Summary

Macrofungi in nature conservation management

Part 1: Ecology, threats and knowledge gaps

General introduction

Within the scope of Natura 2000, rare (plant) species and vegetation types are protected in a European context. It became evident during the course of this study that, despite the functional relevance of fungi, but little long-range research has been conducted in the Netherlands into the effects of specific nature management measures on fungi. Fungi are largely neglected in nature policy and nature management in the Netherlands. There are several reasons why increased awareness of the importance of the conservation of fungi is desirable:

- Fungi play an essential role in the functioning of many ecosystems;
- Fungi represent a major share of the biodiversity (with more than 5000 species in the Netherlands) and make up a kingdom all of their own, alongside plants and animals. In various habitat types, the diversity of fungi exceeds that of vascular plants several times over.
- A large number of fungi is vulnerable or under threat and is included in the Red List (62% of the surveyed species). Yet there are scarcely any nature management measures in place that aim at their restoration.
- Fungi and plants have different habitat requirements and so fungi do not automatically benefit from management that focusses on plants.

Nature reserve/site managers are often willing to take fungi into consideration, but suitable instruments to that end are lacking. Know-how regarding 'fungi-friendly management' is highly scattered and poorly accessible. It is likely that much can be gained regarding the conservation and restoration of fungal diversity through the ready availability of this information. This publication aims to contribute to the above and provides an overview of:

- Biotopes that are valuable to fungi and the requirements that the environments of the threatened fungi species must meet (per functional group);
- Opportunities for facilitating the conservation and restoration of the fungi diversity;
- Knowledge gaps and recommendations for subsequent research.

The target group of this study is twofold: ecologically skilled managers who can use the report when formulating management plans and mycologists with an interest in nature conservation. Inventory reports and lists of species alone often do not suffice for well-intentioned managers without an explanation of 'the story behind the species'.

This report can contribute to providing recommendations that are better geared to managers.

This publication consists of two parts:

- Part 1 (in hand) contains general information on fungi, their ecological role, general threats and knowledge gaps.
- Part 2: provides an overview of the mycoflora per habitat type with quality indicators per biotope.

Ecology of fungi and the functional groups

A 'mushroom' is the reproductive organ (fruit body or sporocarp) of a fungus and is visible to the eye. The larger, virtually invisible part of the organism within a substrate is made up of a network of hyphae (small hollow tubes) called the mycelium. The sporocarps only play a role in reproduction by generating large numbers of microscopically small spores. The mycelium on the other hand has an active role in meeting carbon (energy) and nutrient requirements. For the sake of convenience, this publication refers to 'fungi' as a collective term for the sporocarp and hyphae.

Unlike plants, fungi have no chlorophyll and depend upon dead or living organic material from other organisms for their energy needs. It is useful for a better understanding of the ecological requirements of fungi to distinguish between 'functional groups' based on how fungi meet their energy requirements and which substrate is used to that end. A classification into three main groups is observed in this respect: *mycorrhizal fungi* (soil-dwelling fungi in a mutualistic relationship with plants), *soil- and litter dwelling fungi* (saprotrophs on litter and non-woody plants and plant parts) and *wood-inhabiting fungi* (saprotrophs and parasites on wood). Various subgroups exist within these main groups.

Mycorrhizal fungi
This is a large group of fungi that form a mutually beneficial association with plants. The fungus taps sugars for its energy supply via the roots of the vascular plant and in exchange, supplies the plant nutrients. A large majority of vascular plants (more than 90% of the species) exist in close association with mycorrhizal fungi.

There are several types of mycorrhiza with clear differences in terms of morphology, physiology and ecology. Of all of the fungi that exist in symbiosis, only one group generates fruit bodies that are visible to the eye, the ectomycorrhizal fungi. This type is dominant in many forests in the Netherlands, particularly on nutrient-poor soils. More than 900 species of mycorrhizal fungi can be found in the Netherlands, including Fly agaric (*Amanita muscaria*), Chanterelle (*Cantharellus cibarius*), Porcino (*Boletus edulis*) and Truffles (*Tuber* genus).

*Figure 1. Two well-known ectomycorrhizal fungi: on the left Porcino (*Boletus edulis*), and on the right Fly agaric (*Amanita muscaria*) (photos: W.Ozinga / D.Terwisscha).*

Ectomycorrhizal fungi
(Ecto) Mycorrhizal fungi have a crucial role in a variety of partly related processes, particularly in wooded areas on nutrient-poor soils:

- Improved nutrient uptake by plants (not only macro-nutrients such as N, P, K, Ca and Mg, but also micro-nutrients such as B, Mn, Zn, Cu and Fe);
- A reduction of the sensitivity of plants to draught;
- The protection of plants against heavy metals;
- The protection against pathogenic organisms (in the soil);
- The formation of underground mycorrhizal networks that interconnect plants, contributing to a redistribution of nutrients and, possibly, sugars (favourable for the germination of plants that can 'plug into' this network);
- Carbon sequestration in the soil;
- The stabilization of the soil thanks to the fungal network and through the production of substances ('fungal glue') that make soil particles stick together;
- Contribution to the development of the humus profile.

It is useful to keep in mind with respect to the functioning of the ecosystem that the conservation or restoration of a high diversity of mycorrhiza-forming fungi not only depends upon a low nitrogen availability, but that the mycoflora itself can contribute to a better nutrient balance. An extensive network of hyphae in the soil will increase the resilience of trees against fluctuations in the soil environment and phosphate (P), alkaline cations (Ca, Mg, K) and micronutrients remain more readily available in the ecosystem. Moreover, a higher biomass of mycelium will immobilize a larger fraction of nitrogen, sustaining the shortage of N even further.

Soil- and litter-dwelling fungi
The mycelia of soil- and litter-dwelling fungi fulfil an important role in the decomposition of organic matter and therefore in the recycling of carbon and nutrients. Almost any naturally occurring source of organic matter can be broken down by fungi. The litter consists of finer materials, such as leaves, flowers, fruits, fine twigs and manure. Fungi contribute mainly to the decomposition of recalcitrant substances such as cellulose, hemicellulose and lignin. About 2200 species are involved in litter decomposition. Some species can grow on a variety of substrates, other are highly specialized and require specific substrates for growth.

Wood-inhabiting fungi
Wood is mainly composed of cellulose, hemicellulose and lignin and the decomposition of these components is a complex process. Depending upon the type of decay (rot type) that they induce, wood-inhabiting fungi can be divided into three groups. Brow-rot fungi degrade and remove the pale cellulose and hemicellulose, leaving behind the darker lignin. White-rot fungi, on the other hand, also decompose the lignin, and so the decayed wood is light in colour. Soft-rot fungi primarily degrade the cellulose and hemicellulose inside the cell walls of moist wood. All of these processes involve specialized wood-inhabiting fungi. Some of these may be parasites, leading to tree mortality (approx.. 100 species in the Netherlands), while others are saprotrophic species that inhabit dead wood (approx. 1000 species). The speed at which wood decomposes mainly depends upon the type of wood involved and the environmental variables, such as moisture availability. The most extraordinary species of wood-inhabiting fungi are found on large volumes of wood (thick logs). In part, these concern species that are limited to this particular type of substrate. In the Netherlands, thick (dead) trees are found mostly in wooded areas on rural estates and in parks. Few extraordinary wood-inhabiting fungi live in production forests.

General threats
The 20th century has seen a severe decline in fungal diversity in most of the habitat types. The most important cause of this decline concerns high levels of nitrogen deposition. This is particularly the case for ectomycorrhizal-developing mushrooms. Most mycorrhizal fungi species react to an increase in the available nitrogen in the soil by severely reducing the production of fruit bodies. Many sensitive species largely (or entirely) disappear, including Tooth fungi (hydnoid fungi, such as *Bankera, Hydnum, Hydnellum, Phellodon, Sarcodon*), Knights (*Tricholoma*) and many Webcaps (*Cortinarius*).

A high deposition of nitrogen also has a negative effect on below-ground ectomycorrhizal fungi species, but this is often not evident until later on. Changes in the occurrence of mushrooms above ground are therefore an early indication of changes underground. Most striking in the underground shifts in species composition is a sharp decrease in species that generate an extensive network of hyphae within the soil. These changes are likely to have important consequences for the functioning of the forest ecosystem:

- Disrupted nutrient balance in trees resulting from a reduced uptake of immobile nutrients and alkaline cations;
- An increase in the rate of nitrogen circulation in the soil due to the reduced N-immobilization in fungal tissue;
- Greater sensitivity to extreme drought;
- Greater sensitivity to wind throw;
- Reduced litter decomposition.

Concerning grasslands, a high nitrogen deposition is not the only threat, but also the use of fertilizer or manure and disruptions in the soil resulting from the processing of the land. Tests show that grassland mushrooms (including waxcaps) are more sensitive to phosphate.

Wood-inhabiting fungi are primarily limited by a lack of sufficient volumes and variation of dead wood. Though the significance of dead wood for wood-inhabiting fungi is generally acknowledged, many forest areas see an increase of canopy and understory wood and the amounts of large dead wood strongly lags compared to older, more natural forests.

Mycological hotspots
The habitat types in the Netherlands greatly differ in terms of their mycological diversity. The table below lists the habitat types that are relatively rich in mushrooms.

Table 1. An overview of habitat types that are potentially relatively rich in fungi, with a link to the Natura 2000 habitat type (if applicable) and a rough indication of the diversity of fungi species.

Biotope	**N2000 habitat type**	**no. of species**
Drift sand moorland with heather (grouped trees)	2310	+++
Juniper shrubs	5130	+++
Sand drifts (with small primary pine forests)	2330	++++
Grey sand dunes	2130	++++
Creeping willow shrubs	2170	+++
Bluegrass meadows	6410	+++
(Moist) heath-poor meadows	6230	+++
River valley grasslands	6120	+++
Lime meadows	6210	+++
(Dry) heath-poor grasslands	6230	+++
Oat grass / foxtail grass meadowlands	6510	+++
Moist alluvial forests (ash/elm forests)	91E0B	++++
Dry hardwood ewe forests	91F0	++++
Alder marsh forests (*Alnion glutinosae*)	91E0C	++++
Oak- and hornbeam forests	9160	+++++
Dune woodlands	2180	+++++
Wood rush-beech forests	9110	++++
Beech-oak forests with holly	9120	++++

Biotope	N2000 habitat type	no. of species
Old oak forests	9190	++++
Coniferous forests (Scots pine, Norway spruce)	-	++++
Park woodlands, estates	-	+++++
Avenues, roadsides with trees	-	+++++

Most of the habitat types included in the table concern so-called Natura 2000 habitat types that are listed in the European Habitats Directive. Parks, estates, avenues and arid roadsides with trees are not considered Natura 2000 habitat types, but these biotopes do serve as an important refuge for characteristic types of mushrooms in forest habitats that are included in the habitat directive. Specific environmental conditions often apply to habitats that can potentially develop a rich mycoflora and an important step towards the conservation of the mushroom diversity is recognizing these limiting conditions. This is considered in more detail per habitat type in part 2 of this report.

Recovering from the effects of excessive fertilization, acidification and drought is found to be a difficult process for many characteristic mycoflora. This is particularly the case with respect to excessive fertilization; the restoration is slow and often incomplete, that is to say that a large proportion of the characteristic species do not return. The most effective strategy for the sustainable protection of the mycological diversity is therefore to maintain and possibly strengthen the existing hotspots.

Effects of restoration measures
An important finding of this OBN project is that there are very few long-term studies into the effects of management measures on mushrooms, despite their functional significance. It is evident however that the high nitrogen deposition in the Netherlands is one of the most important threats to many fungal species and this nutrient-rich situation maintains itself. The greatest challenge in managing over-fertilized and acidified ecosystems is therefore to break the vicious circle with restoration measures that create nitrogen-poor circumstances with a rich mycoflora. A general limiting condition with respect to the planning and implementation of measures on a regional level is that due care is observed to maintain the remnant populations of endangered mushroom species.

Knowledge gaps

The questions that stem from gaps in knowledge concerning fungi can be clustered in two groups. The first concerns the formulation of knowledge gaps in which applied research can generate knowledge within the short term, which can be used by (site) managers. The second concerns knowledge gaps that primarily relate to generating fundamental knowledge of how fungi live and their role within the ecosystem. Answers to these questions will probably not lead to changes in nature management in the short term, but they will provide insight into the consequences for the functioning of ecosystems should certain groups of fungi become scarcer or more commonly widespread. Descriptive and experimental research is often the way to go for the first group of questions, whereas the second group also requires fundamental research under more controlled circumstances (laboratory, greenhouse).

Short-term knowledge through applied research
A system of indicator-values (particularly the species that are easily recognized) can provide managers insight into changes in 1) environmental conditions and the 2) mycological values of areas. Regarding the first aspect, fungi have an obvious added value compared to other species in three respects:

- They respond considerably faster to environmental changes than do higher plants (due to their much higher dispersion capacity).

- They can provide information on supplementary factors such as changes in the carbon- and nutrient cycle and the functioning of the soil nutrient web.
- There are habitat types in which the number of fungi species is extremely limited.

Regarding the second aspect, the mycological values, current policy aspires to bring a halt to a reduction in biodiversity of all types of organisms. An evaluation system for mycologically valuable areas can help to portray the location of present mycological hotspots (the information that is currently available is extremely out-of-date).

Examples of systems that may be useful in determining indicator-values:

- the ratios between the number of species of various functional groups. First of all, the ratio between the ectomycorrhizal fungi and soil- and litter-dwelling fungi. This could then be worked out further in sub-groups. A system of this kind provides a global indication of the nutrient cycle and the ‘vitality’ of the forest.
- (weighed) sum of the number of *Hygrocybe* species and other species with similar ecology and lifestyle (*Entolama, Clavaria, Trichoglossum*). This information can be interesting, particularly in relation to information regarding soil chemistry, such as pH, the availability of various forms of phosphate and the nature of the organic matter (humus profile). In addition, the information can be linked to information concerning the species composition of the vegetation (vascular plants and mosses; this also in view of the possibility that these species are associated with higher plants or mosses).
- indicator-value for the nature and quality of organic matter in the humus profile. A system of this kind can be particularly useful in forests for the monitoring of changes in the nutrient-cycle and the soil nutrient web.
- (weighed) sum of wood-inhabiting fungi species that are characteristic for old forests with large quantities of dead wood in various stages of decomposition in relation to data on the quantity and diversity of large wood in various decomposition stages and the size and connectivity of the nature area.

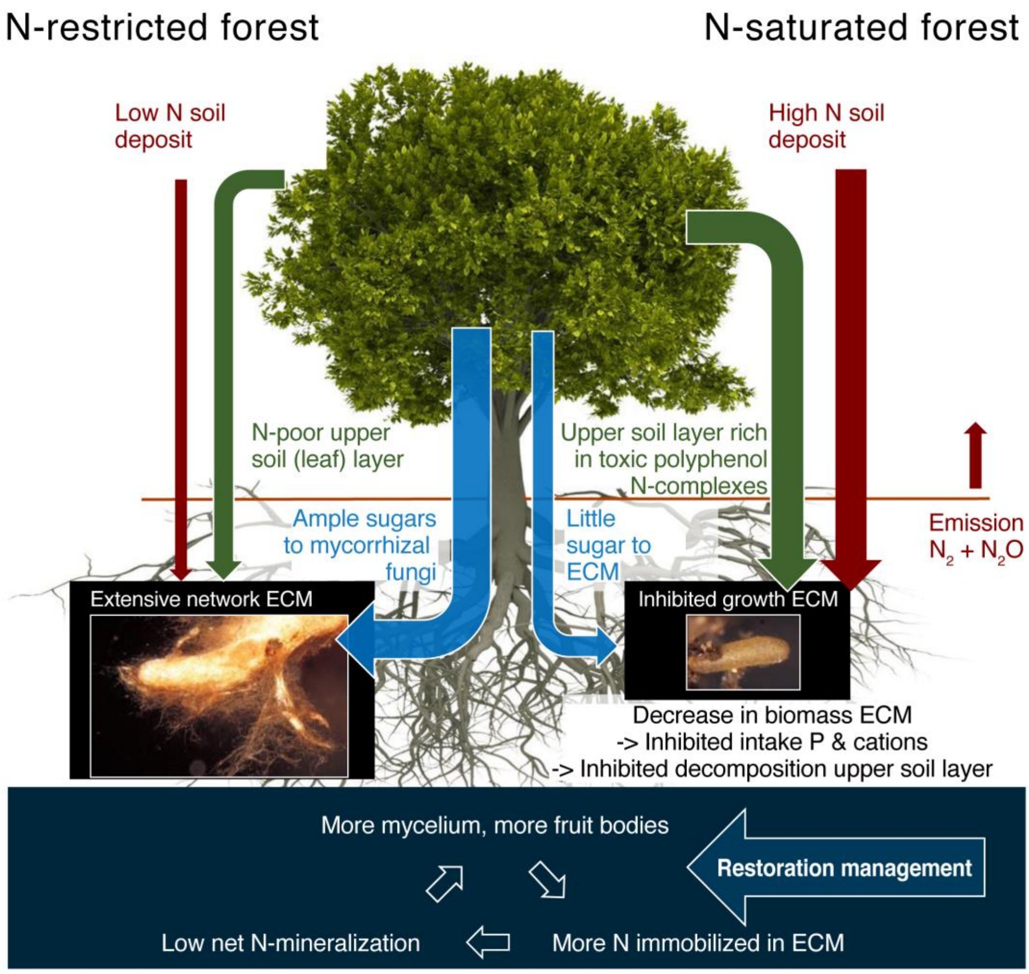

Figure 2. An important knowledge gap concerns the effect of restorative measures on ectomycorrhizal-developing fungi and soil- and litter-dwelling fungi in forests. A number of processes play a role in a high N-deposit in forests that are naturally nitrogen-poor (shift from left to right). It is as yet not clear whether and how restoration management can contribute to a shift to the left in the figure above.

Knowledge gaps requiring fundamental research
This concerns the improved knowledge of ecosystems in which fungi have a steering role, and of which our knowledge presently does not suffice. Stress factors for the existence of fungi are generally examined independently, with little regard for interactions . There are, however, interactions that negatively influence fungi. Examples include:

- The effects of nitrogen-deposit on the acidity and acidification. The potential of N-stressed ecosystems to recover partly depends upon the degree of acid buffering and the pH.
- The interaction between drought and over-fertilization. Drought can increase N-mineralization, but may also cause a shift in the humus profile.

The number of species and the above-ground (fruit bodies) and underground biomass of ectomycorrhizal-developing fungi has highly deteriorated under the influence of nitrogen deposits. Changes in the occurrence of soil- and litter-dwelling fungi have also been reported, but our knowledge of that is even more limited. So far, changes in the two functional systems have been considered independent of one another. However, it is likely that the changes influence each other and that this weakens the link between the carbon cycle (decrease in circulation speed) and the nitrogen cycle (increase in circulation speed). It is to be expected that this will have considerably consequences for the functioning of the ecosystem, particularly for the soil nutrient web. A few examples of interactions that deserve further research are:

- a decrease in the decomposition of soil and litter (lignin decomposition) by saprotrophic fungi, resulting in the accumulation of soil and litter, which in turn can result in the development of polyphenols/nitrogen complexes that are poisonous to ectomycorrhizal fungi.
- a reduction of the biomass of hyphae of ectomycorrhizal fungi can influence the decomposition speed of soil and litter, as the decomposition speed in forests is regulated by the turnover of the hyphae (due to a lack of a 'priming effect'), that is to say, the stimulation of the decomposition of soil and litter thanks to the availability of biomass of mycorrhizal fungi that is easily decomposed. Changes in the mycorrhizal flora can lead to shifts in the humus profiles in such cases.

Limiting conditions
Specific environmental conditions often apply to habitats that can potentially develop a rich mycoflora and an important step towards the conservation of the fungi diversity lies in recognizing these limiting conditions. This is considered in more detail per habitat type in part 2 of this report, in which the possibilities per habitat type are examined in relation to the restorative measures of the PAS (*Programmatische Aanpak Stikstof = Programme-based Approach Nitrogen)*.

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