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Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species

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ABSTRACT

With its strict criteria, required documentation and coverage of all groups of multicellular organisms, the red-listing system of IUCN is recognized as the most authoritative guide to the status of biological diversity. The aim of red-listing *sensu* IUCN is to evaluate the risk of extinction of a species using a comparable, revisable, transparent and objective assessment method. The evaluation estimates the potential change in the species' population size over time, aiming to infer extinction risk. Both extremely rare species and more common ones experiencing ongoing decline may be at risk of extinction. Red-listing is an assessment of conservation status, directing awareness and providing a scientific basis for management and decision-making. The IUCN criteria were originally designed for global assessments. However, they can be, and are, commonly applied at the national or regional level. This paper summarizes the basic aspects and usefulness of red-listing in a mycological context, and suggests methods for fungal red-listing that are applicable to most fungal groups, even with limited information on the species being considered. The suggested methods are based on the accumulated experience of national fungal red-listing throughout the world, coupled with recently published research on fungal diversity, distributions, and population biology.

Introduction

Biodiversity loss is one of the world's most pressing crises, and there is growing global concern about the status of the biological resources on which so much of human life depends (Convention of Biological Diversity 2010). Many species are declining to critical population levels, important habitats are being destroyed, fragmented and degraded, and ecosystems are being destabilized due to climate change, pollution, invasive species, land transformation and other human impacts (Rockström *et al.* 2009). At the same time, there is a growing awareness of the importance of biodiversity (Millennium Ecosystem Assessment 2005). It is necessary to have status and trend analyses of species and habitats to prioritize conservation planning and make appropriate management decisions. With its strict criteria, scientific base and coverage of all groups of multicellular organisms, the red-listing system developed by the IUCN (International Union for Conservation of Nature) is recognized as the most authoritative guide and most widespread assessment and classification scheme used to document the current status of biological diversity, relevant to all species and all regions of the world (Rodrigues *et al.* 2006;

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Zamin *et al.* 2010). The red-listing system comprises a careful assessment of the conservation status of species, including their current population size and past and predicted future developments, directing awareness to and providing information for appropriate ecosystem management. It provides a method to make comparisons among species from different taxonomic groups and among different regions.

This paper focuses on red-listing using IUCN Categories and Criteria (IUCN 2001). IUCN is a global environmental network founded in 1948 which now includes more than 1 000 government and NGO member organizations in more than 160 countries (www.iucn.org). Red-listing was developed for mammals and birds in 1960s, but the criteria have since been substantially modified to be appropriate for assessing the conservation status of all groups of multicellular organisms, and at geographical scales ranging from local to global (Gärdenfors *et al.* 2001; Mace *et al.* 2008). The IUCN Red List of threatened species is increasingly being used as an important tool for setting national, regional, and global priorities for nature conservation actions. To enable appropriate conservation priorities to be set, comparable and workable data on the status and trends of different groups of species and habitats need to be compiled, made available, and be coordinated with political biodiversity goals. In practice, conservation priorities, as all political priorities, are set using the information or inferred information that is available. Hence, conservation priorities will be set whether or not appropriate and adequate information is available. Red Lists are not linked to legislation *per se*, and are not by themselves sufficient for making conservation priorities. While some countries have a direct link between red-listed species and legislation, they do not use the IUCN system (e.g. USA see http://www.fws.gov/Endangered/; Canada see www.sararegistry.gc.ca).

In the November 2009 edition of the IUCN Red List of Threatened Species™, 17 291 animal, plant and fungal species are globally red-listed (IUCN 2010). However, only one macrofungus and two lichenized fungi are included in that list. This is despite the fact that national Red List assessments of fungi have been conducted in at least 35 countries (33 European countries, Japan and New Zealand), resulting in nearly 7000 macrofungal species being nationally red listed (cf. Dahlberg *et al.* 2010). Other ecologically distinctive microfungal species (e.g. host specific obligate pathogens) have also been included in some countries' fungal conservation assessments. Additionally, recent issues of 'IMI Descriptions of Fungi and Bacteria' include conservation status according to IUCN categories (C.A.B. International and International Mycological Institute 1991–Present).

In total probably more than 15 000 fungal species have been evaluated at the national level. While some of these National fungal Red Lists do not fully meet the IUCN criteria, the assessments provide useful information on the conservation status of fungi. In countries where evaluations have more or less covered all known macrofungal species, the percentage of red-listed species ranges between 20 % and 60 % (Anonymous 2004; Kålås *et al.* 2010; Senn-Irlet *et al.* 2007; Arnolds & Veerkamp 2008; Gärdenfors 2010). National Red Lists of fungi have played valuable roles in setting national biodiversity targets, motivating the selection of areas to protect and raising government and public interest, and helping identify fungal species in specific national conservation action programs (e.g. Dahlberg *et al.* 2010; Buchanan *et al.* In press). For example, existing national fungal Red Lists are an important source of information used to identify woodland key habitats (e.g. Hottola & Siitonen 2008) and to identify hot spot habitats (e.g. Brandrud 2007; Sverdrup-Thygeson *et al.* 2010).

The present disconnect between national and regional/global Red Lists for fungi, however, restrain fungi from being considered in many large-scale conservation initiatives. For example, the major biodiversity initiative within the European Community, Natura 2000, is partly based on European and global Red Lists, but since fungi are lacking from these lists, they are not directly considered or monitored as part of the program (Anonymous 2008).

Some mycologists and other scientists question whether species of fungi are tractable to rigorous assessment of their conservation status at this time. There is also discussion on whether IUCN criteria can be applied to fungi. But these concerns are not unique to fungi as most biologists working on conservation initiatives have to deal with significant challenges due to biological issues, paucity of data, and insufficient human and financial capacity irrespective of taxon. We acknowledge that there are special challenges for red-listing fungi, but based on the rapidly expanding knowledge of fungal biology coupled with increased experience in fungal conservation and fungal red-listing evaluations, we posit that these challenges can be overcome and the IUCN red-listing criteria can, and should, be applied to fungi.

In this paper: we (i) summarize the use of fungal Red Lists in conservation action, public awareness, and research; (ii) discuss prospects and limitations of fungal red-listing; (iii) outline the red-listing principles of IUCN; (iv) provide fungal centric interpretations of criteria used for Red List evaluations; and (v) provide specific guidelines for how to undertake fungal red-listing, even with limited information on the species being considered. Our ultimate objective is to provide suggested approaches that will facilitate assessments of the conservation status of fungi at any geographic scale that consistently use the IUCN red-listing standards. Red-listing fungi using these recognized standards will spur a larger public interest in fungi and their conservation, identify fungal species in need of protection and provide recommendations to mitigate the threats, facilitate fungi being included in conservation discussions and action, and identify research questions needing to be addressed in fungal ecology and conservation biology.

The use of fungal Red Lists in conservation action, public awareness and research

The aim of red-listing is to evaluate the risk of extinction for a species in any group of organisms by describing the threat status in a comparable, revisable, transparent and objective system using an internationally accepted set of criteria. The core of the evaluation is estimating the potential change of a species' population size over time. Red-listing calls on information from various sources of scientific studies, rigorous observations, gray literature, observations by collectors, etc. It brings together knowledge from both amateur and scientific sources. Red Lists not only focus attention on extremely rare and fast declining species at the brink of extinction, but also document and direct attention to ongoing declines of still common to uncommon species so that appropriate conservation actions can take place to reverse the trend. The importance of paying more attention to the depletion of common species has recently been addressed (Gaston & Fuller 2008; Gaston 2010). Therefore, it is important to evaluate, document and communicate the status and trend for as many species and species groups as possible. The goal is to provide "objective" information of all species in the biota so that inconspicuous and less charismatic species, e.g. species of fungi, insects and bryophytes are considered equally with popular, attractive and well known species such as whales, primates, orchids and albatrosses.

There are several reasons to produce fungal Red Lists. Firstly, management and conservation of species and ecosystems do not operate in isolation, but rather in a world with multiple, disparate and often opposing interests operating over varying time perspectives. Thus, the better documented the status and trends are, particularly if the underlying causes of these trends and countermeasures to address the trends are identified, the more likely decision-makers and the public will consider the issue and take action. Secondly, Red Lists communicate the presence and value of fungi to politicians, decision-makers and other stakeholders including the public at large. Thirdly, Red List evaluations identify key gaps in our knowledge of fungal biology and diversity. Such gaps include taxonomic problems, distribution and autecological requirements, difficulty of identifying and defining individuals, and challenges of determining the drivers and constraints on population dynamics. Fourthly, omission of fungi in Red Lists invites the mistaken conclusion from conservation agencies that fungi are either not threatened or, worse, that mycologists are disinterested in fungal conservation.

Prospects and limitation for fungal red-listing

The consideration of fungi in conservation is lagging behind most other groups of organisms (Heilmann-Clausen & Vesterholt 2008). This is in large part due to a perception by some mycologists and other scientists that species of fungi are intractable to rigorous assessment of their conservation status due to their unique biology, predominantly cryptic lifeforms and paucity of taxonomic, distribution and ecological data. The strong fluctuation in annual fruiting due to differing weather conditions and irregular fruiting patterns of some species and individuals, and the low correlation between the presence of sporocarps and the presence and extent of mycelia (e.g. Straatsma *et al.* 2001; Mueller *et al.* 2004) are additional issues that need to be considered when assessing changes in population size of fungal species.

These factors, combined with a paucity of mycologists, funding and uncertainty on how to interpret the IUCN criteria are impediments to complete assessments of fungal species at the global, or even regional, scale. Mycologists have often had difficulties in applying the IUCN criteria for fungi, particularly for the concepts of mature individual, generation length, location, fragmented distribution and how uncertainty and absence of data should be handled (Hallingbäck 2007; Heilmann-Clausen & Vesterholt 2008). This has resulted in the use of varying interpretations in different countries rendering it difficult to compare these lists among countries or to Red Lists of other groups of organisms. In fact, most existing national fungal Red Lists are commonly based on slightly different criteria and different interpretations from the ones suggested by IUCN.

We acknowledge these difficulties, but they are not unique to fungi. The IUCN system aims to be applicable to any multicellular organism so the evaluation criteria are general and do not purport to take into account the specific life history of every species. Red-listing is about putting available information into practice. It is a pragmatic attempt to combine various sources of data on species (observational and experimental, from scientists, amateurs, public authorities and other stakeholders) into an evaluation that is useful for making conservation decisions. Many of the challenges facing mycologists regarding how to delimit an individual, interpret the concept of mature individual in the sense of IUCN, estimate population sizes, and judge turnover of genotypes or generation length are equally challenging for scientists working with other clonal organisms such as many vascular plants, bryophytes and various groups of invertebrates (e.g. corals). Other species groups face different significant challenges and the appropriate use of the criteria for such well-studied taxa as sea-turtles continues to be debated (Hamann *et al.* 2010).

The increase in mycological knowledge over the years is immense. Thanks to amateurs, surveys, field and laboratory research, and improvements in bioinformatics there is substantial and growing information available on the systematics, abundance, distribution and ecology of many fungal species. Patterns and dynamics of macrofungal populations are being revealed through recent studies of species from different ecological guilds and displaying various growth forms (cf. Worrall 1999; Peay *et al.* 2008). Knowledge of the dynamics of fungal populations is key to estimating extinction risks. Although current information of population dynamics is limited to few examples, present and future studies are providing data that, with caution, can and should be used as proxies for estimating the size and turnover of fungal individuals and the effective distances of contemporary gene flow among populations (see Heilmann-Clausen & Vesterholt 2008 for a discussion). While such knowledge is clearly incomplete for fungi, emerging patterns and dynamics of fungal populations, despite their cryptic nature, are in principle the same as for any other type of organism. Population genetic studies using molecular markers will increasingly reveal spatiotemporal population dynamics of selected fungi (e.g. Anderson & Kohn 1998; Beiler *et al.* 2010).

Introduction to the principal red-listing categories and criteria

The following is a brief discussion of the principal red-listing categories and criteria. We follow this with recommendations on how to interpret these concepts for fungi. We base our recommendations on the cumulated experience of national fungal red-listing throughout the world coupled with data

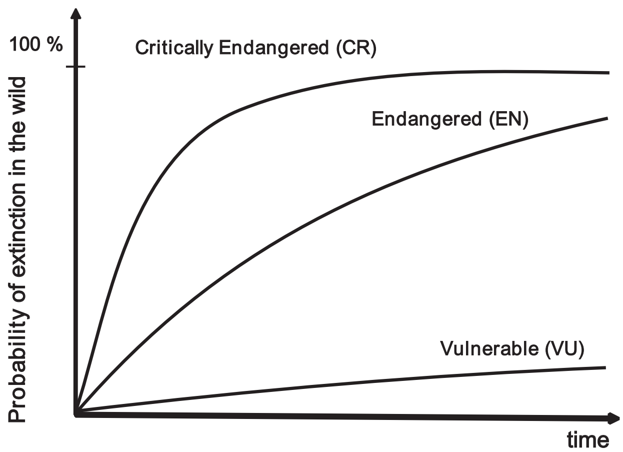

Fig 1 – The IUCN Red List categories are intended to reflect the likelihood of a species going extinct. Critically Endangered (CR) corresponds to a probability of extinction of 50 % in 10 yr or up to a maximum of 100 yr (3 generations) whichever is the longer. Endangered (EN) corresponds to a probability of extinction of 20 % in 20 yr or up to 100 yr (5 generations) whichever is the longer. Vulnerable (VU) corresponds to a probability of extinction of 10 % in 100 yr (cf. Table 2). The figure shows the extinction probabilities at different moments assuming that the annual extinction probability is constant (adjusted from Kindvall & Gärdenfors 2003).

from recent publications on fungal biogeography and population biology. The criteria are described in detail in the IUCN Red List Categories and Criteria (IUCN 2001), the Guidelines for Using the IUCN Red List Categories and Criteria (IUCN Standards and Petitions Subcommittee 2010) and the IUCN Regional Guidelines (IUCN 2003).

The IUCN Red List categories are intended to reflect the likelihood of a species going extinct under prevailing or foreseeable circumstances at the scale being assessed (Fig 1). Thus, a regional or global category listing may not be the same as the listed national threat category. For example, species classified as Least Concern regionally or globally might be Critically Endangered within a nation where the species population is very small, declining, or at the margin of the species' geographical distribution. Similarly, a species may be listed as Least Concern in a particular country's national Red List where its population is stable, even though the species is undergoing a significant and broad scale population decline throughout most of its range, justifying a threatened status on regional or global Red Lists.

The IUCN criteria are intended for species and subunits of species. The focus has been exclusively at the species rank for fungi, and we suggest that this focus continues. The listing system employs a series of nested categories describing the conservation status of a species (Table 1, Fig 2).

The first dichotomy in the assessment of threat status is whether the species has been evaluated or not (Fig 2). If not evaluated, the species is termed NE (Not Evaluated). Species with far too little distributional and ecological knowledge to make any kind of evaluation should be left without

Table 1 – The application of IUCN Red List Categories for fungi at the national, regional or global level

A species is	When
Extinct (EX) or Regionally Extinct (RE)	The species has previously been resident and there is no reasonable doubt that the last individual has died. Due to the cryptic nature of fungi, we recommend RE to be used only if exhaustive surveys in known and/or expected habitat throughout its historic range during an adequate time period have failed to record an individual. Extinct (EX) refers to the global scale and RE to any lower geographical scale.
Critically Endangered (CR)	the best available evidence indicates that it meets any of the criteria A[a]–E for CR, and it is therefore considered to be facing an extremely high risk of regional extinction.
Endangered (EN)	The best available evidence indicates that it meets any of the criteria A[a]–E for EN, and it is therefore considered to be facing a very high risk of regional extinction.
Vulnerable (VU)	The best available evidence indicates that it meets any of the criteria A[a]–E for VU, and it is therefore considered to be facing a high risk of regional extinction.
Near Threatened (NT)	It has been evaluated against the criteria and does not qualify for CR, EN, or VU, but is close to qualifying for, or is likely to qualify for, a threatened category in the near future.
Least Concern (LC)	The species has been evaluated against the criteria and does not qualify for CR, EN, VU or NT. Species in this category are normally widespread and abundant.
Data Deficient (DD)	There is inadequate information to make assessment of the species risk of extinction based on its distribution and population status. DD is not a threat category and species designated DD are rarely targets for conservation action. We recommend using whatever information is available and relevant to make assessments at one of the threat categories and place species into the DD category only when there is no alternative.
Not Applicable (NA)	The taxon is not native to the region or of lower taxonomic rank than considered eligible for red-listing within the region. This category is not used at the global level.
Not Evaluated (NE)	The species has not yet been evaluated against the criteria.

a See Table 2.

classification, i.e. remain in category NE pending additional knowledge. We recommend a case-by-case decision on whether newly described species should be evaluated or not. Not Applicable (NA) is a special category that is applicable at national and regional levels only. NA is used for species that are not native and/or are taxonomically unclear, i.e. where it is unclear what entity to evaluate. The other seven categories cover species that are appropriate to evaluate. Data Deficient (DD) is assigned to species for which insufficient information can be found to make a reasonable threat assessment. While a large portion of fungi in many geographical regions will be classified as DD, many fungi can be classified into one of the

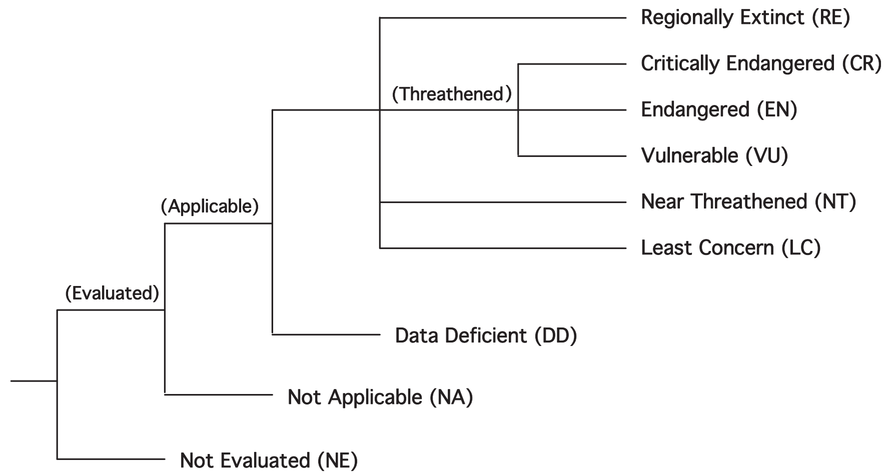

Fig 2 – The structure of the IUCN categories. Classifications are independent of scale, except for NA which applies only at national and regional levels. Regionally Extinct is replaced by Extinct (EX) when applied to the global level (adapted from IUCN 2003).

six categories by extrapolating from existing data and observations. DD categorization has value as it can provide impetus for conservation agencies to commit resources to address deficiencies in knowledge. For example, funding was allocated for molecular detection of New Zealand DD fungal species (Buchanan *et al.* In press). The species that remain are evaluated against five different criteria, A–E, that are designed to reflect different degrees of threat of extinction (Fig 3, Table 2; IUCN 2001; Mace *et al.* 2008) and classified into one of six categories (Least Concern to Regionally Extinct). The category Least Concern (LC) is applied to species that do not qualify as threatened or near threatened while the categories, Critically Endangered (CR), Endangered (EN) and Vulnerable (VU), are assigned to those that qualify as threatened. Regionally Extinct (RE) indicates that there is no reasonable doubt that the last individual has disappeared from the assessed region. The category Near Threatened (NT) is applied to species that do not qualify as threatened now, but may be close to qualifying as threatened.

Only one of the five criteria needs to be met to assign a species to a particular threat category. If multiple criteria can be employed, the criterion that results in the highest threat category is used. The philosophy behind the different criteria is that together, they can accommodate different groups of species with different biologies and different requirements.

Both common species and extremely rare species may be red-listed; common species that have a documented or predicted large decline in population size may meet criterion A (Fig 3; Table 2), while less common species may be listed based on restricted occurrence together with a smaller but not necessarily quantified decline in population size (criteria B and C; Table 2). Very rare species may be listed as threatened without any documented or projected population decline exclusively based on their rarity as very rare species are likely to be sensitive to stochastic events or yet unknown specific threats (criterion D; Table 2). Finally, one may use quantitative analysis to estimate the probability of extinction of a species (criterion E). This last criterion requires a rigorous quantitative model, often including detailed population data. Consequently it has only been used for few species, and only one lichenized fungus (lichen) (Scheidegger *et al.* 2002). The other four criteria are applicable to, and have been used for fungi.

Key concepts used in Red List evaluations interpreted for use with fungi

The following data are necessary to assess the conservation status of any species under IUCN criteria: (1) the geographic distribution of the species; (2) an estimate of the population size of the species; and (3) information on how these features are changing over time.

How best to define and/or estimate key concepts used in the IUCN system such as population, mature individual, population size, generation length, location and severe fragmentation for fungi is challenging. Uncertainty on how to interpret these concepts by the mycological community has led to various interpretations being used or, worse, decisions that the IUCN system cannot be used for fungi. Below we discuss and suggest how these concepts can be interpreted and used for fungi. The appropriate fungal specialist group (Mushroom, Bracket, and Puffball; Lichens; Chytrid, Zygomycete, Downy Mildew and Slime Mould; Cup-fungus, Truffle and Ally; and Rusts and Smuts) within IUCN can be consulted for additional information and help with using these concepts for specific groups of fungi (http://www.iucn.org/about/work/programmes/species/about_ssc/specialist_groups).

Population

Population is the fundamental basis for the IUCN Red List system. In this context, "population" refers to the total number of mature individuals, defined as "individuals known, estimated or inferred to be capable of reproduction" (IUCN Standards and Petitions Subcommittee 2010). Isolated parts of the total population are termed subpopulations in the IUCN Red List system.

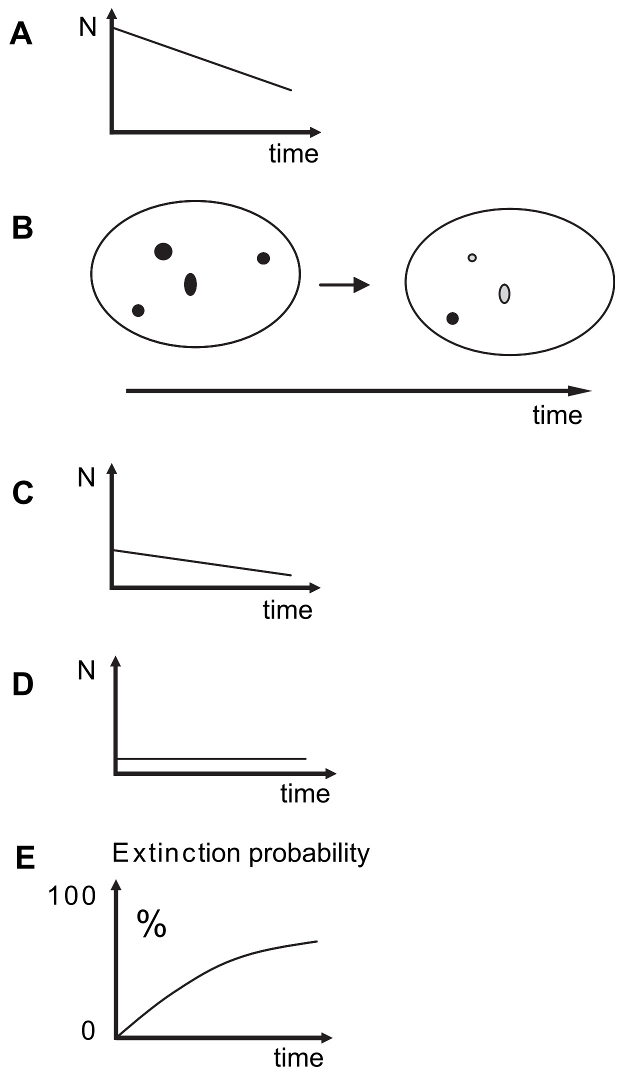

Fig 3 – The red-listing system of IUCN is based on five different criteria: (A) uncommon to common species that have a quantified decline of more than 15 % over 10–50 yrs (criterion A); (B) declining species with restricted distributions (criterion B); (C) species with small total populations that have ongoing, but not necessarily quantified declines (criterion C); (D) species with very small or geographically very restricted populations (criterion D); and (E), (though not considered feasible for current use with fungi) species where a quantitative analysis (e.g. a population viability analysis) indicates a species' probability of extinction over a given time, e.g. 5 % in 100 yrs to be classified as NT (criterion E). The criteria used for red-listing must be written after the indicated Red List category, e.g. VU A2c + 3c + 4c; C1 + 2a(i). N = population size.

Mature individual

Fungal individuals have been variously defined as: (a) the original single genotype; (b) the group of genetically identical individuals (clonal colony or genet) or all asexually originating parts of a genet (ramets). In the IUCN system, the smallest entity capable of both independent survival and reproduction (sexual or asexual) is generally considered a mature individual. That is, it is the potentially reproducing ramet, not the genet, that is the unit of red-listing. Unfortunately, a lack of information on the dynamics of ramets in nature, combined with the cost and logistical challenges of gathering genetic data over large geographical areas over multiple years, likely ensures that estimates of the presence and number of mature individuals of fungi will largely be based on sporocarp observations for the foreseeable future. Therefore, for practical purposes, we propose using the concept of functional individual, distinguished from genet and ramet, for red-listing. We define a functional individual for lignicolous fungi as all conspecific sporocarps inhabiting an individual tree, log, or other discrete substratum unit, and for terrestrial fungi as all conspecific sporocarps within a diameter of 10 m, most often interpreted as arising from the same genet. Our definition of functional individual is modified from the concept used for lichens introduced by Scheidegger & Werth (2009).

In regard to genet size, molecular and other population level studies are providing important information for interpreting sporocarp-based surveys. A review of the few published studies on terrestrial macrofungi that have investigated the size, distribution, and number of genets of a species at a site or region suggests that, in general, genets are of relatively small size (less than 10 m in diameter) (e.g. Hintikka & Näykki 1967; Holmer & Stenlid 1991; Dahlberg 2001; Dunham 2003; Kretzer *et al.* 2004; Lygis *et al.* 2005; Germain *et al.* 2009; Wolfe *et al.* 2009; Beiler *et al.* 2010), except species with rhizomorphs or that form fairy rings (e.g. Thompson & Rayner 1982; Kirby *et al.* 1990; Smith *et al.* 1992; Boddy *et al.* 2008). A large tree trunk may support more than one genet, sometimes numerous, of a particular species (e.g. Rayner & Boddy 1988; Kay 1992, Kauserud & Schumacher, 2002; Stenlid, 2008). However, except for species that form rhizomorphs, a fungal genet usually occurs only on a single trunk (e.g. Barett & Uscuplic 1971; Adams *et al.* 1981; Huss 1993; Holmer *et al.* 1994; Prospero *et al.* 2003; Stenlid 2008).

The following operational rules for defining and counting mature individuals of sporulating macrofungi are consistent with current data from population studies. Due to differing conditions in soil *versus* wood and differing biological interactions in these two substrata, we consider the likelihood of terrestrial mycelia becoming fragmented to be higher than wood-inhabiting mycelia, i.e. terrestrial fungi will have more ramets per genet than lignicolous species. Thus, operational rules are different for terrestrial *versus* lignicolous fungi. We also consider that the typical genet consists of more than one ramet, so each functional individual should at minimum be counted as two mature individuals. We suggest using these rules *except* when more specific information is available.

For ***terrestrial fungi***, one may conservatively assume that sporocarps separated by 10 m or more represent a functional individual or separate genotype (see above). Each mycelial genotype (genet) is likely fragmented, i.e. consists of more than one ramet, and increasingly so with increasing size and age (cf. Brasier & Rayner 1987). We propose that for terrestrial species, each functional individual be considered to correspond to (2–)10 mature individuals (ramets) depending on the distribution of sporocarps to correspond to the IUCN concept of mature individual. We recommend counting each functional individual (i.e. sporocarps of a species separated by

Table 2 – Summary of the four criteria (A–D) used to evaluate if a fungal species meets the criteria for any threatened or near threatened category (Critically Endangered, Endangered, Vulnerable or Near Threatened). The table only contains information appropriate for fungal evaluations (modified from IUCN Standards and Petitions Subcommittee 2010). Thresholds for Near Threatened are as presently recommended in Sweden and Norway as the IUCN Criteria do not give any threshold for NT (Gärdenfors 2010; Kålås *et al.* 2010). For a more detailed description of the criteria, see IUCN Standards and Petitions Subcommittee (2010) or IUCN (2001, 2003)[a]. See the text for suggested operational definitions of mature individuals, population, generation length, etc

Use any of the criteria A–D	Critically Endangered	Endangered	Vulnerable	Near Threatened
A. Population reduction	Reduction measured over 10 yrs or 3 generations, whichever is longer			
A2, A3 & A4	>80 %	>50 %	>30 %	>15 %
A2. Population reduction observed, estimated, inferred or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible, based on any of the following:				
(b) An index of abundance appropriate to the taxon				
(c) A decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality				
A3. Population reduction projected or suspected to be met in the future (up to a maximum of 100 yr) base on any of (b) to (c) under A2.				
A4. An observed, estimated, inferred, projected or suspected population reduction (up to a maximum of 100 yr) where the time period must include both the past and the future, and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible, based on any of (b) to (c) under A2.				
B. Geographic range in the form of either B1 (extent of occurrence) OR B2 (area of occupancy)				
B1. Either extent of occurrence	<100 km^2	<5 000 km^2	<20 000 km^2	<40 000 km^2
B2. Area of occupancy	<10 km^2	<500 km^2	<2 000 km^2	<4 000 km^2 or ≥ EN + 1 subcriterion
and the following two subcriteria:				
(a) Severely fragmented or # locations	=1	≤5	≤10	≤20
(b) Continuing decline in (i) extent of occurrence (ii) area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or subpopulations and (v) number of mature individuals.				
C. Small population size and decline				
Number of mature individuals	<250	<2 500	<10 000	<20 000
and either **C1** or **C2**:				
C1. An estimated continuing decline of at least up to a maximum of 100 yr	25 % in 3 yr or 1 generation	20 % in 5 yr or 2 generations	10 % in 10 yr or 3 generations	10 % in 10 yr or 3 generations, or < 10 000 mature ind. and 5 % on 10 yr or 3 generations
C2. A continuing decline and (a i) or (a ii)				
(a i) # mature individuals in largest subpopulation	<50	<250	<1 000	<2 000
(a ii) or % of mature individuals in one subpopulation	90–100 %	95–100 %	100 %	
D. Very small or restricted population				
D1. Number of mature individuals (use D for CR and EN)	<50	<250	<1 000	<2 000
D2. Restricted area of occupancy (AOO) or number of localities	Not used	Not used	typically: <20 km^2 or ≤5 locations	typically: <40 km^2 or ≤10 locations

a Category A1; options (a), (d), (e) under Category A2-A4; option (c) under Category B2; option b under Category C2 and Category E have been omitted.

10 m) as 10 mature individuals for species typically occurring with scattered, sparse to gregarious fruiting. Each functional individual of a species that typically occurs as isolated solitary sporocarps should be counted as two mature individuals. We suggest using 10 mature individuals as the default translation of a functional individual in terrestrial fungi as most species typically produce clustered scattered to gregarious sporocarps with single to a few genets, each potentially fragmented, e.g. species of the genera *Amanita*, *Cortinarius*, *Laccaria*, *Lactarius*, *Marasmius*, *Onnia*, *Pisolithus*, *Rhizopogon*, *Russula*, *Suillus* and *Tricholoma* (cf. Dahlberg 1997; Sawyer *et al.* 1999; Fiore-Donno & Martin 2001; Redecker *et al.* 2001; Abesha *et al.* 2003; Bagley & Orlovich 2004; Lian *et al.* 2006; Germain *et al.* 2009; Beiler *et al.* 2010; Hitchcock *et al.* In press). An example of a known exception to our assumption of fragmentation is the report that individuals of the mat forming ectomycorrhizal fungus *Hydnellum ferrugineum* typically consist of an unfragmented mycelium (Hintikka & Näykki 1967). As in the example of the solitary species above, each functional individual would be counted as two mature individuals to be conservative. Litter-dwelling fungi occupying leaves and pieces of small woody debris are probably commonly not restricted to single substrata units as their mycelial growth, cords or rhizomorphs facilitate movement and colonization so they should be treated as terrestrial fungi (e.g. Holmer & Stenlid 1991; Murphy & Miller 1993; Frankland *et al.* 1995).

Lignicolous species on larger substrata should typically be considered to consist of different genets on different units of wood. We consider it reasonable that lignicolous fungi typically are spatio-temporally confined to more restricted resources than terrestrial species, and hence are less fragmented than terrestrial fungi. We suggest enumerating 2 (–10) mature individuals per functional individual of lignicolous fungus, i.e. per trunk or log depending on the size of the wood patch and the typical spread of sporocarps. Few aggregated sporocarps on a trunk or log should be counted as two mature individuals. When sporocarps typically are widely scattered within wood units, it may be appropriate to count these as 5–10 mature individuals, e.g. for *Populus tremulae* on aspen (Holmer *et al.* 1994). These suggestions are consistent with published studies, e.g. single logs with *Phellinus nigrolimitatus* may contain three genets (Kauserud & Schumacher 2002), while logs colonized by *Lycoperdon pyriforme* generally contain one genet (Huss 1993).

For species living and confined to discrete and relatively small, resource-limited substrata, e.g. dung, or horn, IUCN recommends that each unit colonized by the species should be considered to contain a single mature individual (IUCN Standards and Petitions Subcommittee 2010).

We judge that estimates made following these guidelines will tend to overestimate the number of mature individuals and thus provide a conservative but realistic estimate of species that are of conservation concern. These templates have been suggested by IUCN (IUCN Standards and Petitions Subcommittee 2010) and are being used in Finland, Norway and Sweden (e.g. Gärdenfors 2010; Kålås *et al.* 2010; Rassi *et al.* 2010). These proxies should be refined as additional pertinent data becomes available. Regardless of what proxy one uses, it is essential that assessments specify the way that mature individuals have been interpreted and counted, i.e. as a functional individual, a genet or an estimate of the number of ramets.

Population size

Like the majority of plants and animals, direct monitoring of total population size (the total number of mature individuals of a species capable of reproducing) is not feasible for fungi. Monitoring, therefore, has to be indirect and based on some kind of population sub-sampling. As with defining and counting functional and mature individuals (see section above), we advocate a pragmatic approach to estimating population sizes of fungal species.

The use of quantitative sampling protocols (e.g. Mueller *et al.* 2004) coupled with the operational guidelines for defining functional and mature individuals given above can provide a reasonable estimate of the population size of a species at a particular site. Combining the accumulated field experiences of amateur and professional mycologists, detailed survey data, and information from other available sources (e.g. maps showing the size and distribution of habit patches and forestry data), it is often possible to estimate the typical number of functional individuals at an average site (see discussion of site versus location below). Due to annual fluctuations in fruiting of most fungal species, we suggest that the typical number of functional individuals at an average site be interpreted as the total number of functional individuals over multiple years. Data on the number of functional individuals at an average site can then be extrapolated nationally, regionally, or globally based on available and estimated information on the range and frequency of the species and its potential habitats at different scales (as calculated in Table 3, Step 6). It is important to take into account both known localities (see below) as well as an estimate of the likely number of unrecorded localities to obtain an estimate of the total number of localities and hence the total population size.

Generation length

Generation length serves as a surrogate for turnover rates within populations and is defined as the average age of parents of the current cohort (i.e. cohort of newborn individuals in the population). Thus, generation length is greater than the age of first fruiting and less than the age of oldest fruiting. It is not the same as maximum or average longevity. We are not aware of any mycological study that has tried to estimate such factors.

To take population turnover into consideration, IUCN guidelines evaluate population size changes over numbers of generations rather than specific numbers of years to compensate for differences among organisms. Declines in population sizes are evaluated over three generations or 10 yr, whichever is the longer under criterion A and over one to three generations under criterion C1 (Table 2). Time frames for evaluations may not be set opportunistically to include desired habitat conditions or inferred population levels, e.g. prior large-scale clear cutting or introduction of artificial fertilizer. For that reason, species with a current population size that is only a fraction of its previous inferred population size is not automatically qualified to be red-listed if the time frame of the decline does fit the IUCN criteria of using biologically realistic estimates of generation length. Thus, it is essential to estimate biologically realistic generation lengths for different ecological groups of fungi to use these criteria.

We posit that mycelia growing in small, discrete, and quickly decomposing substrata, e.g. dung, persist for shorter time periods than do mycelia in wood, and that mycelia growing in continuous substrata such as soil can persist longer than mycelia growing in discrete resource-limited patches like logs and trunks. Based on available data on wood decomposition rates, longevity of perennial sporocarps (e.g. Niemelä 2005), and mycelial longevity of terrestrial macrofungi (e.g. Jahn & Jahn 1986; Dahlberg 2001), we propose the following operational estimates of generation length to assess population changes, *except* when more accurate estimates are available:

(a) For fungi in ephemeral or short-lived discrete substrata likely to have short generation lengths, assess population changes over a 10 yr period, the minimum assessment period according to IUCN.
(b) For wood-inhabiting fungi, assess population changes over 20–50 yr (=three generations), depending on the durability of the type of woody substratum a species is using. In the Nordic countries, the following templates for three generations for species occurring on different types of coarse woody debris with different decay rate have been used: 50 yr (*Quercus* and *Pinus*), 30 yr (*Picea and Fagus*) and 20 yr (*Betula, Alnus* and *Populus*), respectively.
(c) For ectomycorrhizal fungi, assess population changes over 50 yr (=three generations).
(d) For soil and litter inhabiting fungi, assess population changes over 20–50 yr (=three generations).

Location

IUCN defines ‘location’ as a geographically or ecologically distinct area in which a single threatening event can rapidly and significantly negatively impact the individuals of species present. Examples of locations may include a forest patch that would be affected by clear cutting or fire, a grassland that could be affected by changed land use, or a beach that may face exploitation, but a location may also be large forest landscapes that could be affected by land use changes, fire or air pollution, political decisions, volcanic eruptions, hurricanes, or other human-caused or non-human factors that may threaten the habitat. The documentation giving the interpretation and number of locations used in Red List assessments should include justification and reference to the most serious plausible threat(s). In some cases where there are no obvious threats, the term 'location' is undefined and inapplicable. In other cases, regardless of the number of sites, if there is a single common threat, the number of locations is one. In most cases, the threat to a "location" and to a site is the same. For example the most serious plausible threats for fungi in old-growth forests is cutting the site and the primary threat to semi-natural grassland sites is fertilization or ceased management. Thus, while "location" and what mycologists often call a site are two different concepts, in reality a location more or less corresponds to what a mycologist defines as a site.

Severely fragmented

Small and relatively isolated subpopulations are at increased extinction risk due to drift and stochastic events, with a reduced probability of reestablishment. Fragmentation must be assessed at a scale that is appropriate to the biology of the species under study. There have been few published population studies of fungi aimed at inferring metapopulation dynamics, i.e. the extent and frequency of successful establishment as well as local extinctions at different population sizes, different degrees of fragmentation and at contemporary (appropriate) time scales (Grubisha *et al.* 2007). Potential spore dispersal says little about recent and ongoing successful gene flow. Spores often have a large dispersal potential, even though more than 90 % of the spores falls within 100 m (Kallio 1970; Lacey 1996). The few studies that have examined population structure among distant subpopulations suggest that gene flow among subpopulations can be high except when separated by significant geological barriers such as mountains (e.g. Bergemann & Miller 2002; Grubisha *et al.* 2007; Carriconde *et al.* 2008; Hitchcock *et al.* In press). However, it is important to appreciate that these studies are detecting a cumulative measure of past and ongoing gene flow. The impacts on ongoing gene flow from fragmentation caused by greatly intensified human use of landscapes have not been studied for fungi.

Until additional data are available to refine our knowledge of contemporary gene flow among subpopulations and the establishment of new subpopulations, we advocate that it is biologically reasonable to consider subpopulations separated by 500 km or more to be severely fragmented, i.e. it is unlikely that spores may successfully disperse and establish within one generation (see discussion above; Fig 4). This is a concept that should be a focus of research to provide more accurate data for a range of species. It is a conservative estimate and will not lead to unnecessary red-listing. In comparison, moss subpopulations separated by 100–1 000 km are treated as severely fragmented (Hallingbäck *et al.* 2000).

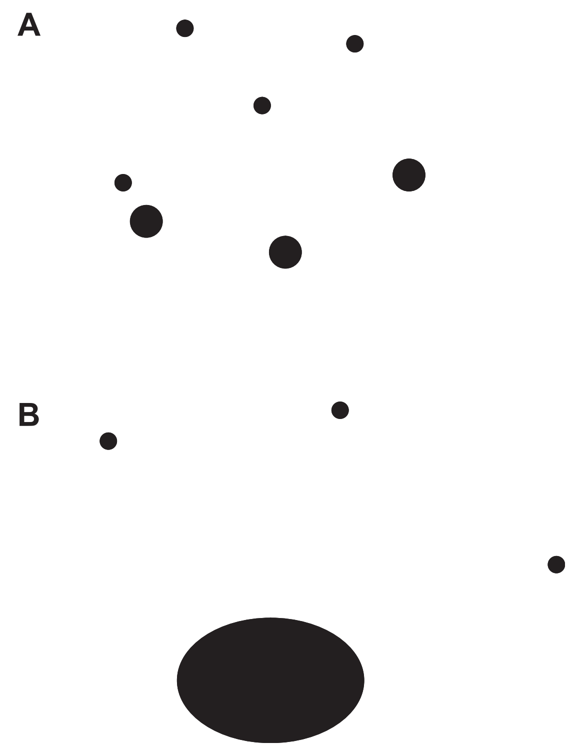

Fig 4 – A schematic presentation of when a species should, and should not be considered as severely fragmented. To be classified as severely fragmented, most mature individuals need to be found in small and relatively isolated subpopulations as in (A). A species is not considered severely fragmented if more than half of the mature individuals, or more than half of the occupied habitat area, are found in few and large patches (B). Fragmentation must be assessed at a scale that is appropriate to biological isolation for the species under consideration (IUCN Standards and Petitions Subcommittee 2010).

Downgrading

The national or regional threat category of a species can be downgraded if the risk of extinction of the species has been reduced (IUCN 2003). This action may be appropriate for national rankings of some species in smaller continental countries where populations and habitats in adjacent countries are not declining and the inflow of spores from those countries is assessed as sufficient to rescue the population from decline. Downgrading normally involves a one-step change in category, such as changing the category from endangered (EN) to Vulnerable (VU) or from VU to Near Threatened (NT). When used, downgrading shall be indicated with a small raised ° following the category, e.g. VU°. Example of the use of downgrading can be found in the Danish national fungal Red List (Anonymous 2004; see Box 1).

Evaluating fungi against criteria A–D

IUCN criteria utilize very broad intervals between thresholds, and precise information on population size, range and decline

Box 1. Four examples of documentation associated with national red-listed species: *Boletopsis grisea* in Sweden, *Cantharellus melanoxeros* in Denmark, *Cortinarius prasinocyaneus* in Sweden and *Hygrocybe citrinovirens* in Norway.

Boletopsis grisea

Vulnerable (VU) A2c + 3c + 4c

Forms ectomycorrhiza with *Pinus sylvestris* and grows mainly on dry and nutrient poor sedimentary soils in open pine forests, possibly favored by fire. Occurs mainly in older, not clear-cut forest, both virgin and thinned forests. A well-known species that has received much attention. Usually only a few mature individuals occur at each location. Individuals are considered to be very old and reestablishment of the species appears to be rare after clear cutting. It is rarely found in pine plantations. Favored by green tree retention forestry and eternity trees. Has been and is being negatively impacted by clear cutting and reducing areas of Scots pine old growth outside protected areas.

The number of mature individuals has been estimated as 1.25×10^6 by multiplying three factors: (a) the probable total number of localities in the country (estimated to be ca. 500); (b) the estimated average number of functional individuals at each locality (estimated to be 5); and (c) a template of how many ramets (mature individual) each reproducing genotype (functional individual) may give rise to (template used = 10). The number of known and existing localities is 150 and the yet unknown number of localities is estimated to be twice as high. The population is estimated to have declined and continues to do so. The decline is suspected to have been at least 30 % over the past 50 yr, is ongoing and is predicted to continue for the next 50 yr. The assessment is based on an estimation of decreasing amount of habitat and diminishing habitat quality.

Reference: www.artdata.slu.se (Accessed April 29 2010, in Swedish).

Blackening Chanterelle, *Cantharellus melanoxeros*

Vulnerable (VU°) D

Blackening chanterelle is very rare in Denmark, where it has been known since 1980 only from four localities spread over the country; Engelstofte Skov at Midtsjælland, Gråsten Dyrehave at Sønderjylland, Staksrode forest at Vejle Fjord and Mourier Petersens forest plantation at Vestjylland. Except for the last locality in a young beech-plantation in a Norway spruce forest, all localities are on clay soil in old deciduous forests. The low number of localities makes it difficult to evaluate the population development of the species. In Nordic countries, blackening chanterelle is also known from Sweden and Norway, where it is especially found in deciduous forests with *Corylus avellana* and *Quercus* spp. It is distributed throughout Europe, but is uncommon overall.

Blackening Chanterelle is evaluated as Endangered (EN) in Denmark based on criterion D. As the Danish population is predicted to obtain spores from adjacent Sweden where the species is more broadly distributed, the species is downgraded to Vulnerable (VU*). The Danish population of blackening Chanterelle is estimated as consisting of 100 mature individuals. The estimation is based on: (a) total number of localities equaling five times the number of localities known as of 1980 and (b) an average of five reproducing genotypes at each locality[1]. The generation length is considered to be 10 yrs.

Reference: www2.dmu.dk/1_Om_DMU/2_Tvaer-funk/3_fdc_bio/projekter/redlist/data.asp?ID¼4104&gruppeID¼84 (Accessed April 29 2010, in Danish).

Cortinarius prasinocyaneus

Endangered (EN) A2c + 3c + 4c; B2ab(iii); C1 + 2a(i)

Forms mycorrhiza with *Corylus avellana* and probably also with other hardwood trees. Occurs in broadleaved forests, old hazel thickets and wooded semi-natural grassland with a long continuity at the border between open and closed forest and warm locations in extensively grazed mosaic habitats, on calcareous soil. A beautiful and sought after *Cortinarius* associated with habitats of high nature value. The population in the country is estimated to continuously decline due to loss and overgrowth of wooded semi-natural grasslands. Threatened strongly by the EU's new rules for environmental protection of wooded semi-natural grasslands.

The number of mature individuals has been estimated at 600 by multiplying three factors: (a) Likely number of current localities in the country (estimated to be c 30); (b) estimated number of functional individuals at each locality (estimated to be two); and (c) a template of how many mature individuals (ramets) each reproducing genotype (functional individuals) may give rise to (template used = 10). The numbers of known localities are 30 and the number of yet unknown localities is estimated to be twice as high. The Extent Of Occurrence (EOO) is estimated as 30 000 km^2 and the Area Of Occupancy (AOO) as 100 km^2. The area of distribution is heavily fragmented. The population is estimated to have declined by more than 20 % in 30 yr (=two generations) and to 50 % within 50 yr (=three generations). The decline is ongoing and is predicted to continue for the next 50 yr. The assessment is based on an estimation of decreasing habitat and diminishing habitat quality.

Reference: www.artdata.slu.se (Accessed Oct 15 2010, in Swedish)

Citrine Waxcap, *Hygrocybe citrinovirens*

Endangered (EN) C1+2a(i)

This species occurs in natural and other open grasslands. In total, 6 localities are currently known in the southern Norway. The total number of localities may be up to 10 times higher and hence, the total number of localities is estimated at 60. This is estimated to correspond to 120 genetically unique mycelia (i.e. 2 functional individuals or genotypes/locality). The estimated total number of mature individuals is 1200 (10 / functional individual). Red-listed by category C1+2a(i) based on small population size (< 2500 mature individuals), small sub-populations, and ongoing reduction of habitat and localities due to ceased or greatly reduced grazing. The population is in continuing decline at a rate of at least 20% per 35 years (2 generations, generation time estimated as 17 years). The present population is judged to be 10–50% of its 1900 maximum population size in Norway. The proportion of the total European population that occurs in Norway is assumed to be 1–5%.

Reference: http://www.artsportalen.artsdatabanken.no/#/Rodliste2010/Vurdering/Hygrocybe+citrinovirens/40168 (Accessed January 2 2011, in Norwegian).

[1] In Denmark, functional individuals are treated as equal to mature individuals and are not translated considering potential ramets.

are not required to evaluate species. Projections and inferences of population reduction may be based on information on closely related species as long as this is clearly defined. For fungi, population estimates are indirect in nature and past and future changes in population size are often assessed based on the status and predicted change of appropriate habitat. However, it is not sufficient that the threshold of the criterion is fulfilled, additional appropriate subcriterion must be met to meet the requirement of the particular criteria (Table 2).

It is important that all Red List evaluations have written public documentation to support the basis for the classification. The documentation should provide brief information on the underlying ecology, distribution, threats, and status (past, present and projected if appropriate) of the species, thereby enabling the proposal to be inspected, updated and reassessed. Four examples of supporting documentation are provided in Box 1.

Criterion A: large population reduction

For criterion A, an estimate of current population size is compared with an estimate from the past or a projection into the future (Fig 3, Table 2). The change in population size over a specified time period, 10 yrs or three generations whichever is longer, is then compared with threshold values – (15–) 30–80 % (Table 2). This criterion covers any species, irrespective of population size, with a population reduction meeting the required thresholds. The population reduction, measured as percent loss, can be estimated from the past to present (criterion A2), from present into the future (criterion A3) or a combination of past and future (criterion A4). The use of this criterion for fungi is typically based on the estimated past, and sometimes also projected future changes in the appropriate habitat (quantity and quality) for the fungal species being evaluated. For example, *Boletopsis grisea* is red-listed as Vulnerable (VU) in Sweden using the criteria A2c + 3c + 4c as its population is estimated to have declined by more than 30 % during the last 50 yrs due to decreasing amount of old-growth forest, its primary habitat. The decrease is predicted to continue over the next 50 yrs (Box 1).

Criterion B: small geographic range and decline

According to Criterion B, a species qualifies as threatened when its geographic range is very restricted and when other factors suggest that it is at risk, e.g. a fungal species is restricted to small areas or to habitat remnants that are disappearing (Fig 3). Many species have persisted successfully for long periods within small geographical ranges and have a low risk of regional extinction. Therefore, to qualify under criterion B, a species must also exhibit two additional risks: (1) continuing decline; or (2) highly fragmented subpopulations (Fig 3). The third possible subcriterion, extreme population fluctuations, is relevant to annual and short-lived species, e.g. insects, annual vascular plants, and possibly to short-lived fungal species confined to ephemeral substrata which severely fluctuate. To our knowledge, this subcriterion has not been used for fungi. The large inter annual fluctuation in fungal fruiting should in general not be considered in this context, as most macrofungi appear to have perennial mycelia and typically remain alive but undetected and refruit with the reappearance of favorable conditions. An example of the use of the B-criteria is the red-listing of *Cortinarius prasinocyaneus* in Sweden as Endangered (EN). Its geographic range in the form of Area of Occurrence (see IUCN Standards and Petitions Subcommittee 2010; Table 2) is less than 100 km^2 fulfilling criterion B2 and two additional subcriteria, the population is severely fragmented (a) and its habitat is continuously declining in area and quality (bii) (Box 1). The evaluation for criteria A and C also complied with Endangered (EN), hence the criteria documentation is A2c + 3c + 4c; B2ab(iii); C1 + 2a(i) (Box 1)

Criterion C: small population size and decline

This criterion covers populations that are numerically small and are experiencing a continuing decline of smaller magnitude than needed to qualify under criterion A (Table 2, Fig 3). The threshold values for the number of mature individuals are derived from minimum values for viable populations. Criterion C1 requires the rate of decline to be quantified. If the decline cannot be measured or is not sufficiently severe to comply with C1, criterion C2 may be used. The C2 criterion may be met if in addition to a non-quantified continuous decline, each subpopulation/location of the species consists of few mature individuals. Based on many years of field experience, this condition is often fulfilled for fungi because locations of many species typically consist of only a few fruiting mycelia, i.e. functional individuals. The population of citrine waxcap *Hygrocybe citrinovirens* in Norway is assessed as having an ongoing decline of >20% in 2 generations (35 yrs). Its current total population in Norway is estimated at 120 functional individuals at 60 localities, i.e. it consists of small sub-populations (Box 1). Therefore it complies with Criteria C1+C2a(i) (Table 2).

Criterion D: very small population size

Species with very small population size may be listed as threatened under criterion D without evidence that there has been, is, or will be a population decline (Fig 3). Listing is justified from theoretical models showing that numerically small populations can have relatively high extinction risks solely from stochastic processes. Many fungi are known only from a few locations within a country, even after yrs of directed inventories and a putative understanding of their ecology. For such species, criterion D is appropriate if the threshold value of less than 1 000 mature individuals is met or if the species is restricted to such a small number of locations that the species may become 'Critically Endangered' or even 'Extinct' in a very short time (Table 2). As with criterion C, it is important to include both known occurrences with mature individuals and an estimate of the likely number of unrecorded individuals or localities to obtain an estimate of the likely total population. This criterion is typically based on the number of known localities together with an estimate of yet undetected localities multiplied by an estimate of the average number of individuals per location. In Denmark, blackening Chanterelle, *Cantharellus melanoxeros* is classified as Vulnerable (VU) due to small population size as the information about possible decline is missing (Box 1).

IUCN requires different levels of information quality to meet the standards for different criteria in the following falling scale: observed, estimated, projected, inferred, and suspected (see IUCN 2010). Estimated information is required for C and D, at least inferred information for C2, B1b and B2b and suspected for A. We consider our recommended operational protocols for calculating population sizes as estimations except for calculations of potential population sizes in the past and in the future which we treat as suspected (and therefore appropriate for criterion A).

Recommended guidelines for red-listing fungi

The diversity of national Red List initiatives clearly shows that the process can be conducted differently for each country or region based on the best available information and resources and that a more comprehensive process gradually can be developed.

Evaluations may be undertaken as private or organizational (NGO or institutional) initiatives and can be voluntary, grant or government funded. In all cases, it is essential to accumulate as much available knowledge as possible from amateurs and scientists to develop estimates as rigorous as possible on the number of locations, population size, threats, and present and estimated future status for each species being assessed. Even coarse national, regional or global data estimating the change of a species' substrata and habitat over time are of great help for inferring current and projected population size and location data. This procedure does not discount that an individual's expert knowledge, often based on considerable anecdotal experiences, can initially be very useful.

Direct analysis of current and past sporocarp observations

One approach that has been used for fungi is to compare the relative number of observations for a particular species over time in relation to the observations of all other fungal species over that time. This procedure requires substantial historical records, but it has been used successfully in the Netherlands and UK (Evans 2007; Arnolds & Veerkamp 2008). This is done by comparing the number of map grids (5×5 km in the Netherlands and 10×10 km in UK) in which a certain species has been recorded during different time intervals (see e.g. Arnolds 2010). The advantage of this approach is that it is based exclusively on real observations. The disadvantages are that few countries have sufficient observations over time and that the correlation between changing number of grids and population may vary largely among different areas, species and over time. Additionally, not all species are equally as likely to be recorded due to size, color, ephemeral fruiting, etc., so their relative frequency compared to other species may be skewed.

Indirect analysis of sporocarp occurrences together with species autecology and habitat data

In fungi, as with most organisms, measurements of population sizes and their trends over time have to be done indirectly due to difficulties in monitoring multiple individuals within multiple subpopulations over time. In these cases, one infers the total population size over time by using knowledge of the species' ecology combined with the past, current and estimated future extent of appropriate habitat (criteria A, B and D2) or, when possible, combined with sporocarp observations to infer functional individuals (criteria A, B, C and D). In both cases, field observations of the number of known and the likely total number of localities are essential for judging the geographic distribution and frequency of each species. The specific procedures depend on the amount of information that is available coupled with the available resources (e.g. number of competent people, time and other resources) to conduct analyses, interpret the results and, when possible, obtain additional data. The following recommended approach is also the most commonly used by biologists studying a wide variety of organisms (Table 3).

Selection of species to evaluate

Identify which taxa to evaluate. The selection of species to be evaluated depends on the situation. For example: (i) a selection of species that, given the best knowledge, may be threatened (e.g. as done in Italy, Russia and in progress in Benin); (ii) selected fungal genera or families; or (iii) as many groups as possible (e.g. in Austria, Germany, Nordic countries, Netherlands, Switzerland, etc.). If available, use a check-list or preliminary stages of check-lists, and then exclude species that will not qualify for red-listing: i.e. species for which too little information exists (NE); not native or lower taxonomic rank (NA); or populations that obviously are large and not declining and hence not threatened (LC) (Table 3). Classify the species for which there is no information about their current status or possible threats as data deficient (DD). This will significantly reduce the number of species needing to be more carefully evaluated. Each species evaluation will require compiling information and making judgments, so selecting fewer species to be more carefully evaluated will lessen the work required. If time permits, it will be valuable to assess and document the data for species classified as LC.

Divide the evaluation into two parts. First, gather and critically analyze the required information. Then evaluate the accumulated data for each of the criteria and assign a threat level.

Identify and estimate amount of appropriate habitat

Knowledge accumulated by amateurs, NGOs, governmental surveys and professional scientists has increasingly revealed the distribution and ecological requirements of fungal species. This knowledge can be combined with information on the occurrence and extent of appropriate habitat to infer the extent of current, and possibly past and future, potentially appropriate habitat. Habitat estimates may be based on official statistics of habitat conditions and documented and projected changes in the area of that habitat over time, e.g. national forest surveys, national agricultural statistics or regional compilations such as those conducted by the European Environmental Agency (www.eea.europa.eu). The spatial resolution of such statistics may not be sufficient to relate well to habitat requirements of specific fungal species, but they will likely provide sufficient data to enable reasonable inferences. We strongly encourage the use of such official statistics rather than unreferenced estimates of habitat change, to strengthen the evaluation. Changing habitat quality, often declining, should be considered as well as complete loss of habitat.

Table 3 – Step-by-step process to red-listing fungi. Careful consideration of steps 1–4 will reduce the number of species to be evaluated, and hence the amount of work

Step 1. ***Exclude*** groups of species with far too little information to be evaluated and let them remain as **NE** (Not Evaluated). When possible, try to evaluate whole groups, e.g. genera, but if unfeasible let single species within otherwise evaluated fungal groups remain as **NE**.

Step 2. ***Exclude*** species that are not eligible to red list within the region, such as species that were introduced after a decided year (such as 1800) or with too low taxonomic rank to be eligible (such as subspecies or variety). Categorize these as **NA** (Not Applicable)

Step 3. ***Exclude*** species that with high certainty can be judged as **LC** (Least Concern), these typically are common species where nothing indicates that their populations have, are or will be declining.

Step 4. ***Classify*** species where there is insufficient information available to adequately assess their conservation status as **DD (**Data Deficient).

Step 5. ***Evaluate*** the remaining species according to the IUCN red-list criteria and the suggested operational methods for fungi outlined in this article.

Step 6. ***Estimate the current population size***. This can be based on either

a A judgment or estimation of total number of localities or geographical grids (known plus an estimation of the unrecorded number), appropriate for Criteria A, B and D2, *or*

b Translation of the estimated total number of localities to an estimation of the total number of mature individuals in two steps, appropriate for Criteria A, B, C, and D;

i Calculate the number of functional individuals (Estimation of total number of localities × estimation of the average number of functional individuals/locality)

ii. Convert the number of functional individuals into mature individuals using the suggested templates.

Note, both under a and b, that it is appropriate to use an estimation of the total amount of appropriate habitat for a species in combination with its frequency to obtain an estimate of the total population size of a species.

Step 7. ***Identify and characterize the ecology of the species***.

a No obvious pattern or disparate ecology. Difficult to evaluate. If estimated population size is small, consider red-listing based on criterion D. If not,
reconsider population estimation at Step 4 and consider LC or Data Deficient (DD) as possible result.

b Distinct ecology

i Extremely rare, – evaluate under criterion D

ii. More "common" continue to Step 8

Step 8. Use statistics or other estimates to assess the status and trends of the potential habitat and substrata for the species over time (past to future).

a No negative trend – classify as Least Concern (LC).

b Negative trend – red-list with appropriate criteria (or classify as LC if the population is large and the decline <15 %)

Estimate the number of localities and functional individuals

It is important to take into account both known localities as well as an estimate of unrecorded localities to obtain an estimate of the likely total number of localities. The likely number of localities can be used directly as an estimate of the population size (Criteria A, B and D2). When possible, convert the information into an estimate of the likely number of functional individuals. This is done by using the combined documented and anecdotal data for the typical number of functional individuals per locality. For many red-listed species there are typically few functional individuals per locality (see examples in Box 1). In the absence of better information, we suggest that the number of functional fungal individuals be considered constant per unit area of appropriate habitat over time. Finally, convert the number of functional individuals into mature individuals according to our suggestions above so that the figures can be used in the IUCN system.

Evaluate the accumulated data for each of the criteria and assign a threat level

The criterion that indicates the highest threat level should be used. If more than one criterion is met, all should be used in the documentation. It may be useful and appropriate to compare the results of evaluations of other species of the same lifeform and ecology in the same habitat to the species being considered as they may be closely related in threat status.

Provide documentation

Irrespective of how the assessments are conducted, it is critically important that all Red List evaluations have written public documentation to support the basis for the classification. The documentation should provide brief information on the underlying ecology, distribution, threats, and status (past, present and projected if appropriate) of the species (Box 1). This will provide credibility and facilitate critical examination of the data and assumptions used to enable subsequent evaluations to be improved. Evaluations are not "final" and the conservation threat to species should be reassessed periodically as new data become available and as conditions change.

Conclusion

Red Lists document the conservation status of individual species and enable the analysis of trends indicating the general state of biodiversity at national, regional, or global scales. Red Lists, therefore, provide invaluable data for conservation decisions at national to global levels. By employing common criteria for evaluations, the approach used by IUCN permits the status of diverse organisms, and from different countries, to be compiled, compared and analyzed together or in a similar manner. This enables political conservation decisions to consider all types of species including inconspicuous relatively poorly known ones. Fungi have not been included in these decisions at the regional, global, or often-times national level as fungi have too infrequently been included in national Red Lists and have not been part of regional or global efforts. This situation must change, and we prepared this manuscript with the hope that our recommendations will make red-listing fungi following IUCN criteria tractable and accepted as it is for most groups of plants and animals. Fungal conservation efforts and research initiatives are synergistic activities. Red-listing efforts identify research needs. New research data will provide information needed to refine our interpretation of concepts such as mature individual and generation time as well as provide more robust estimates of the distribution, frequency and ecology of fungal species and threats to their continued existence. Finally, an increased focus on fungal conservation will raise the profile of fungi in the minds of politicians, land managers, other conservation biologists and the general public which will facilitate the inclusion of fungi in discussion on biodiversity and conservation, and enable the inclusion of fungi in conservation decisions.

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