Mushrooms I have known

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This version: March 21, 2019

Dedicated to Rosa and Rianne

Warnings

- All mushrooms are edible – but some, only once
- There are old mushroom hunters, and bold mushroom hunters … but there are no old bold mushroom hunters

Fungi

- Closer to animals than plants
- The thing you see above ground (that you call a “mushroom”) is just a temporary reproductive organ
- See Wikipedia (next few slides)

De **grote stinkzwam** (*Phallus impudicus*) is een paddenstoel uit de familie *Phallaceae*

Phallus impudicus, known colloquially as the **common stinkhorn**, is a widespread fungus recognizable for its foul odor and its phallic shape when mature, the latter feature giving rise to several names in 17th-century England.

Fungi

Temporal range: Early Devonian–Present (but see text) 410–0 Ma

Clockwise from top left:

Amanita muscaria, a basidiomycete;

Sarcoscypha coccinea, an ascomycete;

bread covered in mold;

a chytrid;

an *Aspergillus* conidiophore.

Wikipedia: “fungus”

A **fungus** (plural: **fungi**[3] or **funguses**[4]) is any member of the group of eukaryotic organisms that includes microorganisms such as yeasts and moulds, as well as the more familiar mushrooms. These organisms are classified as a kingdom, fungi, which is separate from the other eukaryotic life kingdoms of plants and animals.

A characteristic that places fungi in a different kingdom from plants, bacteria, and some protists is chitin in their cell walls. Similar to animals, fungi are heterotrophs; they acquire their food by absorbing dissolved molecules, typically by secreting digestive enzymes into their environment. Fungi do not photosynthesise. Growth is their means of mobility, except for spores (a few of which are flagellated), which may travel through the air or water. Fungi are the principal decomposers in ecological systems. These and other differences place fungi in a single group of related organisms, named the *Eumycota* (*true fungi* or *Eumycetes*), which share a common ancestor (form a *monophyletic group*), an interpretation that is also strongly supported by molecular phylogenetics. This fungal group is distinct from the structurally similar myxomycetes (slime moulds) and oomycetes (water moulds). The discipline of biology devoted to the study of fungi is known as mycology (from the Greek μύκης *mykes*, mushroom). In the past, mycology was regarded as a branch of botany, although it is now known fungi are genetically more closely related to animals than to plants.

https://www.sciencedaily.com/releases/2006/10/061021115712.htm

Discovery About Evolution Of Fungi Has Implications For Humans

Date: October 23, 2006

Source: University of Minnesota

Summary: A University of Minnesota researcher says as early fungi made the evolutionary journey from water to land and branched off from animals, they shed tail-like flagella that propelled them through their aquatic environment and evolved a variety of new mechanisms, including explosive volleys and fragrances, to disperse their spores and reproduce in a terrestrial setting.

FULL STORY

As early fungi made the evolutionary journey from water to land and branched off from animals, they shed tail-like flagella that propelled them through their aquatic environment and evolved a variety of new mechanisms (including explosive volleys and fragrances) to disperse their spores and reproduce in a terrestrial setting.

nature
International journal of science

Article | Published: 19 October 2006

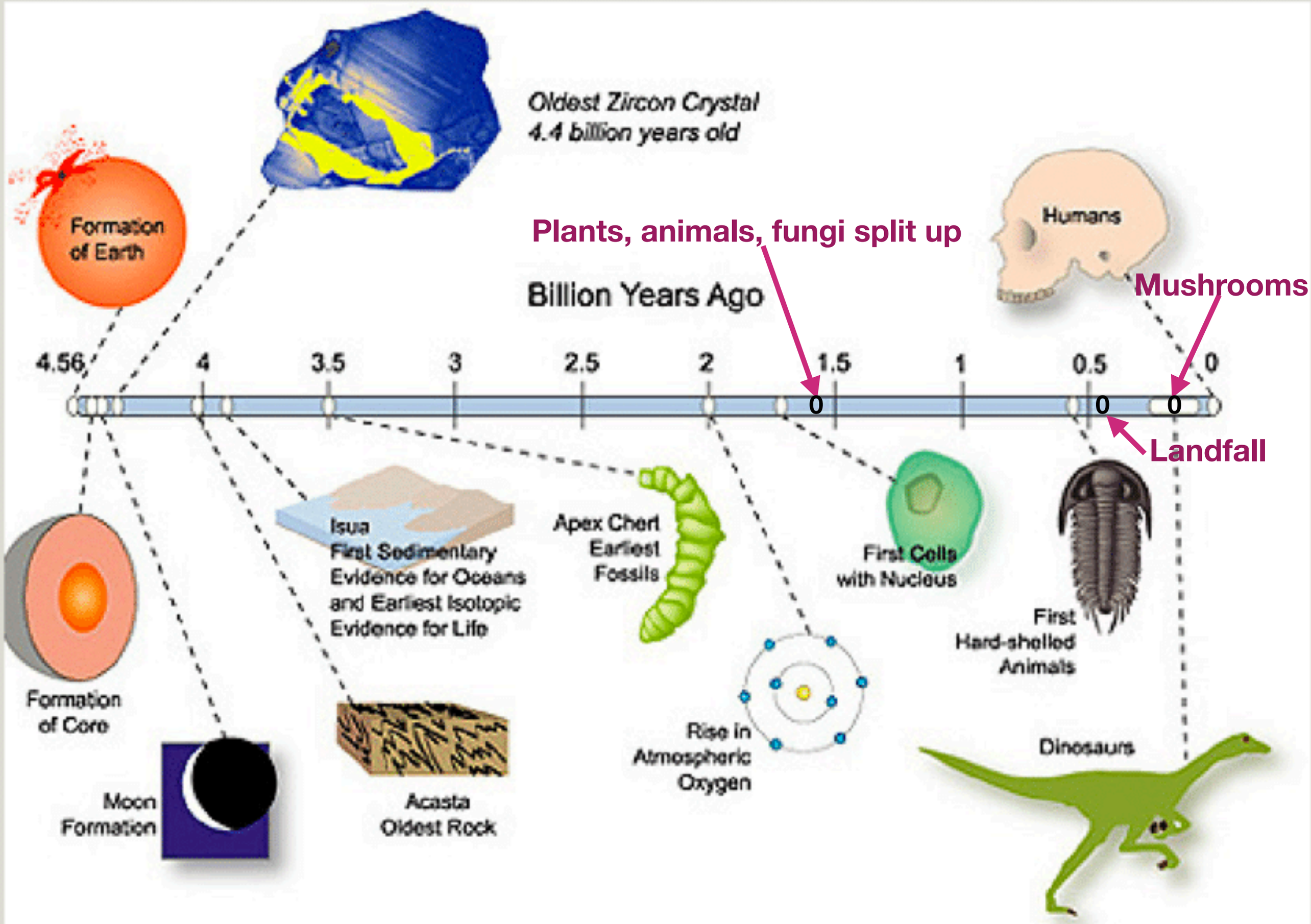
Reconstructing the early evolution of Fungi using a six-gene phylogeny

Timothy Y. James, Frank Kauff [...] Rytas Vilgalys

Nature **443**, 818–822 (19 October 2006) | Download Citation

https://doi.org/10.1038/nature05110

Fungi are also intriguing because their cells are surprisingly similar to human cells, McLaughlin said. In 1998 scientists discovered that fungi split from animals about 1.538 billion years ago, whereas plants split from animals about 1.547 billion years ago. This means fungi split from animals 9 million years after plants did, in which case fungi are actually more closely related to animals than to plants. The fact that fungi had motile cells propelled by flagella that are more like those in animals than those in plants, supports that.


Oldest Zircon Crystal
4.4 billion years old
Formation of Earth
Plants, animals, fungi split up
Humans
Mushrooms
Billion Years Ago
4.56
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Landfall
Isua
First Sedimentary Evidence for Oceans and Earliest Isotopic Evidence for Life
Apex Chert
Earliest Fossils
First Cells with Nucleus
First Hard-shelled Animals
Formation of Core
Moon Formation
Acasta
Oldest Rock
Rise in Atmospheric Oxygen
Dinosaurs

Some famous fungi

- In penicillin, blue cheese, yoghurt, …
- Yeast (beer, bread, wine, …)
- *Zwemmers eczeem* – Athlete's foot
- The largest living organism on the planet?

Armillaria ostoyae

- Alleged cause of death of: Buddha, Emperor Claudius, Hapsburg emperor Charles VI, Julius Schäffer, …
- Digests and recycles animal and plant remains; lives in symbiotic relation with plants and trees, animals, …

Deadly webcap (*Cortinarius rubellus*)

Fraaie gifgordijnzwam

Deadly webcap appears between August and November in conifer and spruce woods. (Photo: Alamy)

Death cap (*Amanita phalloides*)

Groene knolamaniet

Death cap is responsible for most fatal mushroom poisonings around the world. (Photo: Alamy/Wolstenholme Images)

Destroying angel (*Amanita virosa*)

Kleverige knolamaniet

Beautiful but dangerous. Destroying angel can be found in mixed broadleaf and birch woodland. (Photo: Alamy)

Funeral bell (*Galerina marginata*)

Bundelmosklokje

The ominous sounding funeral bell appears on dead and decaying wood. (Photo: Alamy)

Fool's funnel (*Clitocybe rivulosa*)

Weidetrechterzwam

Also known as the sweating mushroom, fool's funnel occurs in grassy areas. (Photo: iStock)

Panther cap (*Amanita pantherina*)

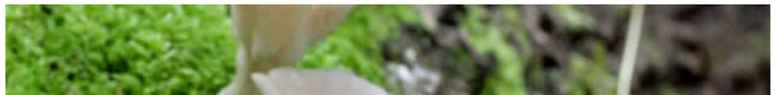
Panteramaniet

Panther cap is the sinister but less common sister to fly agaric. (Photo: Alamy)

Poisonous mushrooms: 7 most dangerous in UK

Angel's wings (*Pleurocybella porrigens*)

????????



https://www.woodlandtrust.org.uk/blog/2018/11/poisonous-mushrooms/

My two favourites

- Amanita muscaria - *fly agaric* [*vliegenzwam*]
- Omphalotus olearius [?] - *jack-o'-lantern mushroom* [*lantaarnzwam*]

Photos:
below: Wikipedia;
above: mine

Amanita from Ancient Greek ἀμανίτης (*amanítēs*), mushrooms.

Musca from the name of the common house fly, *musca domestica*

Amanita muscaria

I have a great deal to say about Amanita muscaria – result of many years research, observation.

This creature is not bright red with white spots for nothing!

Omphalotus from the Byzantine Greek ὀμφαλοειδής, meaning "navel"

Olearius from *oleum* (“olive oil”) + *-ārius*

Omphalotus olearius [?]

I think I found Omphalotus olearius in my garden, a year ago; and this winter it returned (same time, same place).

I fear it is poisonous.

Omphalotus olearius

Scientific classification

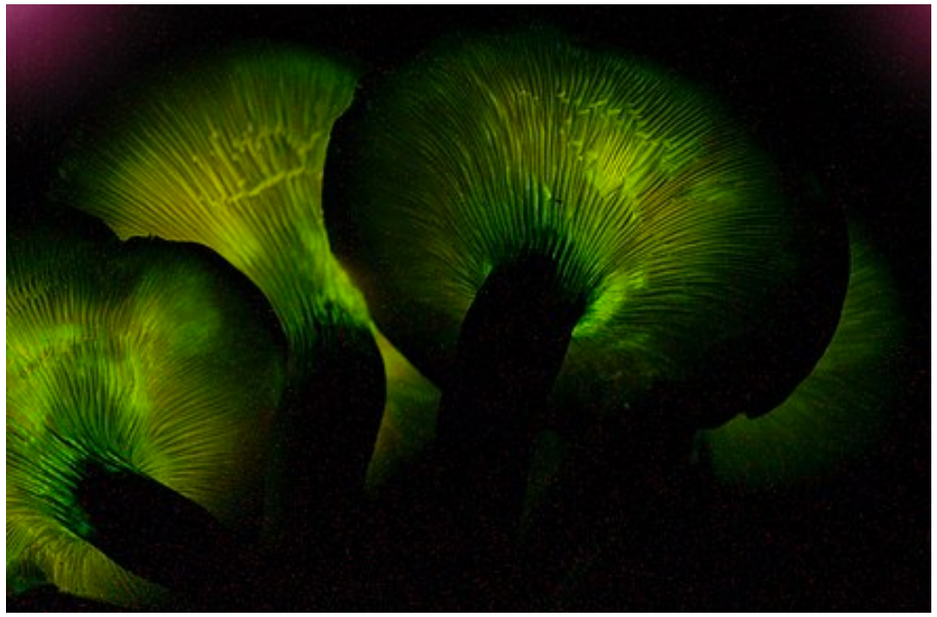
Kingdom:	Fungi
Division:	Basidiomycota
Class:	Agaricomycetes
Order:	Agaricales
Family:	Marasmiaceae
Genus:	*Omphalotus*
Species:	***O. olearius***

Binomial name

Omphalotus olearius
(DC.) Sing. (1948)

Synonyms[1]

- *Agaricus olearius* DC. (1815)
- *Agaricus olearius* subsp. *phosphoreus* Battarra ex Pers. (1828)
- *Dryophila phosphorea* (Battarra ex Pers.) Quél. (1888)
- *Clitocybe olearia* (DC.) Maire (1933)
- *Clitocybe phosphorea* (Battarra ex Pers.) Bohus (1957)



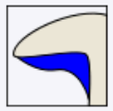
Wikipedia

Omphalotus olearius

Mycological characteristics

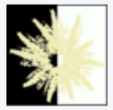
gills on hymenium

cap is **infundibuliform**



hymenium is **decurrent**

stipe is **bare**

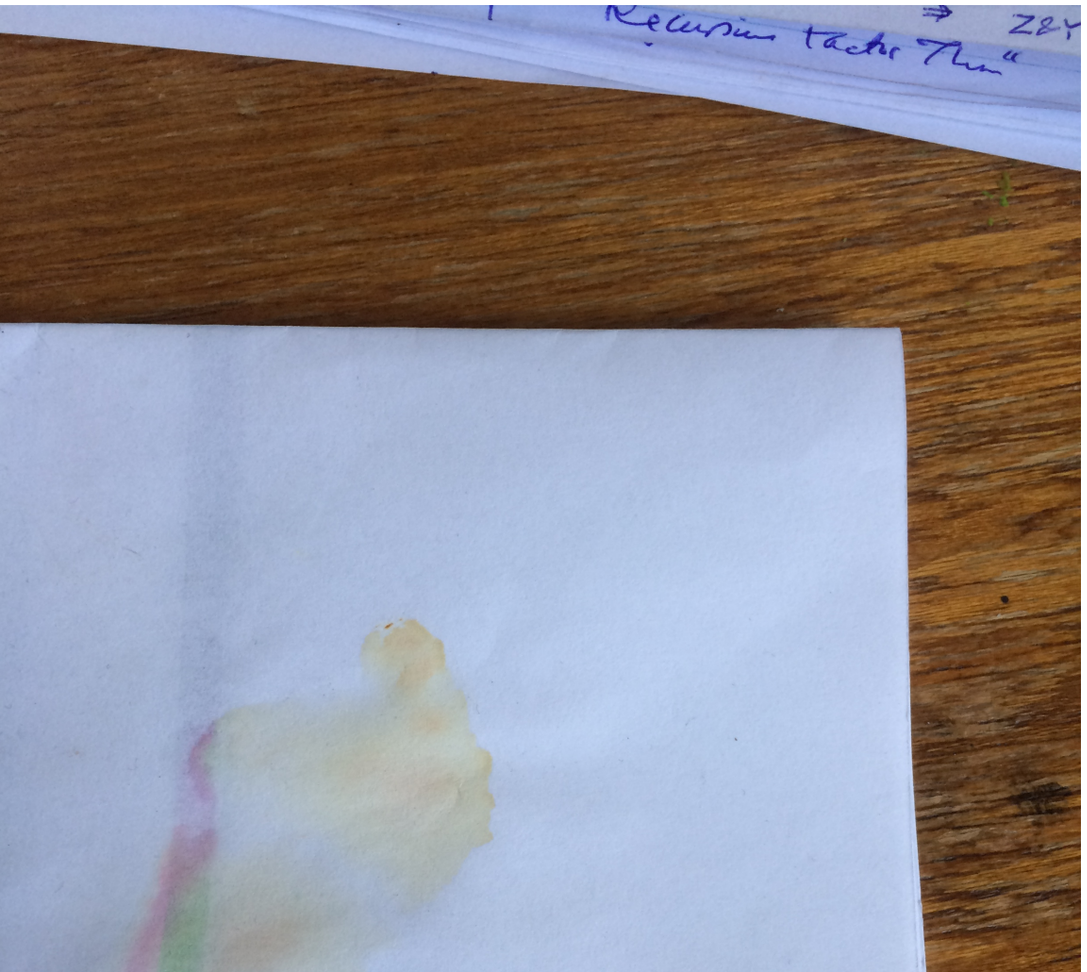


spore print is **yellow**

ecology is **saprotrophic**

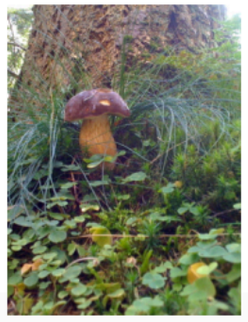
edibility: **poisonous**

My photos



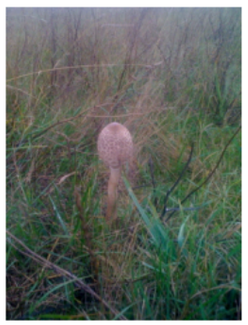
Gallery

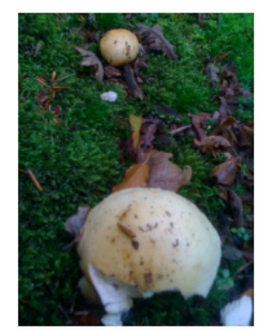
- 10 years of mushroom hunting (6 slides, 35 pictures per slide)

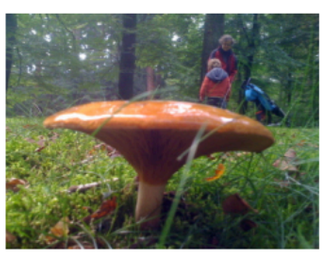


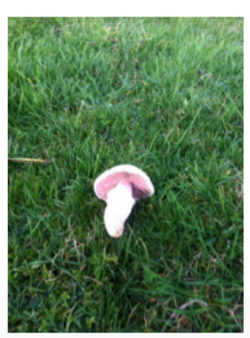
Mushrooms (1 of 6)

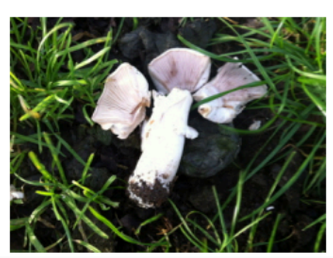
June 2009 – February 2019 209 Photos

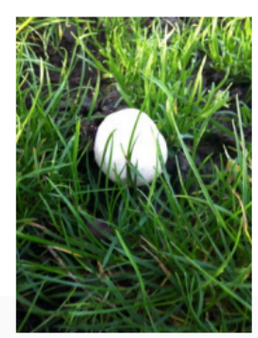












Mushrooms (2 of 6)

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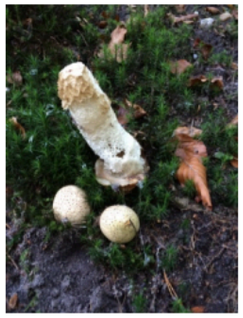
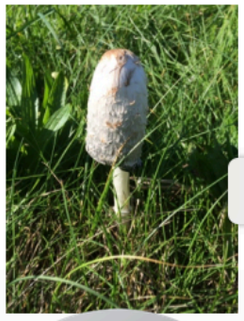
Showing: All Items





Mushrooms (3 of 6)

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Mushrooms (4 of 6)

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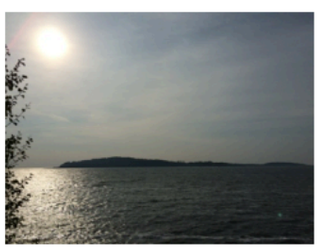

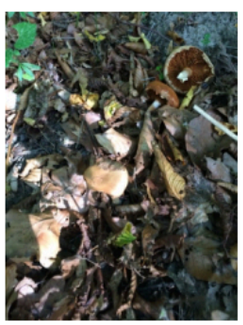
















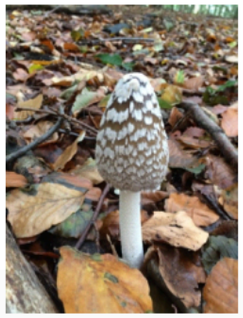





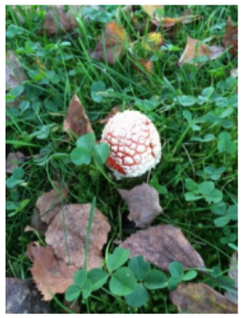

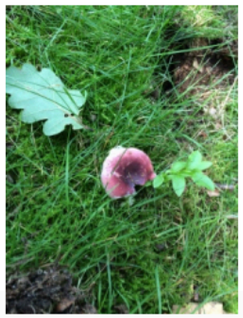

Mushrooms (5 of 6)

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Mushrooms (6 of 6)

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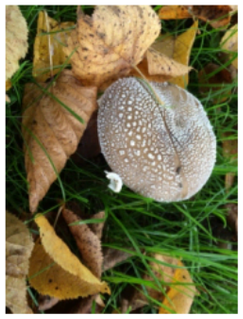
Showing: All Items











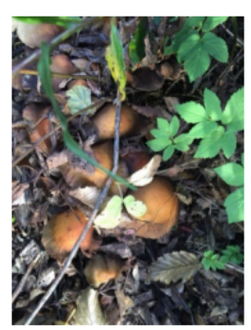


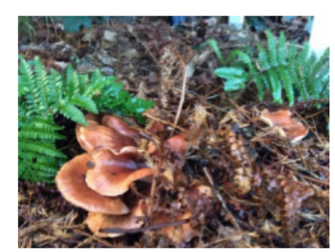
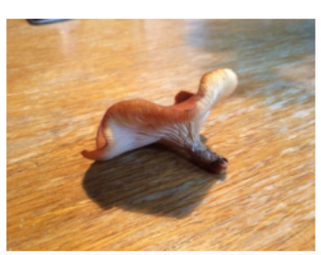
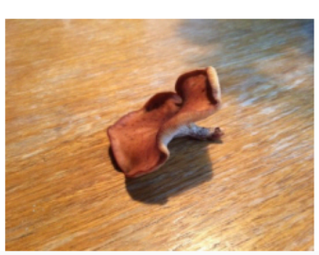
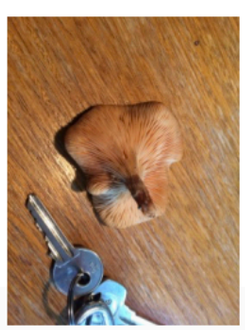











Want to learn more about the joys of mushroom hunting?

- Go out in the fields or forests with someone with a great deal of experience.
- Never pick a mushroom if you don’t have to.
- A photograph is not enough to identify a mushroom.
  Learn about the *important* distinguishing characteristics.
- Never eat a mushroom if you are not *absolutely* certain you have identified it correctly. Be patient. They’ll come again next year, same time, same place.
- Coffee-table books full of large glossy photographs are not much use.
- Internet is wonderful but not everything you read there is true.
- Mushrooms *and* people are natural living beings. Variation is “built in”, and it’s enormous.

Thank you!

- Any questions?
- http://www.math.leidenuniv.nl/~gill
- Slideshare: gill1109

Extras

- Various topics for discussion and further research

Fungi and …

Data science
Big data
Machine learning
AI
Bayesian statistics

Nature:

https://doi.org/10.1038/nature05110

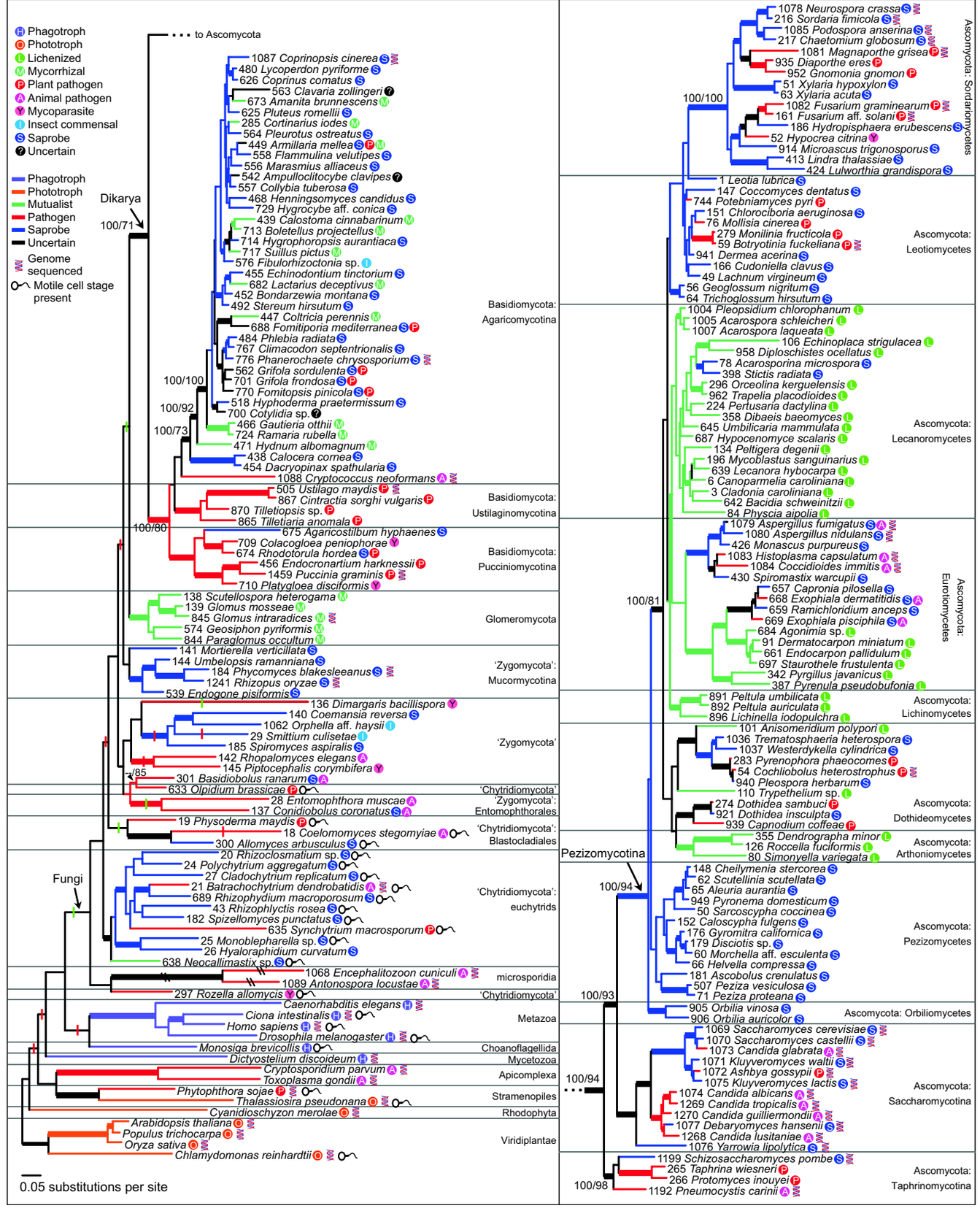
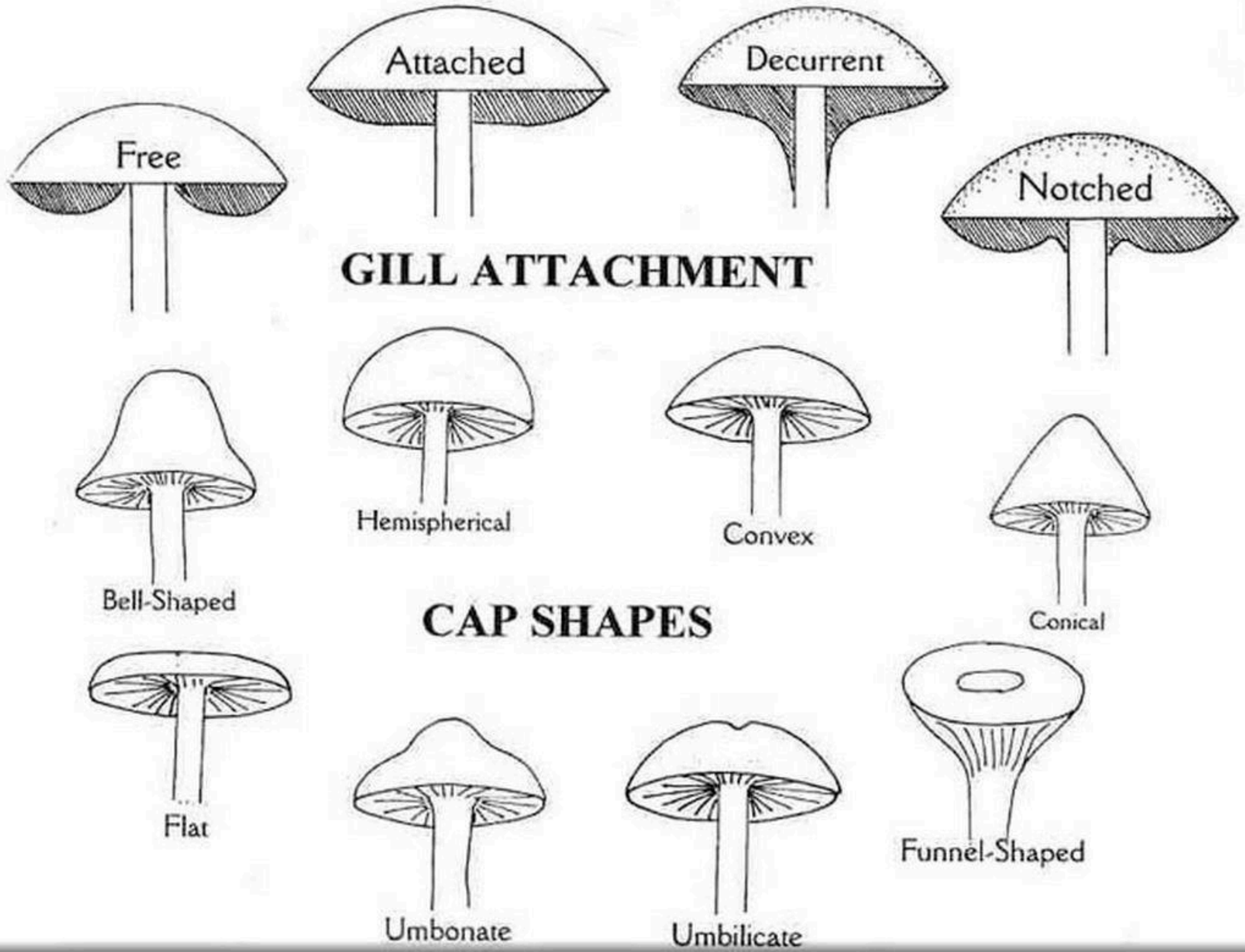


Figure 1 | Phylogeny of the kingdom Fungi using bayesian analysis of the combined, six-gene data set. Each fungal species begins with a unique 'Assembling the Fungal Tree of Life' identifier, followed by genus and species. Indicated for each terminal taxon are: nutritional mode, whether they produce flagellated cells and if there is a genome sequence for the taxon completed or underway. Thickened branches indicate those that are supported both by heterogeneous bayesian analysis (BPP ≥95%) and by MLBS (≥70%). Almost every branch was supported by BPP and thus values are not shown. Where indicated, support values (percentage of trees in agreement out of 58,611 trees) indicate BPP followed by MLBS. Branches are shaded according to reconstruction of nutritional mode. Microsporidia branches have been shortened three times (double black break) to increase readability. Red vertical ticks on branches indicate alternative placements of microsporidia that might be significantly rejected ($P < 0.05$) and green ticks indicate placements that cannot be rejected. Quotation marks indicate non-monophyly of the taxon. The name 'Mucormycotina' will be validated in a manuscript that is in preparation.

FEATURES OF MUSHROOMS USED FOR IDENTIFICATION



Mushroom Identify - Automatic picture recognition

Annapurnapp Technologies Tools

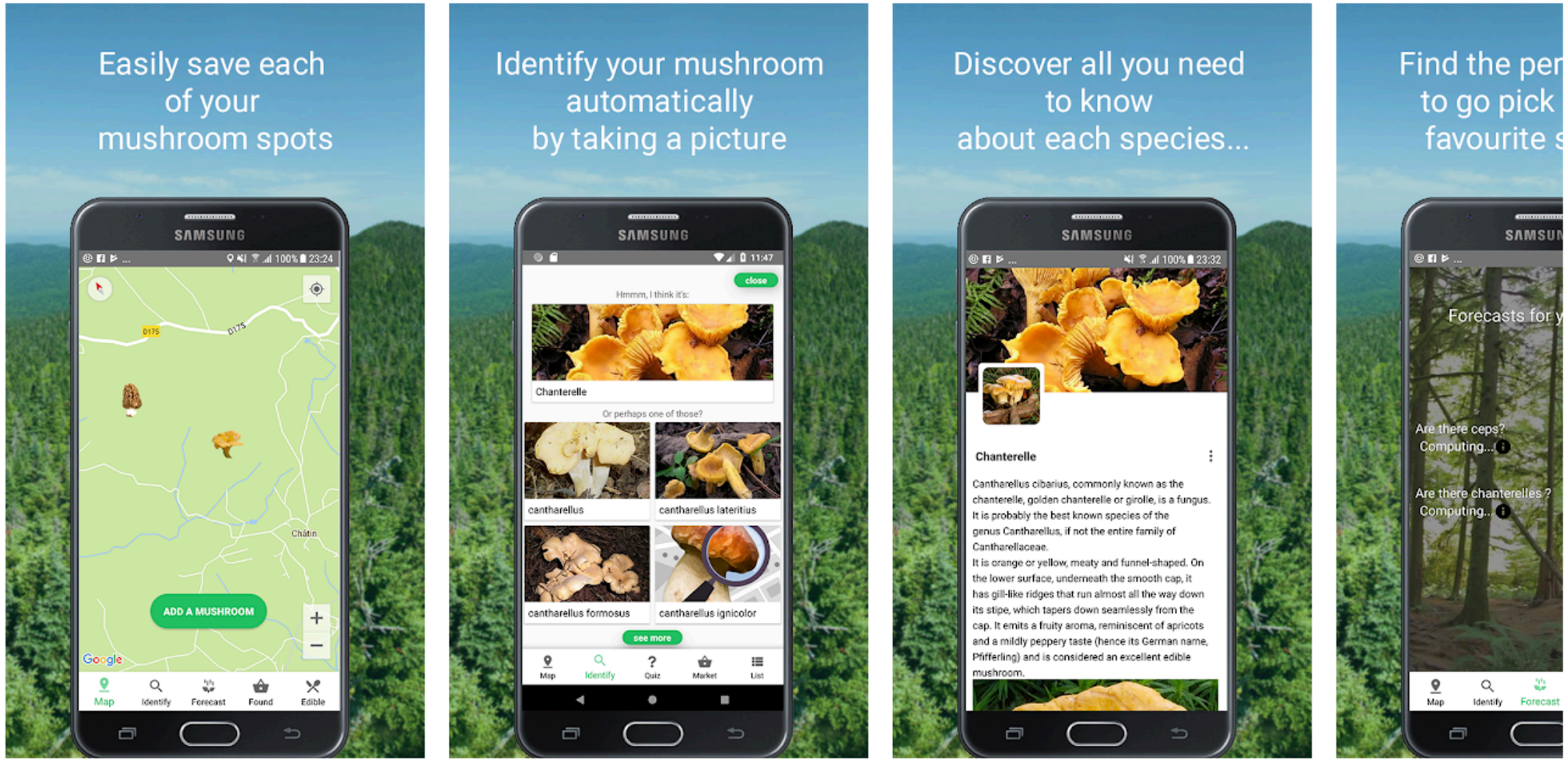
4,456

PEGI 3

Contains Ads · Offers in-app purchases

You don't have any devices.

Add to Wishlist Install



A ‘potentially deadly’ mushroom-identifying app highlights the dangers of bad AI

The app’s creator says it’s just a guide, but experts aren’t happy

By James Vincent | Jul 28, 2017, 7:11am EDT

Missing Mushrooms

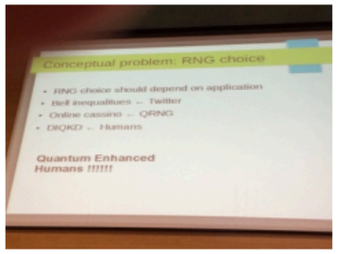
February 2019 27 Photos Show as Memory Slideshow Showing: All Items





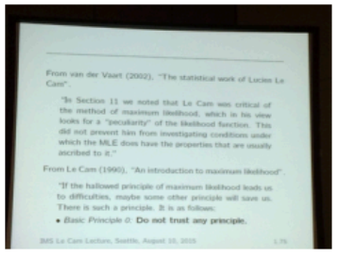








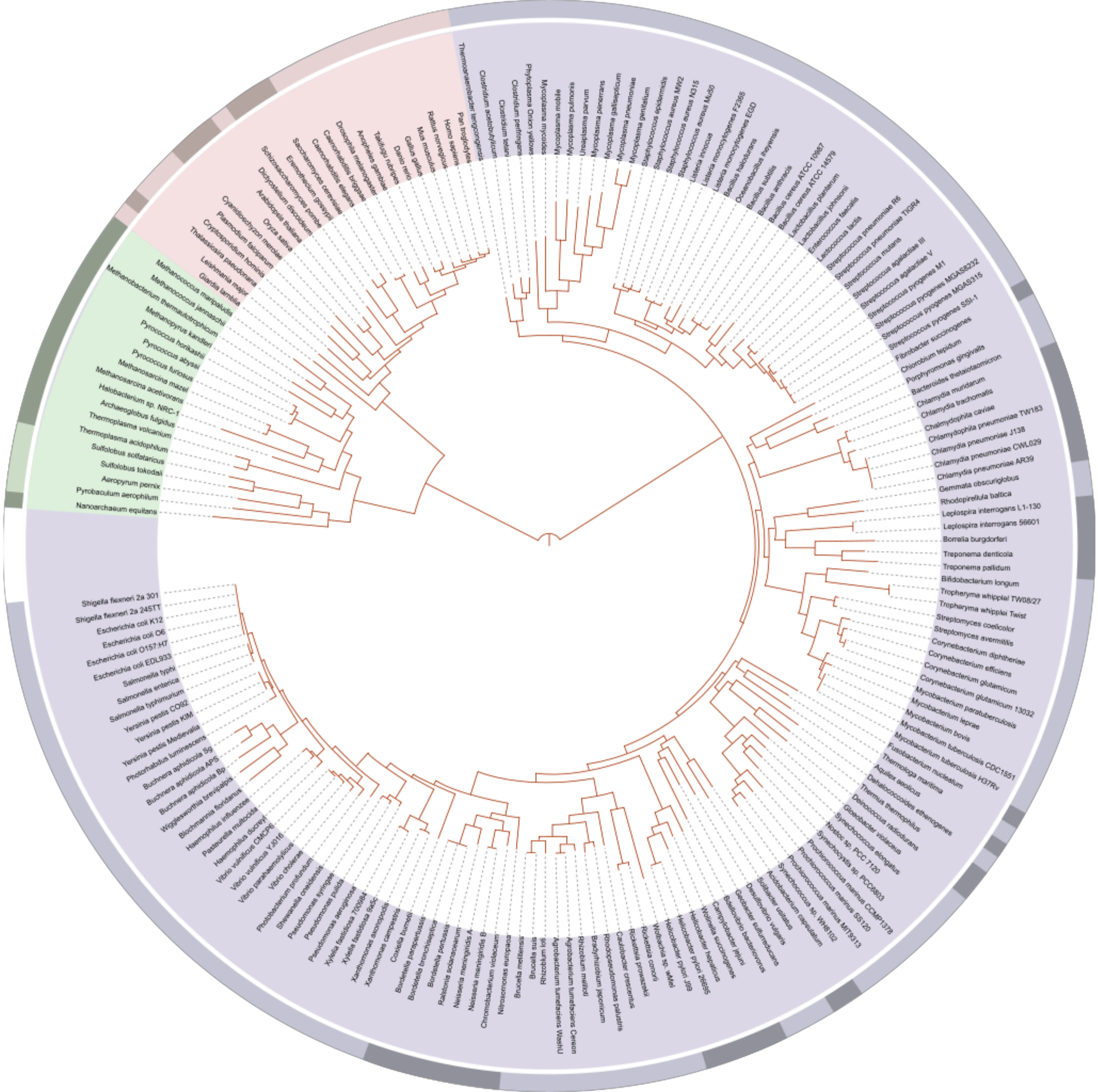











Thermoanaerobacter tengcongensis
Clostridium acetobutylicum
Clostridium tetani
Clostridium perfringens
Phytoplasma Onion yellows
Mycoplasma mycoides
Mycoplasma mobile
Mycoplasma pulmonis
Ureaplasma parvum
Mycoplasma penetrans
Mycoplasma gallisepticum
Mycoplasma pneumoniae
Mycoplasma genitalium
Staphylococcus epidermidis
Staphylococcus aureus MW2
Staphylococcus aureus N315
Staphylococcus aureus Mu50
Listeria innocua
Listeria monocytogenes F2365
Listeria monocytogenes EGD
Bacillus halodurans
Oceanobacillus iheyensis
Bacillus subtilis
Bacillus anthracis
Bacillus cereus ATCC 10987
Bacillus cereus ATCC 14579
Lactobacillus plantarum
Lactobacillus johnsonii
Enterococcus faecalis
Lactococcus lactis
Streptococcus pneumoniae R6
Streptococcus pneumoniae TIGR4
Streptococcus mutans
Streptococcus agalactiae III
Streptococcus agalactiae V
Streptococcus pyogenes M1
Streptococcus pyogenes MGAS8232
Streptococcus pyogenes MGAS315
Streptococcus pyogenes SSI-1
Streptococcus suis
Streptococcus succinogenes
Fibrobacter succinogenes
Chlorobium tepidum
Porphyromonas gingivalis
Bacteroides thetaiotaomicron
Chlamydia muridarum
Chlamydia trachomatis
Chlamydophila caviae
Chlamydophila pneumoniae TW183
Chlamydophila pneumoniae J138
Chlamydia pneumoniae CWL029
Chlamydia pneumoniae AR39
Gemmata obscuriglobus
Rhodopirellula baltica
Leptospira interrogans L1-130
Leptospira interrogans 56601
Borrelia burgdorferi
Treponema denticola
Treponema pallidum
Bifidobacterium longum
Tropheryma whipplei TW08/27
Tropheryma whipplei Twist
Streptomyces coelicolor
Streptomyces avermitilis
Corynebacterium diphtheriae
Corynebacterium efficiens
Corynebacterium glutamicum
Corynebacterium glutamicum 13032
Mycobacterium paratuberculosis
Mycobacterium leprae
Mycobacterium bovis
Mycobacterium tuberculosis CDC1551
Mycobacterium tuberculosis H37Rv
Fusobacterium nucleatum
Thermotoga maritima
Aquifex aeolicus
Dehalococcoides ethenogenes
Thermus thermophilus
Deinococcus radiodurans
Gloeobacter violaceus
Synechococcus elongatus
Nostoc sp. PCC 7120
Synechocystis sp. PCC6803
Prochlorococcus marinus CCMP1378
Prochlorococcus marinus SS120
Prochlorococcus marinus MIT9313
Synechococcus sp. WH8102
Synechococcus elongatus
Acidobacterium capsulatum
Solibacter usitatus
Desulfovibrio vulgaris
Geobacter sulfurreducens
Bdellovibrio bacteriovorus
Campylobacter jejuni
Wolinella succinogenes
Helicobacter hepaticus
Helicobacter pylori J99
Helicobacter pylori 26695
Wolbachia sp. wMel
Rickettsia conorii
Rickettsia prowazekii
Caulobacter crescentus
Rhodopseudomonas palustris
Bradyrhizobium japonicum
Rhizobium meliloti
Agrobacterium tumefaciens Cereon
Agrobacterium tumefaciens WashU
Brucella suis
Brucella melitensis
Rhizobium loti
Nitrosomonas europaea
Chromobacterium violaceum
Neisseria meningitidis A
Neisseria meningitidis B
Ralstonia solanacearum
Bordetella pertussis
Bordetella bronchiseptica
Bordetella parapertussis
Coxiella burnetii
Xanthomonas campestris
Xanthomonas axonopodis
Xylella fastidiosa 9a5c
Xylella fastidiosa 700964
Pseudomonas aeruginosa
Pseudomonas putida
Pseudomonas syringae
Shewanella oneidensis
Photobacterium profundum
Vibrio cholerae
Vibrio parahaemolyticus
Vibrio vulnificus YJ016
Vibrio vulnificus CMCP6
Haemophilus ducreyi
Haemophilus influenzae
Pasteurella multocida
Blochmannia floridanus
Wigglesworthia brevipalpis
Buchnera aphidicola Bp
Buchnera aphidicola APS
Buchnera aphidicola Sg
Photorhabdus luminescens
Yersinia pestis Medievalis
Yersinia pestis KIM
Yersinia pestis CO92
Salmonella typhimurium
Salmonella enterica
Salmonella typhi
Escherichia coli EDL933
Escherichia coli O157:H7
Escherichia coli O6
Escherichia coli K12
Shigella flexneri 2a 245TT
Shigella flexneri 2a 301
Nanoarchaeum equitans
Pyrobaculum aerophilum
Aeropyrum pernix
Sulfolobus tokodaii
Sulfolobus solfataricus
Thermoplasma acidophilum
Thermoplasma volcanium
Archaeoglobus fulgidus
Halobacterium sp. NRC-1
Methanosarcina acetivorans
Methanosarcina mazei
Pyrococcus furiosus
Pyrococcus abyssi
Pyrococcus horikoshii
Methanopyrus kandleri
Methanothermobacter thermautotrophicus
Methanococcus jannaschii
Methanococcus maripaludis
Methanococcus vannielii
Giardia lamblia
Leishmania major
Trypanosoma cruzi
Thalassiosira pseudonana
Cryptosporidium hominis
Plasmodium falciparum
Cyanidioschyzon merolae
Oryza sativa
Arabidopsis thaliana
Dictyostelium discoideum
Schizosaccharomyces pombe
Saccharomyces cerevisiae
Encephalitozoon cuniculi
Caenorhabditis elegans
Drosophila melanogaster
Anopheles gambiae
Takifugu rubripes
Danio rerio
Gallus gallus
Mus musculus
Rattus norvegicus
Homo sapiens
Pan troglodytes

2) Tell us where in the World you are? Location can be VERY important.

3) Take pictures of:
- top of the cap
- underside of the cap
- stipe (preferably the whole stipe with the base)
- if possible, a longitudinal section to see the context (flesh of the mushroom) and the attachment of the hymenium (gills, tubes, spines, etc) to the stipe'
- overview/side view
- as many different ages, from small buttons to worn out mushrooms
- spore print

3) Make sure that these pictures are:
- made preferably in situ (on location), but if that is not possible, then use a neutral background
- in the right white balance (colours of the picture should resemble the real colours in daylight)
- not too dark or over-exposed (preferably in daylight)
- sharp
- free of distracting elements like leafs, twigs, dirt etc. The specimen and characteristics have to be clearly visible

4) Always include the following in the description:

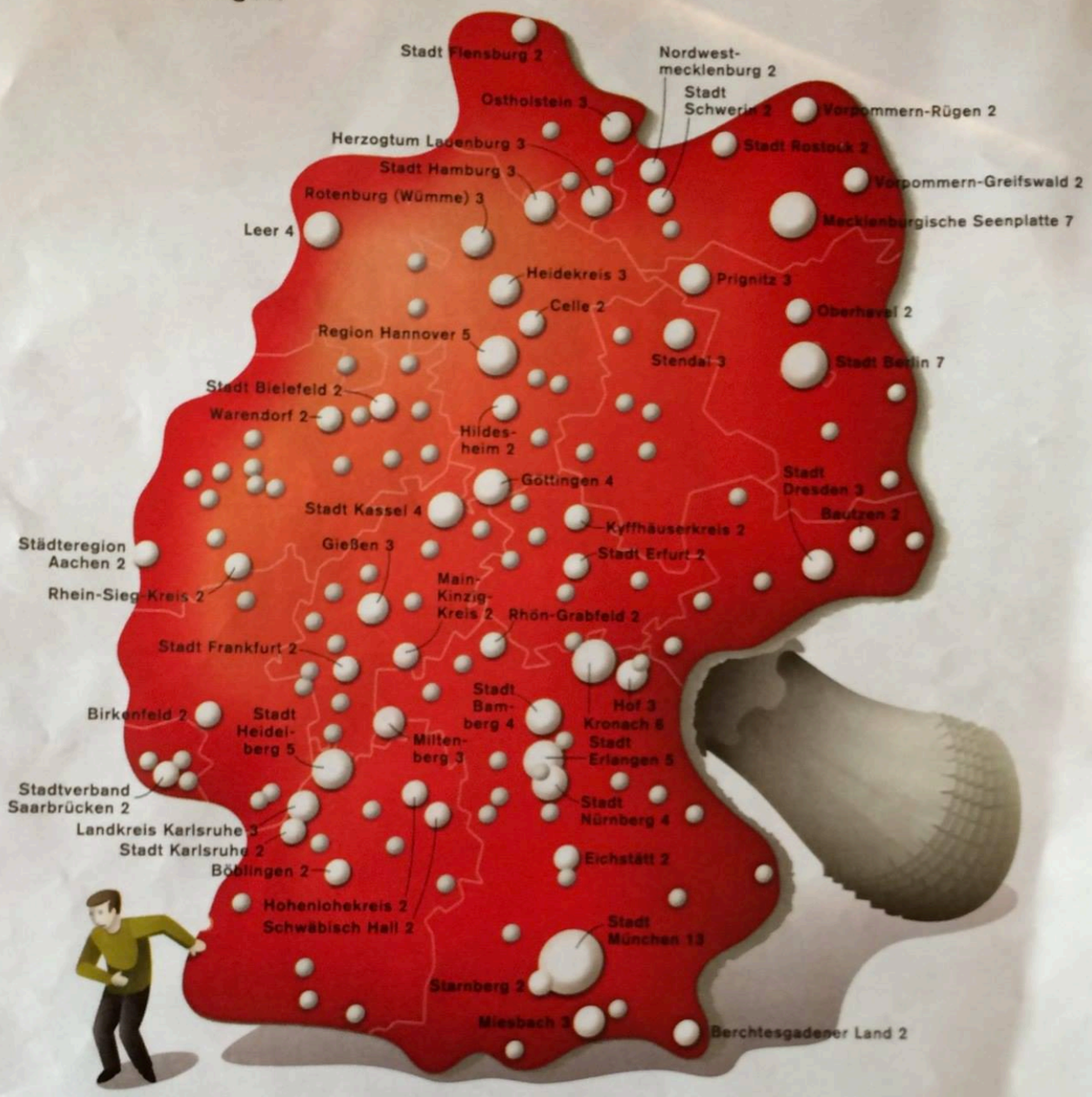
4a) if you already have an idea of what species it may be, add:
- the name (both scientific and common)
- a description of the characteristics you base your ID on
- the sources you used for identification (books/websites)

4b) If you don't know what it is:
- scent
- taste (it is not harmful to nibble a bit off of a mushroom and chew on it for 10 sec. BUT ALWAYS SPIT IT OUT! Even if it tastes nice! Amanita phalloides has quite a slight sweet flavour, but you don't want to swallow a piece of that)
- the true colours (if the colours in the picture does not resemble the true colours by daylight)
- possible discolouration of the cap/stipe/hymenium/context (this may take a while with some species)
- the substrate (mulch/wood/living tree/bare ground/dead animals etc)
- habitat (nearest tree species, woods, calcareous grassland, fen, dry/moist soil, high/low elevation etc)
- location (if in US: state/region; if abroad: country + region)

Medically treated severe mushroom poisonings in Germany 2008–2013

Americans have grizzly bears, Australians have sharks, Japanese have the poisonous globe fish, Germans have poisonous mushrooms. Almost no-one is killed by any of these things.

Deutschlandkarte: Pilzvergiftungen



QUELLE: DAK

Fälle von behandelten schweren Pilzvergiftungen zwischen 2008 und 2013 nach Landkreisen und kreisfreien Städten

In diesem Jahr ist bislang in ganz Nordamerika genau ein Mensch von einem Bären getötet worden. Gemessen an der Zahl der Schilder, die in den Wäldern dort vor Bären warnen, ist das eine niedrige Zahl. In deutschen Wäldern stehen üblicherweise keine Schilder, die vorm Pilzesammeln warnen. Obwohl doch relativ viel schiefgeht dabei: Münchener leben, siehe oben, besonders gefährlich, der naturliebende Großstädter scheint ein Problem zu sein. Pilzsammler sagen interessanterweise auch, sie »gehen in die Pilze«. Das klingt wie »ins Wasser gehen«, fast schon selbstmörderisch. Zwar enden die wenigsten Pilzvergiftungen tödlich, aber die Faszination des Todes spielt immer mit: Kinder zeigen sich begeistert von Grünen Knollenblätterpilzen und Fliegenpilzen, Pfifferlinge lassen sie kalt. Pilze sind für den Mitteleuropäer das, was für Japaner der Kugelfisch ist, für Amerikaner der Grizzly, für Australier der Hai: eine Prise Gefahr, die dem langweiligen Sonntagsausflug einen angenehmen Thrill verleiht.

Von Matthias Stolz
Illustration Jörg Block

Erotische zwammen

Dankzij het warme en vochtige weer beleeft de natuur een tweede bloei, dit keer niet van bloemen maar van paddestoelen. Onstuitbaar dringen al die ogenschijnlijk zwakke hoeden in bos en berm door de humuslaag heen. Samen met het afvallende loof geven ze kleur aan het herfstbos. Maar hoe kom je achter de namen van al die bizarre vertegenwoordigers van het zwammenrijk? Volgens een voorzichtige schatting kent de gemiddelde Nederlander niet meer dan drie of vier namen – de vliegenzwam natuurlijk, het eekhoorntjesbrood, de cantharel en vooruit, het elfenbankje. Wie zijn kennis wil vergroten of bijspijkeren, kan het beste met een excursie meegaan.

- Gerrit Jan Zwier 11 oktober 2001

De laatste tijd liep ik verschillende keren mee. Nu eens met een boswachter, dan weer met een echte deskundige. Er zijn twee soorten deelnemers op wie deze gidsen het niet zo begrepen hebben – gretige plukkers en verzamelaars van paddo's. De eersten gaat het vooral om de cantharel, die weer in opkomst is. De liefhebbers van paddo's zijn gespitst op kaalkopjes die met name op mesthopen in het open veld te vinden zijn. `Hallucinogeen' luidt de toevoeging in de boeken bij twee bescheiden zwammetjes, het puntig kaalkopje en het franjekaalkopje. Sommigen brouwen er soep van, echte heksensoep dus.

De gids moet echt goed thuis zijn in de materie, want alle deelnemers hebben de gewoonte hun vinger naar elke paddestoel uit te steken en naar de naam te vragen. Dat betekent dat je vele honderden soorten (in totaal gaat het in Nederland om een kleine vierduizend), die vaak sterk op elkaar lijken, moet kennen. Echte mycologen (zwammenexperts) beschikken over allerlei foefjes om de ene familie en de ene soort van de andere te onderscheiden. Maar een amateur komt soms voor vele verrassingen te staan.

Zo was ik laatst met een alleraardigste boswachter op stap die zich kennelijk eerst niet op de hoogte had gesteld van de vele nieuwkomers in het door ons te doorkruisen bos. `Wat een leuk zwammetje!' luidde meestal zijn openingszin, als hij bij een aangewezen exemplaar neerknielde. Daarna hield hij een spiegeltje onder de hoed, opdat iedereen de mooi gevormde lamellen kon zien. `Ik denk een melkzwammetje', zei hij dan. Om dat zeker te weten, moest hij het vlees echter kneuzen, en dat ging hem aan het hart. Lag de paddestoel ondersteboven, en begon hij na een kneep in de lamellen niet te `melken', dan hield hij het meestal op een `ridderzwammetje'. In zijn baard hoorde ik hem mompelen over `ridders en schijnridders'. Op zeker moment begon hij zijn tred te versnellen en allerlei vreemde zwammen te negeren. Hij wilde eigenlijk alleen iets vertellen over goede bekenden, zoals het rodekoolzwammetje en de boschampignon.

De gids, die ons laatst in de buurt van Ravenswoud rondleidde, was meer het type van de dorpsonderwijzer. Aan het begin van de wandeling strooide hij wat broodkruimels uit een zakje, om de `bosgeesten mild te stemmen'. Dat deden ze vroeger ook, lichtte hij toe, in de hoop een rijke zwammenflora in het bos aan te treffen. En werkelijk, onze oogst was rijk; laat ik hier slechts de grote oranje bekerzwam, de groene glibberzwam (die uit gelatine gemaakt lijkt te zijn), de radijsvaalhoed en de parelamaniet noemen. De laatste is niet giftig, in tegenstelling tot de panteramaniet, die er sterk op lijkt. Toen de Larousse Encyclopedie het omgekeerde beweerde, moest de hele oplage van 400.000 exemplaren vernietigd worden.

Bij vele soorten had onze leidsman een verhaal bij de hand. Moederkoren, een schimmel op graan, zorgde vroeger voor voedselvergiftigingen. Bekend ook is het apocriefe verhaal over de zuster van Darwin, die het uiterlijk van de Phallus impudicus (grote stinkzwam) zo aanstootgevend vond dat zij die elke herfst uit haar tuin liet verwijderen. De wereld van de mycologie heeft toch al een duidelijk erotische ondertoon. Zo ruiken vezelkoppen naar sperma en herinneren woorden als `schede', `volva' (`beurs') en `hymenium' (kiemvlies; hymen = maagdenvlies) aan een seksuologisch handboek.

`Heeft u wel eens een pruikzwam gezien?' vroeg ik laatst aan een expert. Deze zwam hangt soms als een wit bevroren watervalletje uit de oksel van een oude beuk.

`Jazeker', zei hij, `daar kreeg ik bijna een mycologisch orgasme van.'

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ARTICLES

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OPEN

Megaphylogeny resolves global patterns of mushroom evolution

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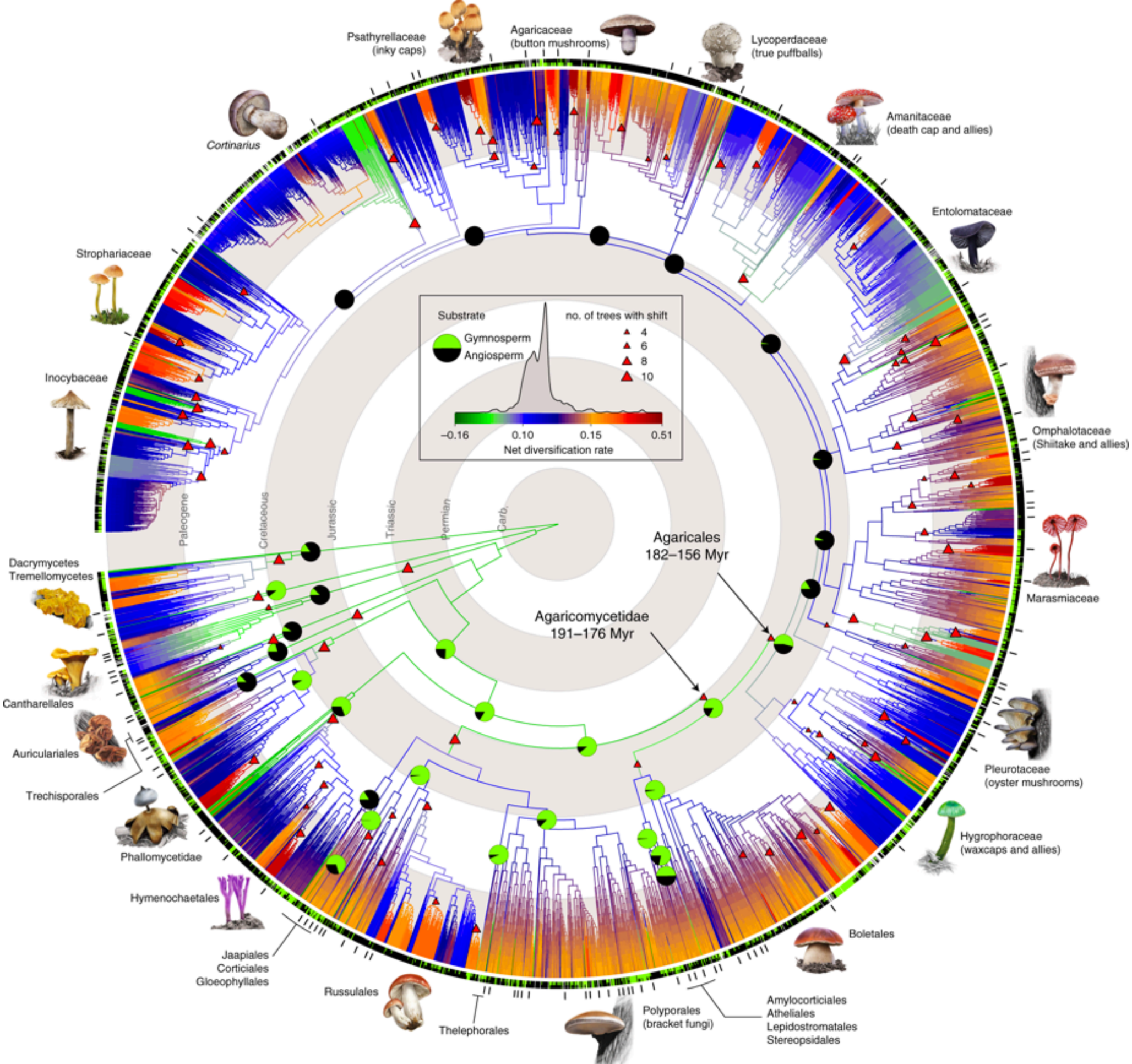
Mushroom-forming fungi (Agaricomycetes) have the greatest morphological diversity and complexity of any group of fungi. They have radiated into most niches and fulfil diverse roles in the ecosystem, including wood decomposers, pathogens or mycorrhizal mutualists. Despite the importance of mushroom-forming fungi, large-scale patterns of their evolutionary history are poorly known, in part due to the lack of a comprehensive and dated molecular phylogeny. Here, using multigene and genome-based data, we assemble a 5,284-species phylogenetic tree and infer ages and broad patterns of speciation/extinction and morphological innovation in mushroom-forming fungi. Agaricomycetes started a rapid class-wide radiation in the Jurassic, coinciding with the spread of (sub)tropical coniferous forests and a warming climate. A possible mass extinction, several clade-specific adaptive radiations and morphological diversification of fruiting bodies followed during the Cretaceous and the Paleogene, convergently giving rise to the classic toadstool morphology, with a cap, stalk and gills (pileate-stipitate morphology). This morphology is associated with increased rates of lineage diversification, suggesting it represents a key innovation in the evolution of mushroom-forming fungi. The increase in mushroom diversity started during the Mesozoic-Cenozoic radiation event, an era of humid climate when terrestrial communities dominated by gymnosperms and reptiles were also expanding.


Psathyrellaceae
(inky caps)
Agaricaceae
(button mushrooms)
Lycoperdaceae
(true puffballs)
Amanitaceae
(death cap and allies)
Entolomataceae
Cortinarius
Strophariaceae
Inocybaceae
Omphalotaceae
(Shiitake and allies)
Marasmiaceae
Pleurotaceae
(oyster mushrooms)
Hygrophoraceae
(waxcaps and allies)
Boletales
Amylocorticiales
Atheliales
Lepidostromatales
Stereopsidales
Polyporales
(bracket fungi)
Thelephorales
Russulales
Jaapiales
Corticiales
Gloeophyllales
Hymenochaetales
Phallomycetidae
Trechisporales
Auriculariales
Cantharellales
Tremellomycetes
Dacrymycetes
Paleogene
Cretaceous
Jurassic
Triassic
Permian
Carb.
Agaricomycetidae
191–176 Myr
Agaricales
182–156 Myr
Substrate
Gymnosperm
Angiosperm
no. of trees with shift
4
6
8
10
−0.16
0.10
0.15
0.51
Net diversification rate

One of the 245 analysed maximum-likelihood trees was randomly chosen and visualized. Trees were inferred from nrLSU, *rpb2, ef1-a* sequences with a phylogenomic backbone constraint of deep nodes. Branches are coloured by net diversification (speciation minus extinction) rate inferred in Bayesian Analysis of Macroevolutionary Mixtures (BAMM). Warmer colours denote a higher rate of diversification. Significant shifts in diversification rate are shown by triangles at nodes. Only shifts present on >50% of ten trees, with a Bayesian posterior probability >0.5 and a posterior odds ratio >5 are shown. See Supplementary Data 6 for detailed discussion of shifts. Reconstructed probabilities of ancestral plant hosts for order-level clades are shown as pie charts partitioned by the inferred ancestral probability for gymnosperm (green) and angiosperm host (black). Pie charts are given for the most recent common ancestors of each order plus backbone nodes within the Agaricales—for small orders see Supplementary Data 3. Inner and outer bars around the tree denote extant substrate preference (black, angiosperm; green, gymnosperm; grey, generalist) and the placement of species used for inferring the 650-gene phylogenomic backbone phylogeny. Geological time scale is indicated with grey/white concentric rings.