURVIVAL.

Legislative and policy measures for promoting the conservation of macrofungi require a collaborative effort. Multiple and diversified actions are needed at different societal and governmental levels as briefly outlined in the following and shown in Figure 46.

The first action needed seems to be **raising awareness** among lawmakers, ministries and environmental agencies about the crucial ecological role fungi play in our ecosystems, and **partnering** with environmental NGOs, scientific communities and mycological societies, which can support efforts to include fungi in environmental protection laws.

Simultaneously, **scientific research and data collection** are critical. Comprehensive studies are needed to identify fungal species, their habitats and ecological roles and to know their distribution. Through their conservation status and trend and vulnerability to pressures it would be possible to identify threatened species and quality indicators.

Existing **environmental laws** should then be amended to explicitly include fungi. Biodiversity protection laws should recognize fungi as integral to ecosystems, ensuring that they receive the same protections as plants and animals.

These actions can lead to the creation of **specific regulations** aimed at fungal conservation, such as restrictions on harvesting and habitat destruction or impoverishment, along with guidelines for sustainable use in economic activities like agriculture and forestry.

International cooperation is also essential. Engaging with global environmental conventions, such as the Convention on Biological Diversity, ensures fungi are incorporated into international biodiversity goals.

Public engagement and **education** play a significant role in this strategy. Increasing people's awareness through educational programs, citizen science initiatives and community involvement can help monitor fungal populations and deter activities that harm fungi.

However, to be able to implement all these actions **funding and resources** are essential. Dedicated funding for fungal conservation, research and public education can be achieved through partnerships between government agencies, academic institutions and private organisations. This financial support is really needed for the long-term success of fungal conservation efforts.

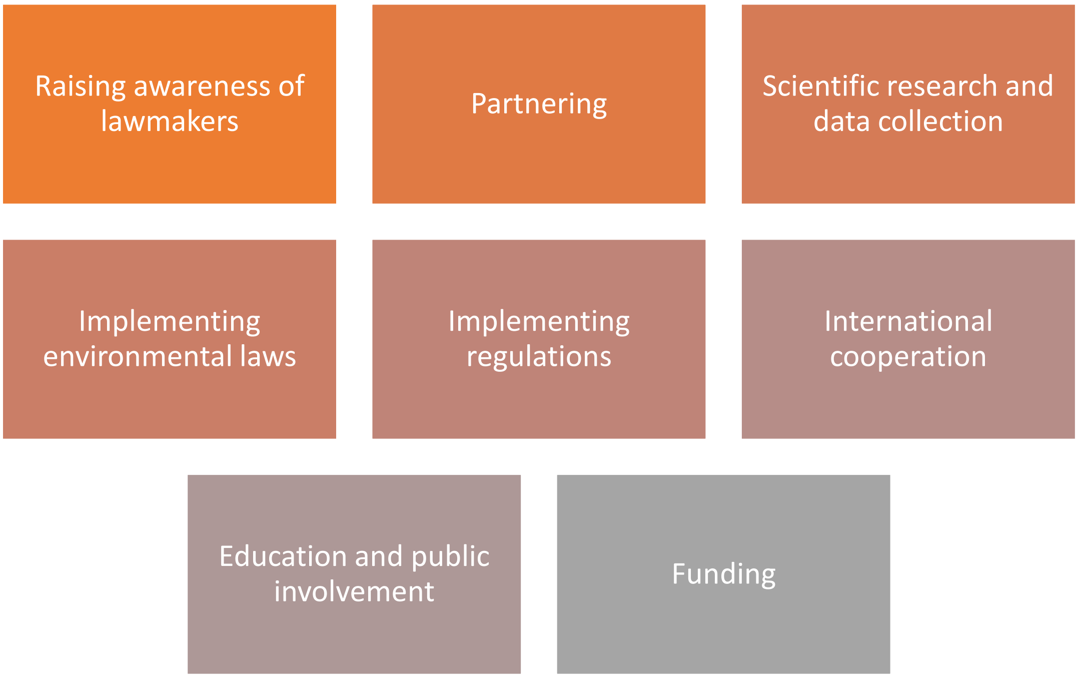

Figure 46. Main actions needed to promote the implementation of legislation and strategies for the conservation of macrofungi

The following focus boxes (from 13 to 14) explore the role of fungi within legislative and policy frameworks in Europe, showcasing national-level efforts to integrate fungal conservation into biodiversity strategies. These studies underscore the importance of national legislation in driving fungal conservation efforts and provide valuable lessons for broader policy development across Europe.

Focus Box 13: Fungi in the Legislative Framework of the Republic of Croatia

Author: Tatjana Lalić Šarić

Affiliation: see Annex I

The fundamental document of nature protection in the Republic of Croatia is the Strategy and Action Plan for Nature Protection (further in the text: Strategy). The Strategy determines the long-term goals and guidelines for the preservation of biodiversity and geodiversity, as well as the means for its implementation. The strategy is drawn up by the Ministry of Environmental Protection and Green Transition (further in the text: the Ministry) in cooperation with other state administration bodies. The Strategy, on the proposal of the Government of the Republic of Croatia, is adopted by the Croatian Parliament. The Ministry performs an analysis of the achievement of goals and the implementation of activities determined by the Strategy, the legislative and institutional framework, as well as the sources and use of financial resources for nature protection and, if necessary, proposes the adoption of changes and/or amendments to the Strategy, or a new strategy. The public is informed about the results of the analysis by publishing them on the Ministry's website.

The currently valid Strategy and Action Plan for Nature Protection of the Republic of Croatia covers the period from 2017 to 2025[72]. In the latest report on the state of nature in the Republic of Croatia for the period from 2013 to 2017[73], among other things, the total number of **fungi** and lichens recorded was stated: approx. 5,500 of which 297 are threatened species (CR, EN and VU).

Croatia became a party to the Aarhus Convention in June 2007. According to the Law on Nature Protection[74], the public has the right to free access to information about the state of nature. The Ministry, administrative bodies, competent bodies of local and regional self-government and public institutions are obliged to ensure the release of data related to the state and protection of nature, unless confidentiality of data is prescribed by a special law or act of the competent body. During the drafting of regulations, i.e. acts on the declaration of protected parts of nature, management plans for protected areas, as well as generally applicable and legally binding regulations and documents in the field of nature protection, public participation is ensured.

According to the Law on Nature Protection, it is forbidden to exterminate a native wild species, reduce the number of individuals in a particular population of a native wild species, reduce or damage its habitat or worsen its living conditions to the extent that that population becomes endangered. It is not necessary to obtain permission from the Ministry to collect native wild species for personal use. As far as mushrooms are concerned, collection for personal needs is the collection of up to 3 kg of above-ground mushroom fruiting bodies per day and up to 0.1 kg of hypogeous mushroom fruiting bodies per day.

The Law on Nature Protection states that in order to collect, i.e. take from nature for the purpose of processing and/or selling (commercial purposes) native wild species for which this is prescribed by the special **Ordinance on the collection of native wild species**[75], legal and natural persons are

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[72] Strategy and Action Plan for Nature Protection of the Republic of Croatia.

[73] Report on the State of the Environment in the Republic of Croatia

[74] Law on Nature Protection

[75] Ordinance on the collection of native wild species

required to obtain permission which can be issued by the Ministry on the basis of the Expert basis for collecting native wild species[76]. In addition to animals, plants, mosses, algae and lichens, 22 genera and 88 individual species of **fungi** are listed in the abovementioned Ordinance.

This permission is issued to them for a maximum period of 3 years, i.e. it is harmonised with the validity of the Expert basis for collecting native wild species, which is prepared every 3 years. The Expert basis for collecting native wild species contains special management and protection measures for a species or group of species from the Ordinance on collection of native species (for truffles there is a quantity limit which amount up to 0.5 kg of hypogeous fruiting bodies per day and for other types of mushrooms quantity limit is up to 10 kg per day of above-ground mushroom fruiting bodies of each species). With regards to mushrooms, the abovementioned Ordinance states that in some protected areas (strict reserves and national parks) it is forbidden to collect native wild species from nature for commercial purposes, while, for example, in special reserves it is prohibited to collect from nature for commercial purposes those of native wild species for which the area is protected.

Some of the general measures of management and protection of individual species or groups of mushroom species prescribed by the Ordinance are:

- collecting above-ground types of mushrooms: only the fruiting body of the mushroom is collected; depending on the shape and place of growth, the fruiting body of the above-ground mushroom is picked by hand or cut with a knife, without using other tools; it is not allowed to discard already collected mushrooms in order to collect some others; it is not allowed to damage the mycelium or the immediate habitat; one third of the total number of fruiting bodies of each collected species must be left intact in the habitat; it is not allowed to collect old fruiting bodies; ect.
- collecting hypogeous species of mushrooms: are collected only with the help of a maximum of two dogs; it is dug only at the point of sniffing; it is dug with a shovel whose blade is no longer than 15 cm and wider than 8 cm; the holes created by removing the fruiting bodies of underground mushrooms must be filled again with excavated soil; it is not allowed to dig holes with a diameter greater than 30 cm; the holes dug by the underground mushroom collector on the same day must not be at a distance of less than 150 cm; ect.

The permit holder for collecting native wild species from natural habitats must obtain the consent of the owner or holder of rights to natural resources before starting the collection, i.e. taking from nature.

The permit for collecting for commercial purposes contains the conditions and deadline for the use of native wild species and the obligation to report on the activity carried out. The report must include a list of the species collected, information on the collected quantities for each species for which a permit was issued, and information on the place of collection and the time of collection. Analyses of pressures on populations due to use are determined, among other things, based on annual reports of collection permit holders.

[76] Expert basis for the collection of native wild species 2024 -2026.

Croatia has a Red List of Mushrooms[77] (349 species), based on The Red Book of Mushrooms of Croatia[78] was issued (314 species are covered in detail, see Figure 47).

66

Helvella queletiana Sacc. et Traverso sensu Dissing

Žilasti hrčak

Helvella queletiana (snimka/photo N. Matočec)

Odjeljak: *Ascomycota*; **Red:** *Pezizales*; **Porodica:** *Helvellaceae*.

IUCN kategorija ugroženosti u Hrvatskoj: kritično ugrožena (CR); **Kriteriji:** D.

Ekologija. Živi uglavnom u termofilnim zimzelenim i listopadnim hrastovim šumama (*Quercus* spp.) sredozemnog područja te u bukovim šumama (*Fagus sylvatica*) toplijeg dijela atlantskog područja.

Fenologija. Plodišta se razvijaju od listopada do travnja na sredozemnom području, a na atlantskom području u svibnju i lipnju.

Rasprostranjenost vrste u Hrvatskoj. Poznata je samo s jednog lokaliteta, na otoku Korčuli.

Rasprostranjenost vrste u Europi. Zabilježena je u sedam zemalja (Bosna i Hercegovina, Danska, Francuska, Hrvatska, Makedonija, Portugal i Španjolska) i iznimno je rijetka.

Rasprostranjenost vrste u svijetu. Izvan europskog kontinenta poznata je samo iz Izraela.

Uzroci ugroženosti u Hrvatskoj. Vrsta je u našoj zemlji vezana za razvijene zimzelene sredozemne šume s hrastom crnikom (*Quercus ilex*). Površine pod preostalim visokim zimzelenim šumama na jadranskoj obali i na otocima su male, i lako bi mogle nestati u požaru ili zbog intenzivne urbanizacije i neprimjerenog razvoja turizma. Osim toga, vrsta je prisutna u izrazito malobrojnim i izoliranim populacijama.

Postojeće mjere zaštite. Žilasti hrčak je strogo zaštićen Pravilnikom o proglašavanju divljih svojti zaštićenim i strogo zaštićenim (»Narodne novine« broj 07/2006).

Predložene mjere zaštite. Sve preostale stare zimzelene sredozemne šume, posebno na lokalitetu na kojem je vrsta pronađena, treba sačuvati od svake sječe i degradacije te prepustiti prirodnom razvoju.

Napomena. Čini se da ova sredozemna vrsta, različita od srednjoeuropske vrste *Helvella phlebophora* Sacc. (= *H. queletiana* Sacc. et Traverso), nema znanstvenog naziva. Za potrebe ove knjige privremeno upotrebljavamo gore navedeno ime u smislu Dissinga, jednog od najvažnijih autora koji su istraživali rod *Helvella*. Dissing je prvi jasno razlučio ove dvije vrste prema njihovim morfološkim i ekološkim obilježjima.

Figure 47. Red book of Mushrooms of Croatia (degree of threat, ecology, phenology, distribution, causes of threat, existing and proposed protection measures)

In the Law on Nature Protection, it is stated that strictly protected species based on the Red List are declared by the minister by ordinance. The **Ordinance on Strictly Protected Species** is currently valid[79]. In this ordinance, which lists 55 critically endangered (CR), 76 endangered (EN) and 118 sensitive (VU) and 65 according to the precautionary principle (DD) species of mushrooms, it prescribes general measures for the protection of strictly protected species and their habitats, the detailed content of requests for issuing permits for deviations from strict protection measures, dealing with dead or injured specimens of strictly protected species, the content, the method of preparation and the procedure for adopting a management plan with an action plan and other rules of dealing with strictly protected species. The Law on Nature Protection prohibits actions with strictly protected species: it is forbidden intentional picking, cutting, felling, digging, collecting or destroying individuals of strictly protected plants, mushrooms, lichens and algae from nature in their natural range is prohibited. The Ministry can allow a deviation from the prohibitions, but a legal or natural person is obliged to obtain the permission of the Ministry.

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[77] Red list of mushrooms
[78] The Red Book of Mushrooms of Croatia
[79] The Ordinance on Strictly Protected Species

The inspection supervision over the application of Law on Nature Protection and the regulations adopted based on Law on Nature Protection is carried out by government officials of the Nature Protection Inspection. Police officers of the Ministry of the Interior carry out inspections if the inspectors are not present or are unable to intervene. During the inspection, the inspector has the right and obligation to temporarily confiscate from the supervised persons objects that have committed a criminal offence, or a misdemeanour provided for in the Nature Protection Act, or a part of nature, and determine its storage or safekeeping. For confiscated objects and parts of nature, the inspector issues a certificate and submits an indictment or a criminal report. The competent court decides on the permanent confiscation of part of nature and object. A part of nature acquired through an illegal act that is subject to deterioration or cannot be properly taken care of, or if its preservation requires disproportionate costs, is sold, and the funds generated are revenue from the state budget, or this part of nature is treated in a way that is most appropriate for its preservation and protection. In the course of the inspection, the inspector has the right and obligation to issue a decision to the supervised persons who do not have a permit or other act, by which prohibit them from picking of protected plants, mushrooms and their parts, the sale of specimens of plant or animal species and mushroom species protected on the basis of international treaties to which the Republic of Croatia is a party, keeping, growing, importing and trading protected species, research.

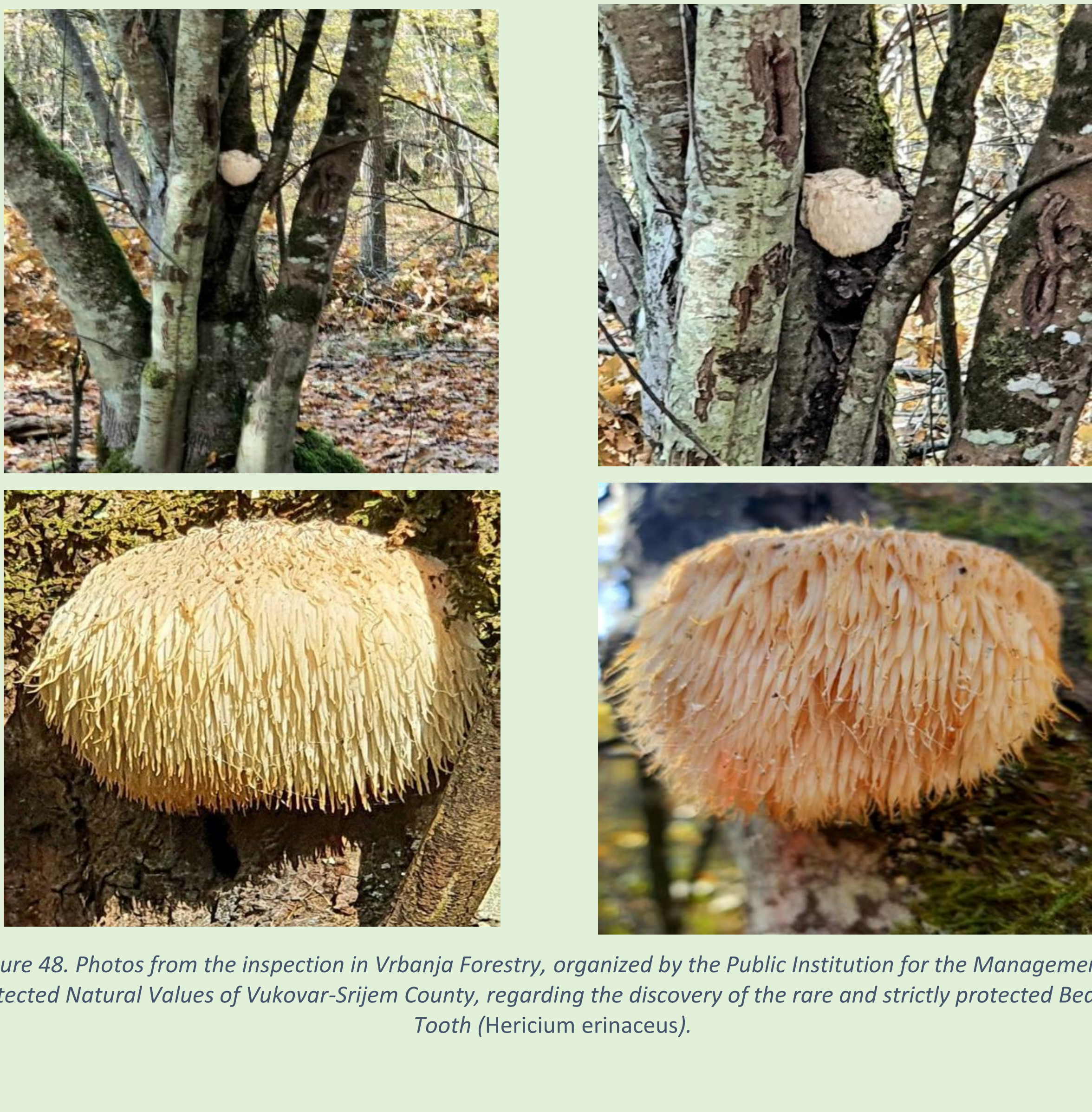

*Figure 48. Photos from the inspection in Vrbanja Forestry, organized by the Public Institution for the Management of Protected Natural Values of Vukovar-Srijem County, regarding the discovery of the rare and strictly protected Bearded Tooth (*Hericium erinaceus*).*

References

Strategy and Action Plan for Nature Protection of the Republic of Croatia. Link: https://narodne-novine.nn.hr/clanci/sluzbeni/2017_07_72_1712.html

Report on the State of the Environment in the Republic of Croatia. Link:

https://mingo.gov.hr/UserDocsImages/GLAVNO%20TAJNI%C5%A0TVO/Strategija,%20planovi%20i%20ostali%20dokumenti/Izvjesce%20o%20stanju%20prirode%20RH%202013-2017_finalno.pdf

Law on Nature Protection. Link: https://www.zakon.hr/z/403/Zakon-o-za%C5%A1titi-prirode

Ordinance on the collection of native wild species. Link: https://narodne-novine.nn.hr/clanci/sluzbeni/2017_11_114_2663.html

Expert basis for the collection of native wild species 2024 -2026. Link: https://mingo.gov.hr/UserDocsImages/UPRAVA%20ZA%20ZA%C5%A0TITU%20PRIRODE/Divlje%20vrste/Strucna_podloga-Pravilnik_o_odrzivom_koristenju_divljih_vrsta_2024-2026.pdf

Red list of mushrooms. Link: https://www.haop.hr/sites/default/files/uploads/dokumenti/03_prirodne/crvene_knjige_popisi/Crveni_popis_gljiva_web.pdf

The Red Book of Mushrooms of Croatia. Link: https://www.haop.hr/sites/default/files/uploads/dokumenti/03_prirodne/crvene_knjige_popisi/Crvena_knjiga_gljiva_WEB.pdf

The Ordinance on Strictly Protected Species. Link: https://narodne-novine.nn.hr/clanci/sluzbeni/2013_12_144_3086.html ; https://narodne-novine.nn.hr/clanci/sluzbeni/2016_08_73_1745.html

Focus Box 14: Fungi in UK Legislation and Policy

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The UKs environmental legislation is complex with layers of legislation from pre and post devolution. Environment is increasingly decentralised with the four legislatures of the UK, Scottish Parliament, National Assembly for Wales, Northern Ireland Executive and the UK Government (England), presiding over their own environmental laws and policies. Up until Brexit, environmental standards were driven by EU Directives and thus far, all these laws have been retained. The absence of the EU is creating new environmental governance structures in the four countries and diverging responses to species protections may begin to emerge as the countries develop their own environmental principles. In all four countries, legal and policy protections for fungi, where they exist, are generally weak.

Fungi and the protected sites network

The strength of legal protection for nature conservation sites is hierarchical from International to Local. The internationally designated Natura 2000 sites receive the greatest protection, but in common with the rest of Europe none are designated for fungi since they were excluded from Habitats Directive Annex II Species List.

At the national level, the strongest protections for sites are through the national network of Sites of Special Scientific Interest (SSSIs) in Great Britain (GB: England, Scotland, Wales) designated under the Wildlife and Countryside Act, 1981, and Areas of Special Scientific Interest (ASSIs) in Northern Ireland under The Environment (Northern Ireland) Order 2002. Both were a response to the EU Birds Directive. There are close to 7,000 SSSIs/ASSIs in the UK, 6570 of which are in GB. The legal protection given to all these SSSIs benefit fungal communities, however just 0.4% of SSSIs have been designated for non-lichenized fungi (Table 6).

In GB, there is a robust and periodically reviewed criteria for selecting SSSIs for lichen (Sanderson et al, 2018) and other non-lichenized fungi (Bosenquet et al 2018). These are based on ecologically coherent assemblages of threatened species or functional groups associated with high quality habitat such as Pinhead lichen, Lichen of Upland Rainforest, Stipitate hydnoid fungi or Grassland fungi.

Table 6. The number of Protected SSSIs/ASSIs in each of the four countries and Great Britain (England, Scotland and Wales) with the percentage designated for fungal assemblages (excluding lichen) and lichen assemblages.

Country	Number of SSSIs/ASSIs	Sites designated for Fungi (%)	Sites designated for Lichen (%)
England	4,130	0.3	2.9
Wales	1,000	0.7	7.7
Scotland	1,440	0.55	4.5
Northern Ireland	400	3.5	2.25
Great Britain	6570	0.4	4

Species-level protection for fungi

As with protected sites, the strictest protections are given to species listed on the European Habitats Directive, which do not include any fungi. In GB, the Wildlife and Countryside Act also lists 30 species of lichen and four species of non-lichenised fungi where they are protected from "intentional picking, uprooting, or destruction" as well as selling and buying (Table 7). The lion's mane fungus, *Hericium erinaceus*, is the only edible species on the Schedule list and the protection given to this species has been a successful deterrent to its wild harvesting. Scheduled species are reviewed every 5 years and has led to the recommended removal of Royal Bolete *Butyriboletus regius* after it was found not to be a British species, though removing its protected status has been slow. In the 2022 review, species assessed as Critically Endangered or Endangered were eligible for inclusion which would have boosted the number of protected fungi in the UK, but recommendations have yet to be adopted by the UK Government.

In addition to the protected species, legislation in all four nations identifies priority species for biodiversity conservation. Priority species are not legally protected but public bodies have a duty to conserve them where possible in the undertaking of their work. In practice, these protections have been weak, but the priority species lists have provided a useful framework for conservation planning. Revision of the priorities species lists have not kept pace with the fungal taxonomy, including species no longer considered British.

Table 7. The number of fungi (non-lichenised) and lichen species on the officially accepted GB Red List; the Wildlife and Countryside Act (WCA, GB only); and priority species lists of each country.

	Red List (GB only)	**WCA (GB only)**	**Priority Species**			
			England	Scotland	Wales	Northern Ireland
Fungi	68	4	63	209	28	14
Lichen	2380	31	95	484	68	5
Total	2448	35	158	693	96	19

Nature Recovery in England post-Brexit

The Environment Act 2021 sets legally binding targets for nature recovery in England, critically for threatened fungi, this includes a target to reduce extinction risk by 2042, irrespective of taxon group. A result of this is to move conservation planning away from the priority species to threatened species with red-lists and their production is now a government policy priority. To date the only red-list assessments for fungi officially recognised by the UK Government are for Lichen (2012) and Boletaceae 2013 (2013) (Table 7), but a programme of fungal Red Lists is expected to emerge in the coming years. While the Environment Act could help reduce extinction risk in fungi, other targets may also be undermining it. The ambitious tree planting targets in the Act are a direct threat to the internationally important grassland fungi sites which are largely unprotected and currently without a recognised red-list. Furthermore, the Government strategy for achieving its nature recovery targets, the Environment Improvement Plan (2022), makes no explicit reference to fungi in its Apex Goal "Thriving Plants and Wildlife", leaving them at risk. Nonetheless, there is optimism that the Environment Act will benefit fungal conservation in the UK.

References

Bosanquet S., Ainsworth M., Cooch S., Genney D., Wilkins, T., 2018. Non-lichenised fungi. Guidelines for the Selection of Biological SSSIs. Part 2.

Sanderson N., Wilkins T., Bosanquet S., Genney D., 2018. Lichens and associated microfungi. Guidelines for the Selection of Biological SSSIs. Part 2.

Integrating Priorities in Macrofungal Conservation

A comment by Eric Boa

There is an unstated tendency by researchers and others to treat separately the conservation of edible and medicinal mushrooms and the dominant diversity of fungal species which do not have a practical use to people. Different groups of scientists see the world differently, and it is challenging to combine and integrate perspectives and priorities.

Edible mushrooms are deserving of particular attention because of persistent concerns about over-exploitation, despite a lack of compelling evidence to support these concerns. However, all macrofungi, regardless of their direct importance to people, provide ecosystem services and are an essential component of the natural world.

Conservation efforts and priorities will differ between functional groups of macrofungi, but not to the extent that justifies separate and unconnected legislation on edible, medicinal, and other macrofungi. JoNeF has an important role to play in providing integrated solutions that ensure effective conservation and sustainable use of all macrofungi.

JoNeF Manifesto: Protecting Fungi, Sustaining Life

A declaration from the Joint Network for wild Fungi (JoNeF)

Statement for the inclusion of fungi in European conservation policies

We recognize fungi as vital components of ecosystems and call for their inclusion in European environmental conservation policies.

Fungi are indispensable to the health and resilience of the planet's ecosystems. They play key roles as decomposers and mutualists driving geochemical cycles. Despite their fundamental contributions to biodiversity and ecosystem services, fungi remain one of the most underrepresented groups in conservation efforts across Europe and around the world.

To ensure truly effective nature conservation, all components of biodiversity must be considered, fungi alongside animals and plants. Including fungi in conservation efforts reflects a more holistic understanding of ecosystems, where each group contributes essential functions that support the stability and resilience of natural environments. Strengthening fungal conservation actions in Europe, through initiatives led by the EU and its Member States, could set a global example and inspire broader efforts to protect this vital kingdom.

Our Call to Action

We urge European policymakers to recognize the importance of fungi and to:

1. Integrate Fungi into Legislation: Include fungi in all relevant European environmental legislation and national conservation policies, alongside animals and plants. The absence of fungi from key directives such as the Habitats Directive limits their protection and conservation. As a first step, we recommend that in every document, "animals and plants" be replaced with "**animals, plants, and fungi**" and "fauna and flora" with "**fauna, flora, and funga**".

2. Develop Fungal Conservation Strategies: Establish specific fungal conservation strategies and action plans at national and European level. These should focus on the protection of threatened fungal species and the promotion of sustainable habitat management practices that benefit fungal biodiversity in line with the *Global Strategy for Fungal Conservation* currently being prepared.

3. Support Research and Monitoring: Invest in research initiatives and monitoring programs that specifically target fungal diversity, ecology, and conservation. Standardised data collection methods must be developed to ensure consistent and comparable information on fungal species across European countries. Including fungi in long-term monitoring programs will enhance our understanding of biodiversity dynamics and ecosystem health.

4. Promote Fungal Awareness: Launch educational and public awareness campaigns to highlight the critical ecological roles fungi play and their importance to biodiversity and ecosystems. Greater awareness will foster public support for fungal conservation efforts and help shift societal perceptions towards recognizing fungi as equal partners to plants and animals in nature.

5. Foster Collaboration Across Borders: Create a unified European framework for fungal conservation that encourages collaboration between countries. Shared knowledge, data, and best practices will be essential for effectively conserving fungal biodiversity on a continental scale and for integrating fungi into broader conservation strategies.

The Case for Fungal Inclusion

To conserve nature effectively, we must conserve it completely. Animals, plants, and fungi together form the foundation of ecosystems. Fungi form the hidden backbone of ecosystems, facilitating the survival of countless plant and animal species. Without fungi, nutrient cycles would break down, plant growth would be impaired, and natural environments would collapse.

Despite this, fungi continue to be overlooked in conservation policies. Of the estimated 2.5 million fungal species worldwide, only about 5-10% has been described, and many face extinction due to habitat loss, pollution, and climate change. Ignoring fungi in conservation efforts leaves a critical gap in our understanding and management of biodiversity.

To address the biodiversity crisis, all groups—fungi, plants, and animals—must be included in conservation policies. **Fungal knowledge is nature knowledge**, and including fungi will strengthen conservation outcomes, benefiting entire ecosystems and the species that depend on them.

Our Commitment

We commit to advocating for the full and equal inclusion of fungi in European conservation policies. Together, we will work towards a future where fungi receive the protection they deserve, contributing to a more balanced, resilient, and biodiverse Europe.

JoNeF Project Team

Bibliographic References

Allen J.L., Lendemer J.C., 2015. Fungal conservation in the USA. Endangered Species Research. 28. 10.3354/esr00678.

Bader P., Jansson S., Jonsson B.G., 1995. Wood-inhabiting fungi and substratum decline in selectively logged boreal spruce forests. Biological conservation, 73(3): 355–362.

Bazzicalupo A., Gonçalves S.C., Hébert R., Jakob S., Justo A., Kernaghan G., Lebeuf R., Malloch B., Thorn R.G., Walker A.K., 2022. Macrofungal conservation in Canada and target species for assessment: a starting point. FACETS 7: 448–463. doi: https://doi.org/10.1139/facets-2021-0180

Berlinches de Gea A., Verdú M., Villar-dePablo M., Pérez-Ortega S., 2024. The combined effects of habitat fragmentation and life history traits on specialisation in lichen symbioses. Journal of Ecology, 112(1): 200-216.

Brainerd S., Doornbos S., 2013. European Charter on fungi-gathering and biodiversity, Strassbourg, T-PVS/Inf (2013) 26.

Brown N., Bhagwat S., Watkinson S., 2006. Macrofungal diversity in fragmented and disturbed forests of the Western Ghats of India. Journal of Applied Ecology, 43: 11-17. https://doi.org/10.1111/j.1365-2664.2005.01107.x

Burrascano S., Chianucci F., Trentanovi G., Kepfer-Rojas S., Sitzia T., Tinya F., Doerfler I., Paillet Y., Nagel T.A., Mitic B., Morillas L., 2023. Where are we now with European forest multi-taxon biodiversity and where can we head to? Biological conservation, 284, p.110176. https://doi.org/10.1016/j.biocon.2023.110176

Caiafa M.V, Gómez-Hernández M., Williams-Linera G., Ramírez-Cruz V., 2017. Functional diversity of macromycete communities along an environmental gradient in a Mexican seasonally dry tropical forest, Fungal Ecology, 28: 66-75, https://doi.org/10.1016/j.funeco.2017.04.005

Dahlberg A., Genney D., Heilmann-Clausen J., 2010. Developing a comprehensive strategy for fungal conservation in Europe: current status and future needs. Fungal Ecology, vol. 3. DOI 10.1016/j.funeco.2009.10.004

Dahlberg A., Mueller G., 2011. Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species. Fungal Ecology, Volume 4: 147-162. DOI: 10.1016/j.funeco.2010.11.001

DG Environment, 2023. Reporting under Article 17 of the Habitats Directive: Guidelines on concepts and definitions – Article 17 of Directive 92/43/EEC, Reporting period 2019-2024. Brussels. Pp 104.

Diamandis S., Topalidou E., Avtzis D., Stara K. Tsiakiris R., Halley J.M., 2021. Fungal diversity in sacred groves vs. managed forests in Epirus, NW Greece. Journal of Microbiology & Experimentation, (5): 142-154. DOI: https://doi.org/10.15406/jmen.2021.09.00335

Dinakarkumar Y., Ramakrishnan G., Gujjula K-R., Vasu V., Balamurugan P., Murali G., 2024. Fungal bioremediation: An overview of the mechanisms, applications and future perspectives, Environmental Chemistry and Ecotoxicology, 6: 293-302. https://doi.org/10.1016/j.enceco.2024.07.002.

Ding L.J., Ren X.Y., Zhou Z.Z., Zhu D., Zhu Y.G., 2024. Forest-to-Cropland Conversion Reshapes Microbial Hierarchical Interactions and Degrades Ecosystem Multifunctionality at a National Scale. Environmental Science & Technology.

Directorate of Culture and Cultural and Natural Heritage, 2003. Report of the Standing Committee of Bern Convention (Convention on the conservation of European wildlife and natural habitats). 23rd meeting Strasbourg, 1-4 December 2003. Doc T-PVS (2003) 24e. https://rm.coe.int/CoERMPublicCommonSearchServices/DisplayDCTMContent?documentId=0900001680746640

Durall D.M., Jones M.D., Lewis K.J., 2005. Effects of forest management on fungal communities. In *The fungal community*. CRC Press. Pp. 853-876.

Ellwanger G., Runge S., Wagner M., Ackermann W., Neukirchen M., Frederking W., Müller C., Ssymank A., Sukopp U., 2018. Current status of habitat monitoring in the European Union according to Article 17 of the Habitats Directive, with an emphasis on habitat structure and functions and on Germany. Nature Conservation 29: 57–78. https://doi.org/10.3897/natureconservation.29.27273

European Commission, 2013. Interpretation Manual of European Union Habitats (EUR 28). https://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf

Fraiture A., Otto P., 2015. Distribution, ecology and status of 51 macromycetes in Europe Results of the ECCF Mapping Programme. Scripta Botanica Belgica, Volume 53. SN: 9789082352559.

Fung S., Mohamad R-M., 2021. Bioprospecting Macrofungi for Biotechnological and Biomedical Applications. 10.1201/9781003096818-6.

Gautam A.K., Verma R.K., Avasthi S., Sushma S., Bohra Y., Devadatha B., Niranjan N., Suwannarach N., 2022. Current Insight into Traditional and Modern Methods in Fungal Diversity Estimates. Journal of Fungi 8(3): 226 (49pp). https://doi.org/10.3390/jof8030226

He K., Chen G., Zeng G., Huang Z., Guo Z., Huang T., Peng M., Shi J., Hu L., 2017. Applications of white rot fungi in bioremediation with nanoparticles and biosynthesis of metallic nanoparticles. Appl. Microbiol. Biotechnol, 101: 4853-4862. https://doi.org/10.1007/s00253-017-8328-z

Heilmann-Clausen J., Barron E.S., Boddy L., Dahlberg A., Griffith G.W., Nordén J., Ovaskainen O., Perini C., Senn-Irlet B., Halme P., 2015. A fungal perspective on conservation biology. Conservation biology, 29(1): 61-68. https://doi.org/10.1111/cobi.12388

Heilmann-Clausen J., Frøslev T.G., Petersen J.H., Læssøe T., Jeppesen T.S., 2021. Experiences from the Danish Fungal Atlas: Linking mushrooming, nature conservation and primary biodiversity research. Biodiversity Information Science and Standards, 5: e75265. https://doi.org/10.3897/biss.5.75265

Heilmann-Clausen J., Vesterholt J., 2008. Conservation: selection criteria and approaches. In: Boddy L., Frankland J.C., van West P. (eds). Ecology of Saprotrophic Basidiomycetes. Elsevier Academic Press, Oxford, pp. 325–347.

IMPEL, 2024. JoNeF Survey Report. Survey on macrofungi conservation and data collection in Europe. IMPEL Report 2022(VII) WG7. Report adopted at IMPEL General Assembly Meeting 26-28 June 2024, Brussels. https://www.impel.eu/en/projects/joint-network-for-wild-fungi-jonef

Juhász-Nagy P., 1986. The lack of, and necessity for an operative ecological science, Academic Print, Budapest.

Karlsson K., 2024. Phenological shifts in Fungal spore-production: Response of six fungal genera to three decades of changing climate.

Kauserud H., Heegaard E., Büntgen U., Halvorsen R., Egli S., Senn-Irlet B., Krisai-Greilhuber I., Dämon W., Sparks T., Nordén J., Høiland, K., 2012. Warming-induced shift in European mushroom fruiting phenology. Proceedings of the National Academy of Sciences, 109(36): 14488-14493.

Kinge T.R., Goldman G., Jacobs A., Ndiritu G.G., Gryzenhout M., 2020. A first checklist of macrofungi for South Africa. MycoKeys 63: 1-48. DOI: https://doi.org/10.3897/mycokeys.63.36566

Komonen A., Puumala I., Varkonýi G., Penttilä R., 2021. Wood-decaying fungi in old-growth boreal forest fragments: extinctions and colonizations over 20 years. Silva Fennica, 55(1).

Kotowski M., 2016. Differences between European regulations on wild mushroom commerce and actual trends in wild mushroom picking. Slovenský národopis / Slovak Ethnology. 64: 169-178.

Lagiotis G., Topalidou E., Bosmali I., Osathanunkul M., Madesis P., 2021. DNA-based species identification of Greek macromycetes. Current Research in Environmental & Applied Mycology (Journal of Fungal Biology) 11(1): 373–390. Doi 10.5943/cream/11/1/28.

Lindahl B.D., Tunlid A., 2015. Ectomycorrhizal fungi – potential organic matter decomposers, yet not saprotrophs. New Phytol., 205: 1443-1447. https://doi.org/10.1111/nph.13201

Lofgren L.A., Stajich J.E., 2021. Fungal biodiversity and conservation mycology in light of new technology, big data, and changing attitudes. Curr Biol. 2021 Oct 11, 31(19): R1312-R1325. doi: 10.1016/j.cub.2021.06.083. PMID: 34637742; PMCID: PMC8516061.

McHugh R., Mitchel D., Wright M., Anderson R., 2001. The fungi of Irish grasslands and their value for nature conservation. In Biology and Environment: Proceedings of the Royal Irish Academy (pp. 225-243). Royal Irish Academy.

Minter D., 2011. Fungal conservation needs help from botanists. Plant Biosyst., 145(4): 945-949.

Moersberger H., Martin J.G.C., Junker J., Georgieva I., Bauer S., Beja P., Breeze T., Brotons L., Bruelheide H., Fernández N., Fernandez M., Jandt U., Langer C., Lyche Solheim A., Maes J., Moreira F., Pe'er G., Santana J., Shamoun-Baranes J., Smets B., Valdez J., McCallum I., Pereira H.M., Bonn A., 2022. Europa Biodiversity Observation Network: User and Policy Needs Assessment. ARPHA Preprints. https://doi.org/10.3897/arphapreprints.e84517

Mony C., Vandenkoornhuyse P., Bohannan B.J.M., Peay K., Leibold M.A., 2020. A landscape of opportunities for microbial ecology research. Front Microbiol 11: 16.

Moore D. (Ed.), 2001. Fungal conservation: issues and solutions (No. 22). Cambridge University Press.

Mueller G.M., Cunh, K.M., Ma T.W., Allen J.L., Westrip J.R.S., Canteiro C., Costa-Rezende D.H., Drechsler-Santos E.R., Vasco-Palacios A.M., Ainsworth A.M. et al., 2022. What Do the First 597 Global Fungal Red List Assessments Tell Us about the Threat Status of Fungi? Diversity 2022, 14(9), 736. https://doi.org/10.3390/d14090736

Müller-Kroehling S., 2019. What are the "characteristic species" of the habitats directive? A new statistics-driven approach connecting species, habitats and key habitat characteristics. ARPHA Conference Abstracts 2: e37430. doi: 10.3897/aca.2.e37430

Niego A.G., Rapior S, Thongklang N., Raspé O., Hyde K., Mortimer P., 2022. Reviewing the contributions of macrofungi to forest ecosystem processes and services. Fungal Biology Reviews. 44, doi10.1016/j.fbr.2022.11.002.

Niskanen T., Lücking R., Dahlberg A., Gaya E., Suzl L. M., Mikryukov V., Liimatainen K. Druzhinina I., Westrip J. R. S., Mueller G. M., Martins-Cunha K., Kirk P., Tedersoo L., Antonelli A., 2023. Pushing the Frontiers of Biodiversity Research: Unveiling the Global Diversity, Distribution, and Conservation of Fungi. Annual Review of Environment and Resources, 48: 149-176. https://doi.org/10.1146/annurev-environ-112621-090937

Njuguini S., Muchane M., Wachira P., Okoth S., Muchai M., Abdillahi H., 2018. Effects of Land Use on the Diversity of Macrofungi in Kereita Forest Kikuyu Escarpment, Kenya. 8. 10.5943/cream/8.

Oberwinkler F., 2012. Evolutionary trends in Basidiomycota. Stapfia 96: 45–104.

O'Hanlon R., Harrington T.J., 2011. Diversity and distribution of mushroom-forming fungi (Agaricomycetes) in Ireland. Biology and environment: proceedings of the Royal Irish Academy, Vol. 111, No. 2: 117-133. Royal Irish Academy. https://doi.org/10.1353/bae.2011.a809629

Orumaa A., Agan A., Anslan S., Drenkhan T., Drenkhan R., Kauer K., Köster K., Tedersoo L., Metslaid M., 2022. Long-term effects of forest fires on fungal community and soil properties along a hemiboreal Scots pine forest fire chronosequence. Science of the Total Environment, 851: 158173. https://doi.org/10.1016/j.scitotenv.2022.158173

Osmundson T.W., Robert V.A., Schoch C.L., Baker L.J., Smith A. et al., 2013. Filling Gaps in Biodiversity Knowledge for Macrofungi: Contributions and Assessment of an Herbarium Collection DNA Barcode Sequencing Project. PLOS ONE 8(4): e62419. https://doi.org/10.1371/journal.pone.0062419

Ozinga W.A., Arnolds K., Keizer P.J., Kuyper T.W., 2013. Macrofungi in Conservation Management. OBN Knowledge Network for Restoration and Management of Nature.

Peintner U., Schwarz S., Mesic A., Moreau P.A., Moreno G., Saviuc P., 2013. Mycophilic or Mycophobic? Legislation and Guidelines on Wild Mushroom Commerce Reveal Different Consumption Behaviour in European Countries. PloS one. 8. e63926. 10.1371/journal.pone.0063926.

Peláez F., Martínez M.J., Martínez A.T., 1995. Screening of 68 species of basidiomycetes for enzymes involved in lignin degradation. Mycological Research. Doi 10.1016/S0953-7562(09)80313-4

Perez-Rosas B., Gomez-Hernandez M., Gandara E., 2022. Variation in macrofungal diversity and species composition across different vegetation types in Oaxaca, Mexico. Bot. sci [online]. 2022, vol.100(4): 827-836. Epub 01-Ago-2022. ISSN 2007-4476. https://doi.org/10.17129/botsci.3012

Pointing S.B., 2001. Feasibility of bioremediation by white-rot fungi. Applied Microbiology and Biotechnology. Doi 10.1007/s002530100745

Pointing S.B., Pelling A.L., Smith G.J.D., Hyde K.D., Reddy C.A. 2005. Screening of basidiomycetes and xylariaceous fungi for lignin peroxidase and laccase gene-specific sequences. Mycological Research. Doi 10.1017/S0953756204001376

Pouliot A.M., May T., 2010. The third 'F'- fungi in Australian biodiversity conservation: actions, issues and initiatives. Mycologia Balcanica, 7: 41-48.

Raimbault A., Brin A., Manzi S. et al., 2024. Influence of habitat fragmentation and habitat amount on soil fungi communities in ancient forests. Landsc Ecol 39, 19 (2024). https://doi.org/10.1007/s10980-024-01821-3

Read D.J., Perez-Moreno J., 2003. Mycorrhizas and nutrient cycling in ecosystems e a journey towards relevance? New Phytol. 157, 475e492. https://doi.org/10.1046/j.1469-8137.2003.00704.x

Senn-Irlet B., Heilmann-Clausen J., Genney D., Dahlberg A., 2007. Guidance for conservation of macrofungi in Europe. Document prepared for the European Council for Conservation of Fungi

(ECCF) within the European Mycological Association (EMA) and the Directorate of Culture and Cultural and Natural Heritage, Council of Europe, Strasbourg. https://www.researchgate.net/publication/259323515_Guidance_for_conservation_of_macrofungi_in_Europe

Singh B.P., Lallawmsanga, Passari A.K., 2018. Exploration of Macrofungi in Sub-Tropical Semi-Evergreen Indian Forest Ecosystems. Biology of Macrofungi: 1–13. Doi 10.1007/978-3-030-02622-6_1

Sridhar K.R., Deshmukh S.K., 2023. Ecology of Macrofungi. In: Sridhar K.R., Deshmukh S.K. (Eds.), 2023. Ecology of Macrofungi. An Overview (1st ed.). CRC Press, Taylor & Francis, pp 1-14. https://doi.org/10.1201/9781003429272

Tomao A., Bonet J.A., Castano C., de-Miguel, S., 2020. How does forest management affect fungal diversity and community composition? Current knowledge and future perspectives for the conservation of forest fungi. Forest Ecology and Management, 457, p.117678.

Wang Z.G., Bi Y.L., Jiang B., Zhakypbek Y., Peng S.P., Liu W.W., Liu H., 2016. Arbuscular mycorrhizal fungi enhance soil carbon sequestration in the coalfields, northwest China. Sci. Rep. 634336. https://doi.org/10.1038/srep34336

Xiankai L., Jiangming M., Shaofeng D., 2008. Effects of nitrogen deposition on forest biodiversity. Acta Ecologica Sinica, 28(11): 5532-5548. https://doi.org/10.1016/S1872-2032(09)60012-3

Yiallouris A., Pana Z.D., Marangos G., Tzyrka I., Karanasios S., Georgiou I., Kontopyrgia K., Triantafyllou E., Seidel D., Cornely O.A., Johnson E.O., 2024. Fungal diversity in the soil Mycobiome: Implications for ONE health. One Health, p.100720.

Zotti M., Persiani A.M., Ambrosio E., Vizzini A., Venturella G., Donnini D., Angelini P., Di Piazza S., Pavarino M., Lunghini D., Venanzoni R., Polemis E., Granito V.M, Maggi O, Gargano M.L, Zervakis G.I, 2013. Macrofungi as ecosystem resources: Conservation versus exploitation. Plant Biosystems, 147(1): 219-225. https://dx.doi.org/10.1080/11263504.2012.753133

Websites

Bern convention presentation: https://www.coe.int/en/web/bern-convention/presentation

EMA - European Mycological Association: http://euromould.org/

ECCF - European Council for the Conservation of Fungi: http://www.eccf.eu/

JoNeF – Joint Network for wild Fungi: https://www.impel.eu/en/projects/joint-network-for-wild-fungi-jonef ; https://ndm.isprambiente.it/en/activities/projects-and-initiatives/project-jonef/

LIFE Programme: Forest Conservation: https://webgate.ec.europa.eu/life/publicWebsite/search

GBIF - Global Biodiversity Information Facility: https://www.gbif.org/

iNaturalist: https://www.inaturalist.org/

Biodiversa: https://www.biodiversa.eu/

Glossary

IMPEL: European Union Network for the Implementation and Enforcement of Environmental Law.

Macrofungi: Fungi that produce reproductive structures visible to the naked eye.

Mycoremediation: The use of fungi to degrade or transform harmful substances into less toxic or non-toxic forms.

JoNeF: Joint Network for wild Fungi, an initiative for fungal conservation in Europe.

Habitats Directive: Directive 92/43/EEC for conserving natural habitats and species in the EU.

Natura 2000: A network of protected areas in Europe to preserve biodiversity.

ISPRA: Italian Institute for Environmental Protection and Research.

IUCN (International Union for Conservation of Nature): Organization providing criteria for assessing species conservation status.

IUCN Criteria: Standards established by the International Union for Conservation of Nature for assessing species' conservation status.

Fungal Conservation: The protection and preservation of fungal species and their habitats.

Saprotrophic Fungi: Fungi that decompose organic matter for nutrition and rely on carbon derived from dead remains of plants, animals and other fungi.

Mycorrhizal Fungi: Fungi that form mutualistic symbiotic relationships with plant roots.

Red List - list of threatened species assessed using IUCN criteria.

Nature 2000: A network of protected areas across the EU for the conservation of biodiversity.

Ecosystem Services: Benefits that humans derive from ecosystems, such as biomass production, nutrient cycling and carbon sequestration.

Fungaria: Collections of preserved fungal specimens for scientific study (equivalent to Herbaria for plants).

Biodiversity: The variety and variability of life forms in an ecosystem.

Citizen Science: Public participation in scientific research and data collection.

Environmental Legislation: Laws and regulations aimed at protecting the environment.

Protected Species: Species safeguarded by laws due to their vulnerability or ecological importance.

Annexes

Annex 1. JoNeF Team Members Country and Affiliation

(in alphabetical order by surname)

SURNAME AND NAME	COUNTRY	ORGANISATION NAME	TYPE OF ORGANISATION
Ainsworth Martyn	UK	Royal Botanic Gardens, Kew	Non-departmental public body
Aruqaj Zelfije	Kosovo	Ministry of Environment Spatial Planning and Infrastructure	National public authority
Cerneviciene Dalia	Lithuania	Ministry of Environment, Department of Environmental Protection	National public authority
D'Elia Gabriela	USA	Fungal Diversity Survey	NGO
Diaco Massimo	Italy	Italian Institute for the Environmental Protection and Research (ISPRA), Department for the monitoring and protection of the environment and for biodiversity conservation	National public authority
Dāniele Inita	Latvia	Latvian Museum of Natural History	Public research institution
Ercole Stefania	Italy	Italian Institute for the Environmental Protection and Research (ISPRA), Department for the monitoring and protection of the environment and for biodiversity conservation	National public authority
Floccia Francesca	Italy	Italian Institute for the Environmental Protection and Research (ISPRA), Department for the monitoring and protection of the environment and for biodiversity conservation	National public authority
Gerguri Miradije	Kosovo	Ministry of Environment Spatial Planning and Infrastructure	National public authority
Giacanelli Valeria	Italy	Italian Institute for the Environmental Protection and Research (ISPRA), Department for the monitoring and protection of the environment and for biodiversity conservation	National public authority
Gonçalves Susana C.	Portugal	University of Coimbra, Centre for Functional Ecology	Academic institution
Grima Connell Matthew	Malta	Environment and Resources Authority (ERA)	National public authority
Eyjólfsdóttir Guðríður Gyða	Iceland	Natural Science Institute of Iceland	Public research institution
Hoekstra Pier	The Netherlands	Omgevingsdienst Noord, Holland Noord	National public authority
Jagucanskyte Akvilė	Lithuania	Ministry of Environment, Department of Environmental Protection	National public authority
Kałucka Izabela	Poland	University of Lodz	Academic institution

SURNAME AND NAME	COUNTRY	ORGANISATION NAME	TYPE OF ORGANISATION
Kasom Gordana	Montenegro	Environmental Protection Agency of Montenegro	National public authority
Kisne Fodor Livia	Hungary	Ministry of Agriculture	National public authority
Lalić Šarić Tatjana	Croatia	State Inspectorate	National public authority
Madesis Panagiotis	Greece	University of Thesaly	Academic institution
Manley Bethan	UK	SPUN	NGO
Martin Francis	France	INRAE	Public research institution
Mifsud Stephen	Malta	EcoGozo Directorate	National public authority
Nai Corrado	-	Freelance	Freelance
Oga Enxhi	Albania	National Environment Agency	National public authority
Ottosson Elisabet	Sweden	Swedish Species Information Centre, SLU Artdatabanken	Public research institution
Ramshaj Qendrim	Kosovo	Universiteti i Prishtinës	Academic institution
Rathore Dheeraj	Ireland	Teagasc	Public research institution
Rusevska Katerina	North Macedonia	Ss. Cyril and Methodius University in Skopje, Faculty of Natural Science and Mathematics, Institute of Biology, Mycological Laboratory	Academic institution
Santos e Silva Celeste	Portugal	University of Evora	Academic institution
Savenkovaite Aistė	Lithuania	Ministry of Environment, Department of Environmental Protection	National public authority
Siauciulis Gustas	Lithuania	Ministry of Environment, Department of Environmental Protection	National public authority
Somhorst Inge	The Netherlands	Dutch Mycological Society	NGO
Spahiu Vehbi	Kosovo	Ministry of Environment Spatial Planning and Infrastructure	National public authority
Spazzi Jonathan	Ireland	Teagasc	Public research institution
Tanase Catalin	Romania	Alexandru Ioan Cuza University of Iasi	Academic institution
Topalidou Eleni	Greece	Forest Research Institute Elgo Dimitra	Public research institution
Treindl Artemis	Switzerland	Swiss Federal Institute for Forest, Snow and Landscape Research WSL	Public research institution

The end

JoNeF
Joint Network
for wild Fungi

JoNeF PROJECT

TOWARDS COMMON PROCEDURES FOR MACROFUNGI

State-of-the-art and recommendations for implementing conservation in Europe