MASARYK UNIVERSITY, FACULTY OF SCIENCE

DEPARTMENT OF BOTANY AND ZOOLOGY

FUNGAL ECOLOGY

(sometimes with special regard to macromycetes)

Fungi and their environment • Life strategies and interactions of fungi • Ecological groups of fungi, saprotrophs (terrestrial fungi, litter and plant debris, wood substrate, etc.) • Fungal symbioses (ectomycorrhiza, endomycorrhiza, endophytism, lichenism, bacteria, animal relationships) • Parasitism (parasites of animals and fungi, phytopathogenic fungi, types of parasitic relations) • Fungi in various habitats (coniferous forests, broadleaf forests, birch stands and non-forest habitats, fungal communities) • Fungal dispersal and distribution • Threat and protection of fungi

(the study material has not been corrected by native speaker)

THREAT AND PROTECTION OF FUNGI

CHANGES OF FUNGAL OCCURRENCE

Human influence on the occurrence of fungi begins already in the Neolithic period with deforestation of the land (today, forests cover ca 30% of our territory). However, the greatest changes came during the 20th century, when, in addition to mechanical changes, there are significant changes in the chemistry of eco-systems, which as a result lead to changes in species representation (including disappearance of some species) of previously unseen dimensions. Since around the 1970s, the decline of not only individual species, but also entire systematic and ecological groups in forest and non-forest habitats has been recorded.

Causes of fungal decline can be distinguished to natural and anthropogenous.

Natural causes are mainly two:

• **climate change and weather fluctuations** – uneven precipitation, more pronounced and longer dry periods (rainfall then occurs suddenly, in torrents), sudden temperature changes and longer periods of heat or frost, recently more frequent in Europe („continentalisation“, resp. „Mediterranisation“ of Europe) => fluctuations acting as a stress factor lead to selection => reduction of the mycelia vitality up to disappearance of stenoecic species; there is also a distribution shift, recently thermophilic and xerotolerant species are spreading here, and on the contrary, psychrophilous species which require balanced humidity are receding;

• **habitat loss** and/or **vegetation changes**:

– natural succession in forest stands, change in tree species composition => can lead to disappearance of accompanying mycorrhizal fungi (see below); such changes can be observed even in the „most natural“ forests (in the Žofín or Boubín virgin forests, spruce and beech gradually dominate at the expense of fir); => lignicolous fungi with a narrow substrate specificity are also threatened (for example *Rhodotus palmatus* bound to dead wood of elms, which in recent decades have been widely affected by tracheomycosis – when the currently dead trunks decay, *Rhodotus* will have nothing to grow on and will disappear);

http://www.nahuby.sk/obrazok_detail.php?obrazok_id=48181&poradie=23

Photo Eva Čolláková *Rhodotus palmatus*

– overgrowth of non-forest habitats with tall herbs (grasses) and trees or shrubs (which can be a part of natural forest regeneration), affecting steppe habitats (with occurrence of a number of gasteroid species), already unmown meadows or ungrazed pastures (affecting, for example, fungi of the genera *Hygrocybe*, *Entoloma*, family *Clavariaceae*) or overgrown mires (*Geoglossaceae*) => in such cases human intervention is a suitable solution to maintain the desired conditions.

The most serious **anthropogenic influences** which are manifested today are:

• **direct destruction of localities** during the construction of roads, buildings, waterworks, conversion of meadows into fields, etc. – it acts on a local level, but in specific cases the locality of a species, which does not occur a long way off, may be destroyed;

• **changes in forest management**:

– replacement of natural stands by others => change of accompanying species of fungi (there are known cases of elimination of single localities of rare species), or change of the life strategy of fungi (originally saprotrophs => parasites of trees weakened in conditions unnatural for them);

– "generation change", felling of mature trees and complete replacement with new planting => it has an effect on the mycorrhizal partners or (sapro-)parasites of mature trees (more than in the forest stand, it is manifested in places of isolated or scattered tree growth – in alleys, parks, orchards, on dams of ponds);

– fragmentation of stands (clear-cuts) => change in climatic and vegetation conditions, a fragmented forest holds water more difficult, possibility of fungal dispersal in the stand is also limited (especially important for mycorrhizal species);

– use of heavy mechanisation => disruption of the surface layer of the soil and/or its compression („damped“ soil will „rise“ back in 4–8 years), water erosion easily follows on slopes;

– chemical treatment of stands (herbi-, insecti-, fungicides – these substances affect not only occurrence of fungi, but potentially also humans – „false poisonings“ were reported after eating edible mushrooms from stands treated with herbicides);

– fertilization => higher nitrogen content in the soil, changes in pH;

– the removal of litter (bedding for farm animals) is practically no longer done => it has a partly negative effect – removal of the „food“ of fungi (limiting growth of saprotrophic fungi in particular, which participate in its decomposition), changes in the soil structure, physical (the litter helps to regulate moisture, reduces evaporation) and chemical properties (loss of some elements) – but, on the contrary, it can be better for ectomycorrhizal species preferring mineral soils;

– removal of dead wood (trunks, branches) from the forest is good from the forest protection point of view (restriction of the „food“ for potential parasites of trees), but it leads to a reduction of fungi – not only directly (elimination of lignicolous saprotrophs bound to wood at a certain stage of decay), but also by worsening the humidity conditions in the growth (rotting wood retains water, which evaporates in dry season and humidifies the air);

• **management changes**, especially in cases of long-term human-maintained habitats suddenly left to natural succession:

– pastures, meadows, fields, gardens represent artificially maintained forest-free areas => if they remain fallow, there are initial changes in the herb vegetation and then spontaneous overgrowth of woody plants until onset of the forest => elimination of non-forest species (see above);

• **environmental pollution**:

– dust fallout, especially in the vicinity of industrial plants (exhalation of toxic substances, ash, lime dust => affecting the soil pH and physical properties);

– air pollution by smoke emissions (1971, annual total for Czechoslovakia: 35 million tons, of which 3 million tons of SO_2, nitrogen oxides also have a significant share) then falling in the form of „acidic“ precipitation (up to around pH = 2, for comparison, normal rain has pH 5.6–5.7) => decrease in pH and change in ratio of cations in the soil => affects fungi both directly and through weakening of mycorrhizal partners
=> it turns out that impact on the ecosystem can be reversible, after a significant reduction in emissions of sulphur and nitrogen oxides in the 1990s, the situation in the affected areas improved – occurrence of some mycorrhizal species, missing in previous decades, has been again recorded in the last three decades;

– accumulation of nitrogen compounds in the environment (nitrates from fertilizers, NO_x oxides from exhaust gases) => eutrophication => reduction of diversity, sensitive oligotrophic species disappear (e.g. of the genera *Cortinarius, Inocybe, Lactarius, Russula*);

– accumulation of heavy metals (e.g. 14–36 ppm of lead measured in boletes 10 m from the road, while the WHO norm is 0.5 ppm), radioactive isotopes, etc.;

– around salted roads, salinity also increases (NaCl, KCl, $MgCl_2$) up to ca 50 m;

• **change in the water regime** (especially the groundwater level) – melioration (=> drainage), irrigation, connection with construction activity => in particular wet habitats are threatened (mires, springs, banks of ponds and lakes, floodplains, wet meadows);

• excessive **„pressure“ of mushroom pickers** in some places – not only the collection of fruitbodies (restriction of spore dispersal), but especially massive trampling, damaging the mycelium in the litter and surface layers of the soil (it can lead to 2–3x higher compactness of the soil in 10 years).

Although **human interventions** can in some cases lead to **enrichment of the mycobiota** in a given area (meadow or steppe species in long-term deforested habitats, in some cases also replacement of original forests by other stands – for example, rare finds from planted spruce stands in vicinity of Karlštejn are known), to a greater extent they **limit the occurrence** of popular edible mushrooms (chanterelles, boletes, *Tricholoma* species etc., see below) and many others – for example, in Germany, around a third of macromycete species are currently considered threatened, and about a quarter of our species are in the Red List of Macromycetes of the Czech Republic.

Ectomycorrhizal species are disappearing most markedly – the occurrence of these fungi is completely bound to partner trees (conversely not), and it depends not only on the presence of trees at the site, but also on their age and vitality => damage or weakening of symbiotic tree species can reduce occurrence of „their“ fungi => changes in the mycobiota can thus signalise later changes in the ecosystem, which may not be visible at the level of vascular plants. A really „killer“ combination for mycorrhizal fungi, which has become a reality in many places during the 20th century, is represented by a changed spectrum of tree species and atmospheric emissions changing the soil pH (increasing acidity).

Examples: fungi of the genera *Boletus*, *Suillus*, *Gomphidius*, *Sarcodon*, *Cantharellus*, *Ramaria*, *Gomphus*, some species of other genera – *Tricholoma equestre*, *Amanita caesarea* or *Lactarius volemus*; significant decline of hypogeous fungi (*Tuber, Elaphomyces*) was also recorded.

Left: *Tuber aestivum*; right: *Elapho-myces granulatus*.

Top left: *Sarcodon imbricatus*; centre: *Boletus pinophilus*; right: *Tricholoma equstre*;
bottom left: *Cantharellus cibarius*; centre: *Gomphidius glutinosus*; right: *Lactarius volemus*.

Mycorrhizal *Ramaria botrytis* (left) and *Gomphus clavatus* (right).

Availability of a suitable substrate and its condition (wood/detritus/humus, raw/fine humus, tree species, trunk/branches/twigs/litter, chemistry, water content) are essential for **saprotrophic species**, but the overall composition of the community in the substrate, succession and mutual interactions between organisms can also play a key role.

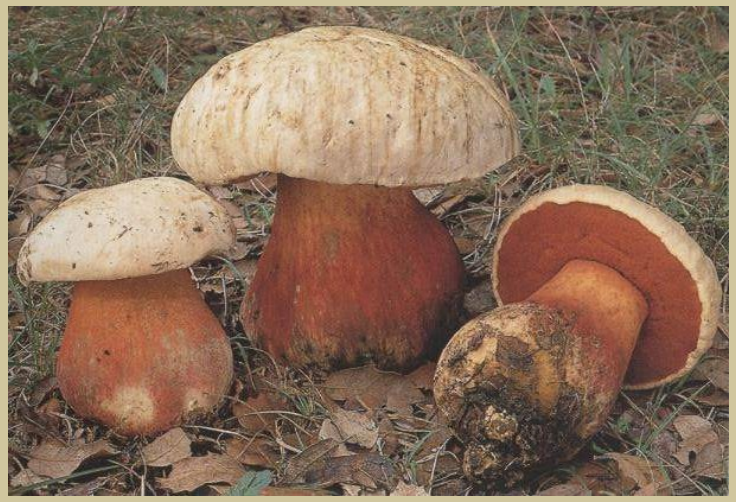
Saprotrophic species are not affected by changes in ecosystems so fundamentally as mycorrhizal fungi, but decline of the genera *Morchella*, *Verpa*, *Helvella*, meadow fungi of the genus *Hygrocybe*, the polypore *Polyporus umbellatus*, *Albatrellus* species or montane fungi of the genera *Hericium* and *Bondarzewia* was also recorded.

Hygrocybe miniata

Top left: *Morchella esculenta*; centre *Helvella lacunosa*; right *Albatrellus ovinus*; bottom left *Verpa bohemica*; centre *Hericium flagellum*; right *Bondarzewia mesenterica* and *Polyporus umbellatus*.

Abiotic factors of the environment also play a role, for example acid rain decreases the pH => a change in the soil reaction leads to influence on the occurrence of calciphilous species, such as mycorrhizal *Boletus satanas*, *Inocybe erubescens* (= *I. patouillardii*) or saprotrophic *Entoloma sinuatum*.

Top right: *Entoloma sinuatum*; bottom left: *Boletus satanas*; right: *Inocybe erubescens,*



Situation of **parasitic fungi** is quite simple, especially obligate parasites (facultative ones usually with a wider „scope“ are not so threatened) – the presence and vitality of the host organism is essential (contrary to mycorrhizal symbionts, saproparasites commonly „welcome“ weakening of the host), and environmental conditions and interspecies relationships also play a role (similar to previous groups).

Other species expand into the niches which become vacant – mycorrhizal *Imleria badia* (= *Boletus badius*), *Tylopilus felleus*, *Paxillus involutus*, *Russula ochroleuca*, *Lactarius turpis* or *Amanita phalloides*, terrestrial saprotrophic *Clitocybe* species, *Lepista nuda*, *Gymnopus dryophilus* and *Agaricus* species, lignicolous *Auricularia auricula-judae*, *Pycnoporus cinnabarinus* and *Stropharia aeruginosa* or parasitic *Armillaria*, *Heterobasidion* or *Fomes* species.

Left: *Tylopilus felleus*; right: *Paxillus involutus*.

Mycorrhizal fungi at the left – top: *Russula ochroleuca*; bottom: *Amanita phalloides*; other species are saprotrophic – top centre: *Clitocybe nebularis*; right: *Gymnopus dryophilus*; bottom centre: *Lepista nuda*; right: *Agaricus xanthodermus*.

Lignicolous saprotrophs or saproparasites – top left: *Auricularia auricula-judae*, centre: *Heterobasidion annosum*; right: *Pycnoporus cinnabarinus*; bottom left: *Fomes fomentarius*; centre: *Armillaria ostoyae*; right: *Stropharia aeruginosa*.

OPTIONS OF PROTECTION OF FUNGI

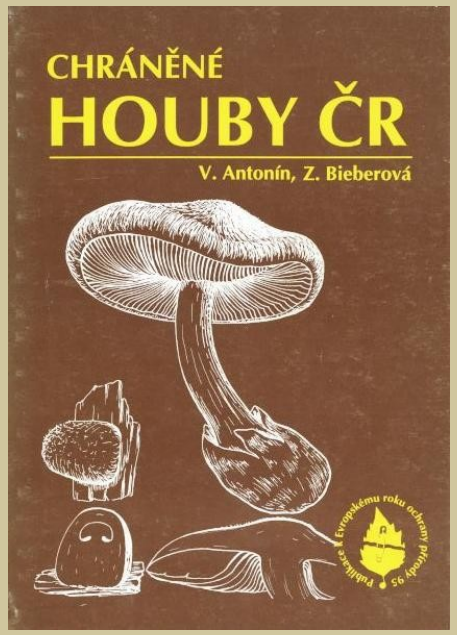
• **Regulation of mushroom picking** means restriction of the fruitbody collection for a certain period of time, possibly on certain days of the week, or weight limit of collections for one mushroom picker per day (e.g. in Switzerland – here both these methods of regulation are applied in addition to „total protection“, the ban on the collection of all mushrooms in certain protected areas) – this approach is only relevant for rare species (restriction of fruitbody collection => greater chance of spore dispersal) and to some extent for reduction of trampling.

• Much more effective way is **overall protection of the site** (protected area – National Nature Reserve, National Nature Monument) and related restrictions (access restricted to paths, prohibited collection of nature specimens).

• The most effective way of protection of fungi is the **protection of entire habitats** – appropriate land management is crucial (in particular, limited mechanical interventions and chemical changes, leaving dead wood as a substrate for lignicolous fungi).

Protection of fungi in the Czech Republic was an empty concept until roughly the 1960s. In the 1970s, professional mycologists began to „sound the alarm“in connection with marked decline of some species (especially mycorrhizal ones). Fungi are no longer perceived only as food and the object of mushroom picking as a „national sport“, research concerning distribution of disappearing species and inventorying in a number of protected areas has started.

In the 1990s and the 2000s, concrete steps were taken at the professional level (issue of the Red Book and the Red List, ongoing inventory in protected areas) and practically applied (legal protection of selected species, protection of mycologically valuable sites, consideration of fungi in management of some areas).



Introduction of mushroom picking regulation (see above) would probably have a hard time in our country, not to mention any effective control. The picking ban applies only to selected **protected species**, since the issuance of the Nature Protection Act (114/92 Coll.) and the decree (395/92 Coll.) in which these species are listed; the law defines the protection of plant species (their underground and above-ground parts) including their habitats, whereby plants are meant here including fungi.

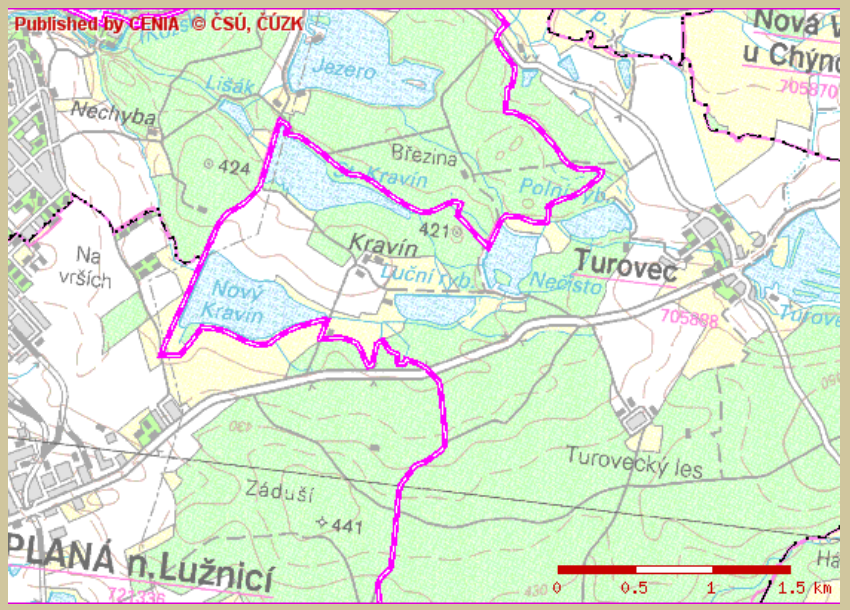
This publication provides an overview of protected species of Czech fungi with descriptions and distribution maps.

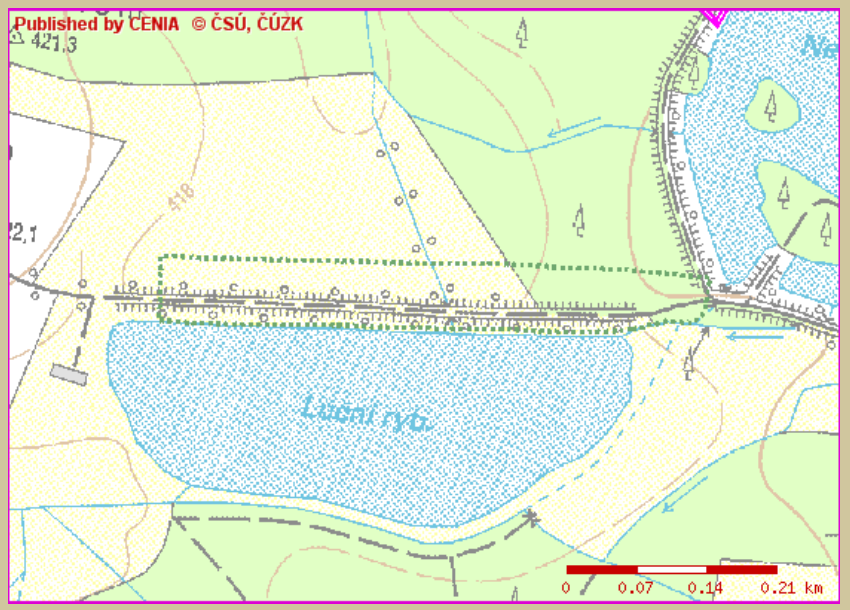
According to which criteria should the species deserving protection at local or national level be selected? At first, rare species (with a minimum absolute number of localities), relict species (destruction of the locality would probably mean the irreversible end of its occurrence here), endemic species (if they disappear from here, so...), or species having edge of the distribution range or extrazonal occurrence here; conspicuous edible mushrooms are under greater threat (this is why *Amanita caesarea* and *Butyriboletus regius* are protected in our country, even though among other species they have significantly more localities here).

Species whose habitats are acutely threatened by economic activities deserve increased attention.

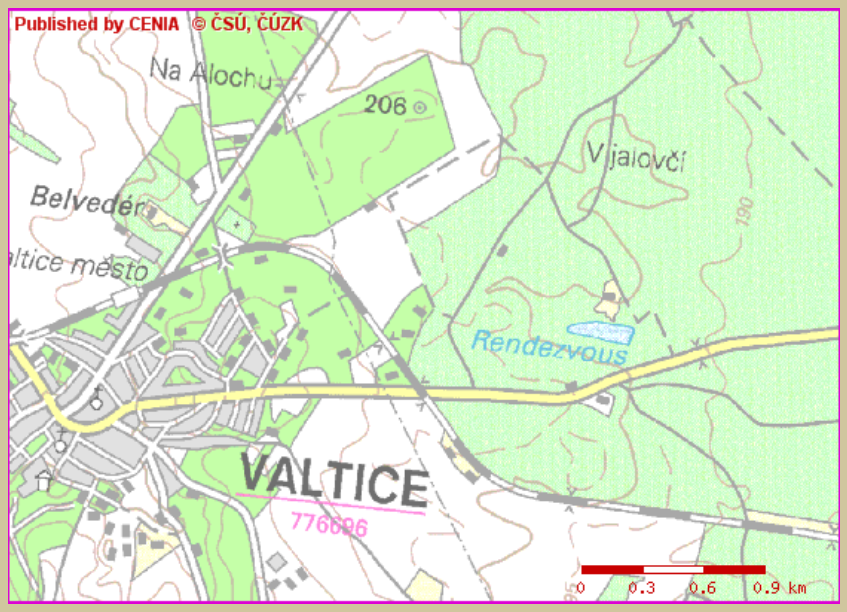
Left: *Butyriboletus regius*; right: *Amanita caesarea*.

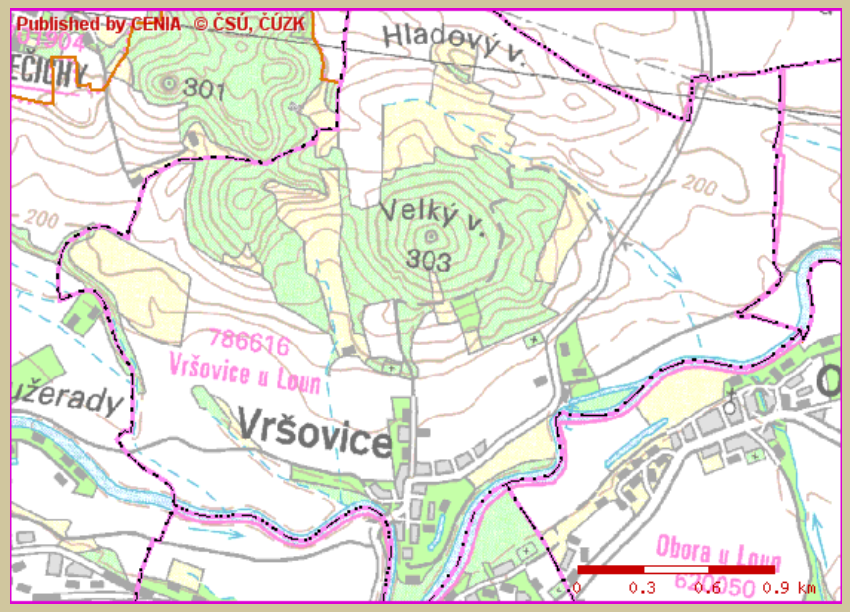
There are 46 protected species of fungi in the Czech Republic, while the number of more or less threatened ones is in the hundreds, and most of the protected species cannot be recognised by the layman in the field (however, they are not usually picked, with the exception of a few species, as the already mentioned *Amanita caesarea*, *Butyriboletus regius*) => the main impact of the legal protection of fungi is „educational“ (fungi also deserve protection) and especially as a basis for justifying the declaration of protected areas – since the 1980s, some **protected areas** have been declared directly for mycological purpose (dam of the Luční pond near Tábor) or protected mainly due to occurrence of rare fungi (Rendezvous near Valtice, Velký vrch near Vršovice in Louny District; all three areas are today classified as National Nature Monument).

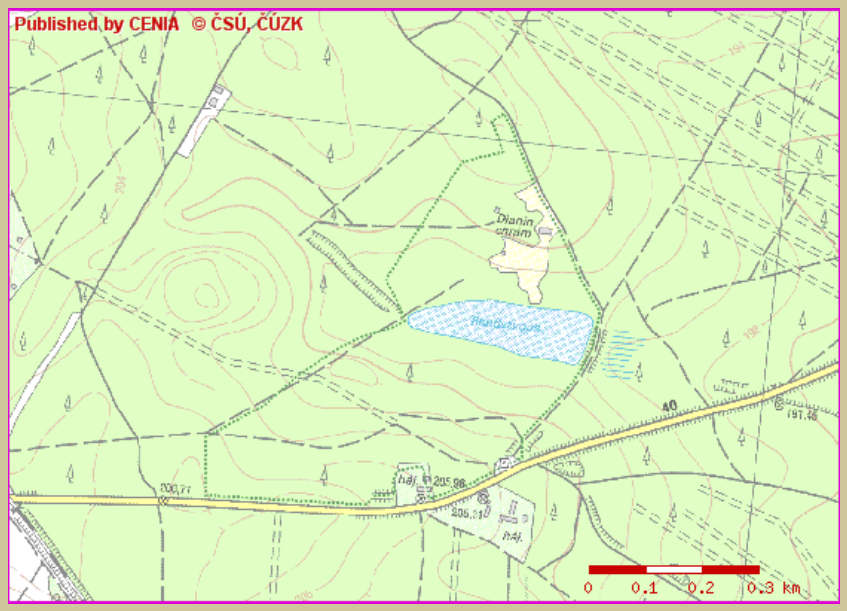


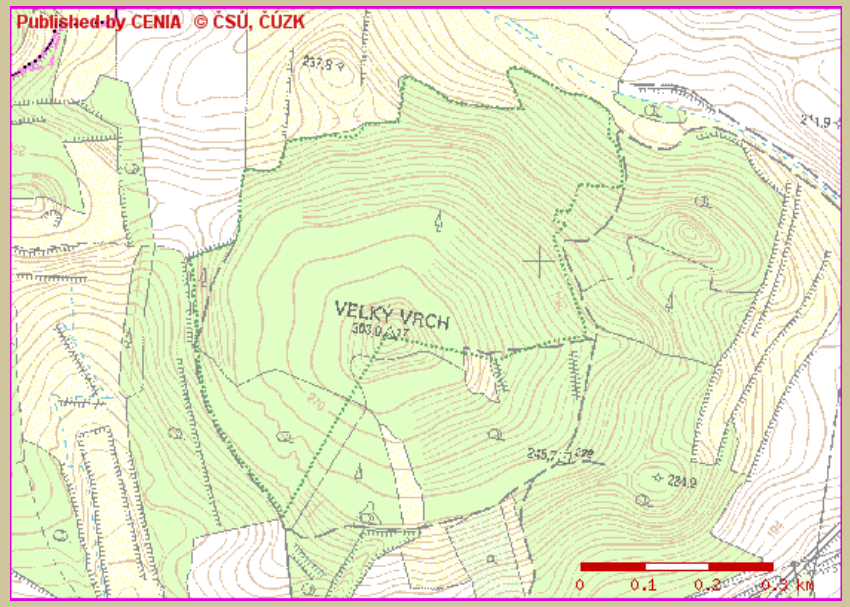


Maps taken from http://geoportal.cenia.cz/mapmaker/cenia/portal







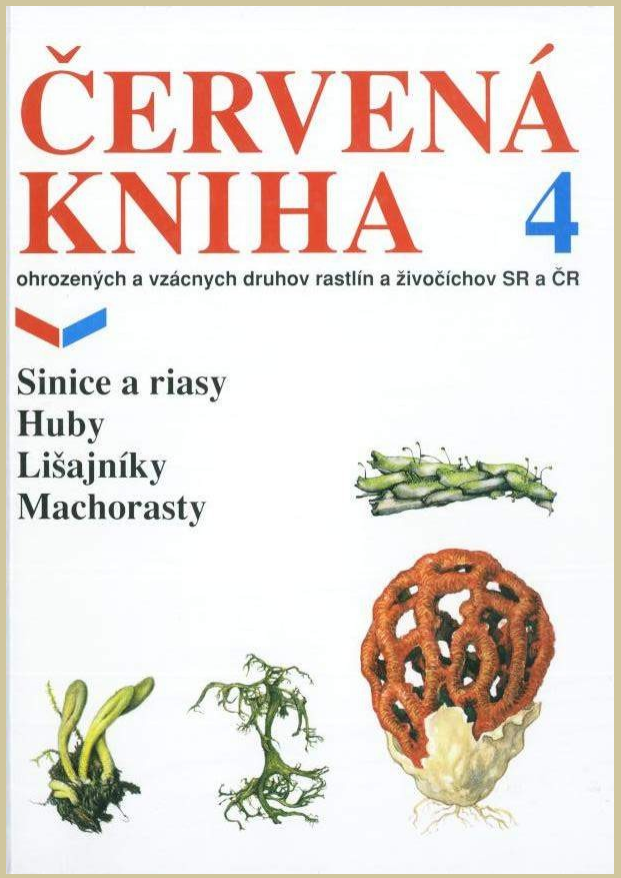


Maps taken from http://geoportal.cenia.cz/mapmaker/cenia/portal

The ideal constellation for enforcing the protection of fungi and their habitats (can be applied in general, not only for fungi) is the cooperation of „local experts“ (regular monitoring of localities => knowledge of the occurrence of species which no „externalist“ can have), mycologists-specialists (with knowledge, on the basis of which they can put the data on the species occurrence into a wider context) and politicians (who apply the results of the work of experts at the national or local level => legal regulations, protection of the localities).

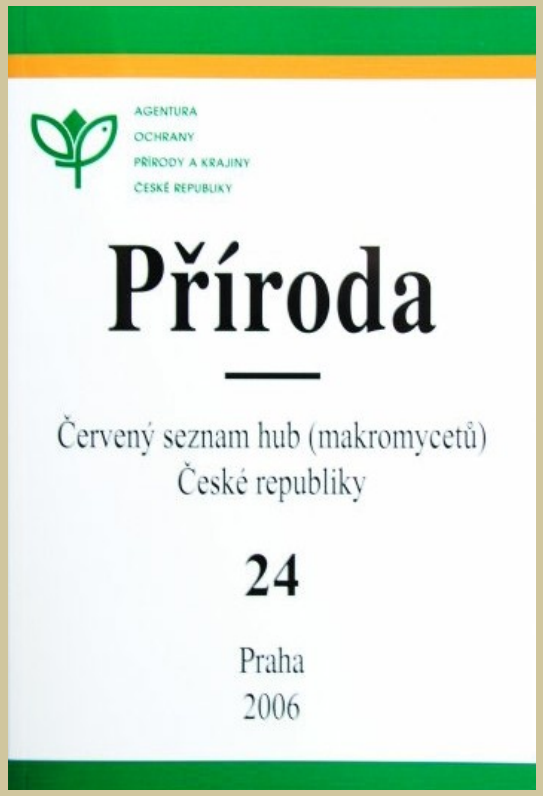
As a guide for interested persons in the state administration, experts and the public, **Methodology for Species Protection of Fungi** was published in 2022. It presents the fungi of important habitats in the Czech Republic, analyses the causes of their threat and, above all, is focused on practical options of their protection with an emphasis on appropriate management in various habitats. *The methodology is available on the website of the Ministry of Environment of the Czech Republic as a ZIP file (60 MB), partial files and appendices (see below) on the website of the Czech Scientific Society for Mycology.*

A proposal of 87 species, suitable for amending the list of protected fungi in the aforementioned decree 395/92 Coll., was prepared at the same time. These are presented in appendices of the methodology with a detailed description, data on their ecology, current distribution, main threatening factors and proposed level of protection.



A complete overview of the entire issue of protection of fungi is also provided by an excellently prepared page on the website of the Czech Mycological Society.

In the **Red Data Book**, fungi were elaborated in the 4th volume (cyanobacteria, algae, fungi, lichens and bryophytes); it was completed in 1991 (still as „federal“ Red Data Book of the Slovak Republic and the Czech Republic), published in 1995 (Príroda publishing house, Bratislava).



The **Red List** of Macromycetes of the Czech Republic was published in 2006 and, unlike the Decree 395/92 Coll. (list of 46 species) and the Red Data Book (114 species), it contains 904 species of Czech fungi, which can be considered potentially threatened => thus it represents a valuable basis for declaring new protected areas, but also a tool for routine decision-making about the value of particular localities.

Note: With the exception of species of lichenised Agaricomycetes, lichenised fungi are not included in the Red List - a separate Red List of Lichens of the Czech Republic was published for them in 2010.

Most European countries currently have their Red Lists of fungi (in varying quality and with different amounts of species included).

At the pan-European level, 33 species of threatened fungi (representing their occurrence in various habitats and different climatic conditions) were selected for inclusion in the appendix of the Bern Convention (orig. Convention on the Conservation of European Wildlife and Natural Habitats).