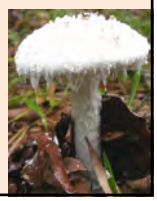



'Mates' – mycorrhizal and endophytes are fungi that plants need

Dr Sapphire McMullan-Fisher
Fungimap Conservation & Biodiversity Subcommittee



'Fungi' in 3 of the KINGDOMS of LIFE

EUKARYOTES

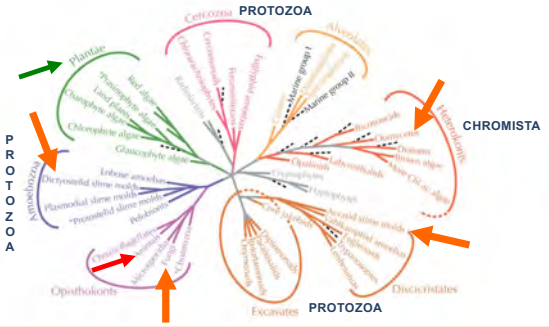
- PLANTAE
- EUMYCOTA
- ANIMALIA
- CHROMISTA
  - **Oomycetes**
- PROTOZOA
  - **Acrasiomycota**
  - **Myxomycota**

PROKARYOTES

- BACTERIA
- ARCHAEA

Fungi are different

'fungi' in several Eukaryote lineages



Evolution (2007) Cold Spring Harbor Laboratory Press

What are fungi?

- Sessile organisms (mostly)
- Heterotrophic
  - cannot produce own energy, non-photosynthetic
- Absorptive
  - excrete enzymes, digestion outside fungus, absorb nutrients
- Glycogen
  - main energy storage (starch in plants)

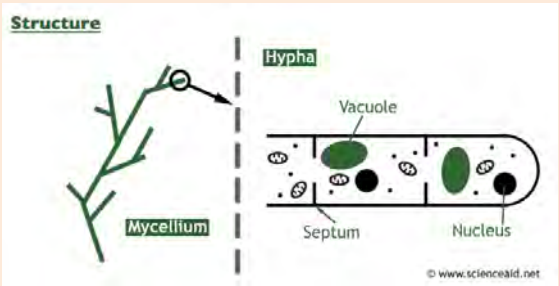
What are fungi?

- Reproduce by spores (mostly)
  - Distinctive nuclear division (Eumycota)
- Usually filamentous
  - tubes almost all fungi are called hyphae (s. hypha)
  - mycelium (pl. mycelia) collective term for hyphae

hyphae

- Cell walls composed of chitin (mostly)
  - walls chitinous in eumycotan fungi
  - walls of cellulose in oomycetes

Hyphae



http://scienceaid.co.uk/biology/micro/fungiyeast.html

Hyphae & mycelium

- **explore** the habitat with rapidly growing, sparsely branched hyphae, then, when some of those hyphae find a nutrient resource, the extension rate declines, rate of branching increases, and the mycelium **captures and exploits** the resource

Resources Box from the 21st Century Guidebook to Fungi:© David Moore, Geoffrey D. Robson and Anthony P. J. Trinci 2011

Hyphae & mycelium

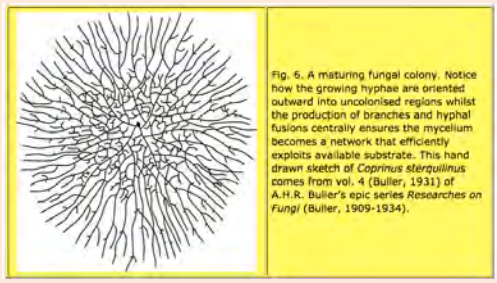
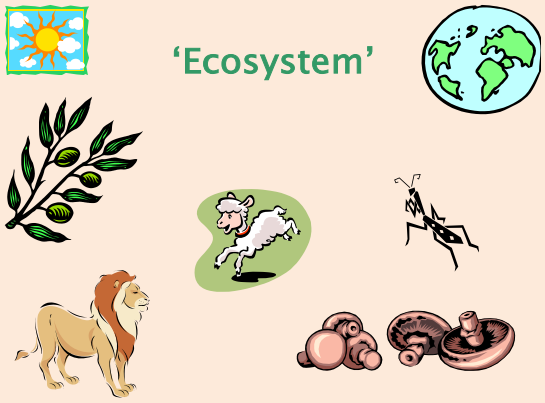


Fig. 6. A maturing fungal colony. Notice how the growing hyphae are oriented outward into uncolonised regions whilst the production of branches and hyphal fusions centrally ensures the mycelium becomes a network that efficiently exploits available substrate. This hand drawn sketch of *Coprinus sterquilinus* comes from vol. 4 (Buller, 1931) of A.H.R. Buller's epic series *Researches on Fungi* (Buller, 1909-1934).

Resources Box from the 21st Century Guidebook to Fungi:© David Moore, Geoffrey D. Robson and Anthony P. J. Trinci 2011

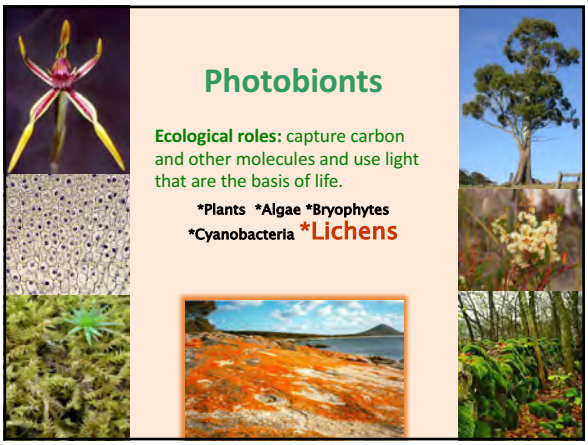
'Ecosystem'



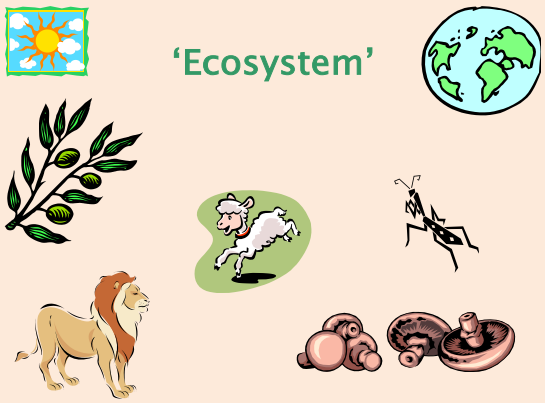
Photobionts

Ecological roles: capture carbon and other molecules and use light that are the basis of life.

*Plants *Algae *Bryophytes
*Cyanobacteria *Lichens

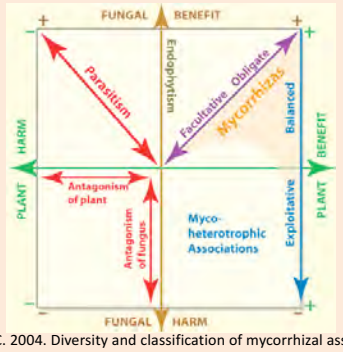


'Ecosystem'



Biotrophs

*Diseases *Viruses
*Gut Microbes
*Endophytic Fungi
*Mycorrhiza
*Rusts & Smuts



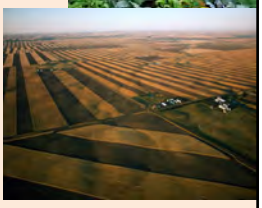
Brundrett MC. 2004. Diversity and classification of mycorrhizal associations. *Biological Reviews* **79:** 473-495. Mutualistic associations occupy the mutual benefit (+ +) quadrant

'The bad'

- Many plant pathogens

e.g.rusts, mildews, smuts, leaf spots etc

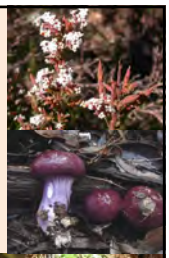
- Monoculture vs polyculture
- Population control



http://ruminances.u-r.f.unblog.fr/files/2010/10/monoculture-peu.jpg https://s-media-cache-ak0.pinimg.com/236x/0e/bc/91/0ebc914a0caeec2a3be77ec2246eac13.jpg

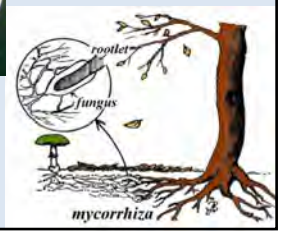
'The Good' or Mates

- Mycorrhiza
- Endophytic fungi



Mycorrhiza

Mycorrhiza = fungus root



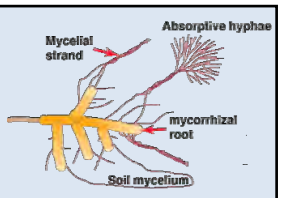
Hyphae vs Root

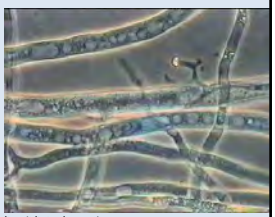
Average hyphae 10 µm

Vs

Av. fine root 0.1 mm = 100 µm

1 millimitre = 1000 micrometres µm = micrometres = 10^{-6}





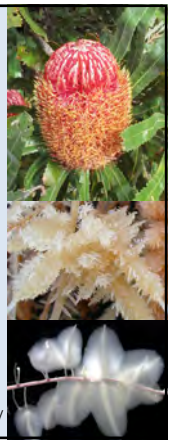
http://www.microbiologybytes.com/iandi/ipics/Vacuoles.JPEG
http://mycorrhizas.info/ecm/ecmhyphae2.gif

Non-mycorrhizal (NM) plants

Are highly resistant to mycorrhizal fungi and normally remain un-colonised:

- Proteaceae → cluster roots
- Cyperaceae, Restionaceae and Juncaceae & Brassicaceae (Cruciferae), Chenopodiaceae, are generally considered to by NM families, but exceptions may be are AM e.g. Marrum Grass *(Ammophila)* & saltbush *(Atriplex)*
- Holoparasites, Carnivorious & some Hemi-parasites
- Cymodoceaceae NM Marine plants (Nielson et al. 1999)

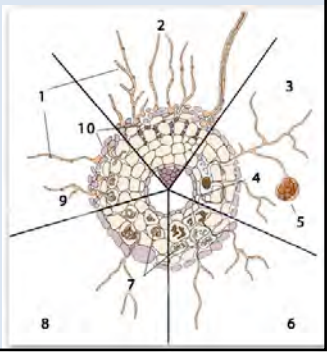
http://mycorrhizas.info/



Mycorrhizea

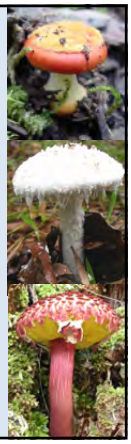
2. Ectomycorrhiza,
3. Arbuscular mycorrhizae,
6. Orchid endomycorrhizae,
8. Ericoid endomycorrhizae
9. Ectendomycorrhiza of some conifers

m.harunyahya.com/tr/Buku/14942/The-Microworld-Miracle/chapter/4956/Fungi-moulds-and-yeasts/www.davidmoore.org.uk/assets/mostly_mycology/diane_howarth/images/types.png



Ectomycorrhizea (ECM)

- These produce the mushrooms, boletes, truffles and other larger fungi (Basidiomycetes & Ascomycetes)
- Mainly associated with woody species (trees and shrubs) ~3% of mycorrhizal associations
- **ECM Families in Australia include:** Casuarinaceae, Fabaceae (Mimosoideae, Papiloinoideae), Meliaceae, Myrtaceae, Nothofagaceae, Nyctaginaceae, Phyllanthaceae and Rhamnaceae.



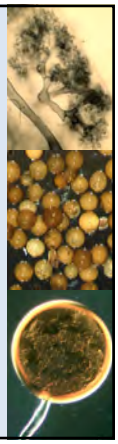
Endomycorrhizea – early lineages

No sheath and fungus penetrates into root cortex cells

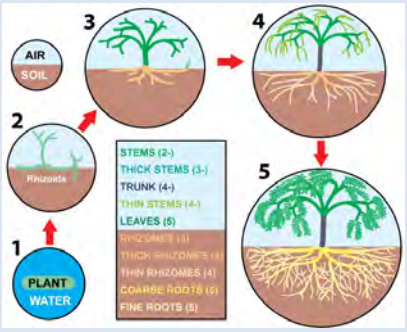
- **Mucoromycotina mycorrhizae**
  - Faculative mycorrhiza with liverworts and hornworts
  - Mucoromycotina, an ancient and partially saprotrophic fungal lineage, associates with the basal liverwort lineage
- **Arbuscular mycorrhizae** (AM) = **Glomeromycota**
- Obligate biotrophs, early lineage but maybe not the first
  - form arbuscules, vesicles and hyphal coils within root cortex cells; occur in the widest range of plants (also known as Vesicular Arbuscular Mycorrhizae or VAM)

Note. *Multiple associations increases the stability of systems.*

S Abel



Evolution of Endomycorrhizea



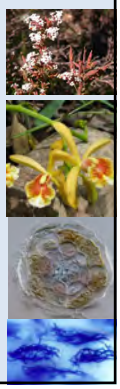
Mycorrhiza of Liverworts & Hornworts

- Liverworts & hornworts have mycorrhizal similtantious associations with AM (Glomeromycota) and some Mucoromycotina & Ascomycota.
- Liverworts are likely sister group to vascular plants
- Note mosses are NOT mycorrhizal

Sally E. Smith & David J Read 2010 Mycorrhizal Symbiosis (3rd edition) **Ebook Library.** *Online access* Chapter 14 Fungal symbiosis in lower land plants

Chris Cargill

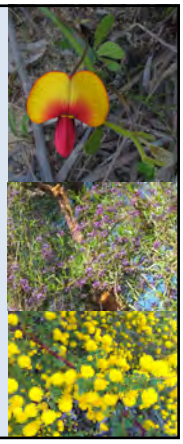
Endomycorrhizea – new lineages



No sheath and fungus penetrates into root cortex cells

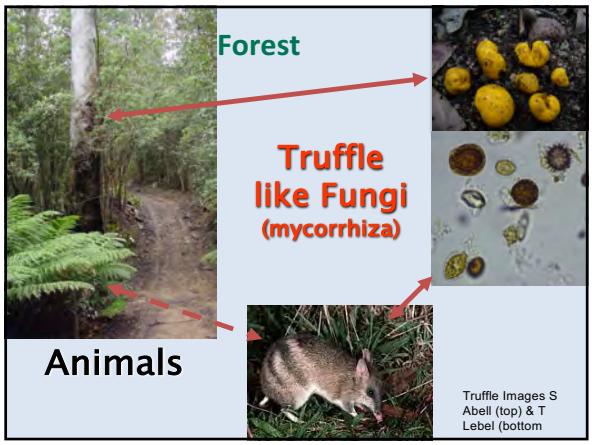
- **Heath mycorrhizae** – hyphal coils in cortex cells of heath families (Ericaceae and Epacridaceae) so also called ericoid mycrorrhizae
- **Orchid mycorrhizae** – hyphal coils in cortex cells of orchid roots (seen in prac class)
- Other types of mycorrhiza – have been found, often in single plant species or genera with fungi known for form typical mycorrhizas in another plant group.

Facultative mycorrhizal associations



- These form with facultative (variable) mycorrhizal associations
- Australian leguminous plants in the Fabaceae can have VAM, ECM and VAM, NM cluster roots, or VAM and cluster roots (Brundrett & Abbott 1991)

Brundrett MC, Abbott LK. 1991. Roots of jarrah forest plants. I. Mycorrhizal associations of shrubs and herbaceous plants. *Australian Journal of Botany* **39:** 445-457.



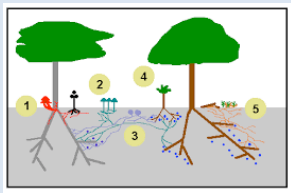
Truffle Images S Abell (top) & T Lebel (bottom

common mycelial (or mycorrhizal) networks

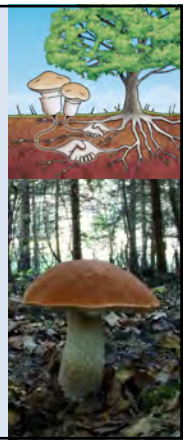
- **CMNs** can be formed not only by ectomycorrhizal fungi, but arbuscular mycorrhizal fungi as well.

➔ Robust ecosystem is based on facilitations & dynamic relationships

✦Each tree in a forest can form mycorrhizas simultaneously with tens or even hundreds of different fungi
✦each fungal mycelium can be associated with many different trees. And it is likely that the individual associations are coming and going constantly.



Mycorrhiza fight global warming



- **Healthy mycorrhizal networks are carbon sinks!**

http://mycorrhizas.info/roles.html

http://thinkprogress.org/climate/2014/01/09/3137501/eem-fungus-climate/

Tedersoo et al 2014 Global diversity and geography of soil fungi. Science 346 (6213) 1256688. DOI: 10.1126/science.1256688
https://www.newphytologist.org/symposiums/view/4

Mycorrhiza & Restoration

- Examples of commercial innoculants include:
  - Mycogold, Mycrormax, BioCoat & Myco-Symbiont, MycoApply etc
- Include generalist mycorrhiza and bacteria that act as mycorrhizal probiotics
- Often from northern hemisphere cultures
  - E.g. Australia has ~20 native species of *Laccaria* but NOT *Laccaria bicolor*

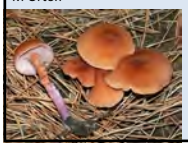
US Department of Agriculture, Agricultural Research Service, Systematic Botany and Mycology

Mycorrhiza & Restoration

- Mycorrhizal generalists
  - *Glomus* = Glomoermycota = AM or VAM
  - *Trichoderma*
  - *Pisolithus, Scleroderma and Laccaria*

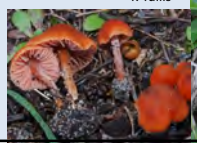
  E.g. Australia has ~20 native species of *Laccaria* but NOT *Laccaria bicolor*
- mycorhizal "probiotics" like Rhizobacteria etc

M Orton

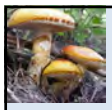


VS

K Tullis



Mycorrhiza



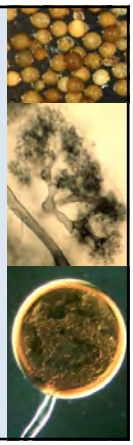
Roles

- **Mycorrhiza** are necessary partners for most terrestrial plants
- Truffle like are food for ground dwelling mammals
- Other dispersal mechanisms

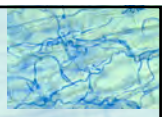
Manage

- Diversity of "hosts"
- Only mulch when necessary
- Protect or reintroduce vector species like small ground dwelling marsupials

S Abel



Endo (inside)- *phytic* (plant) fungi



~= **PROTECTIVE MUTUALISTS**

~= **SAPROBIC COMMENSALS**
(Latent pathogen)

Endo (inside)- *phytic* (plant) fungi

Continuum endophytes:

~= **PROTECTIVE MUTUALISTS**

~= **SAPROBIC COMMENSALS**
(Latent pathogen)

Define 'Endophytic Fungi'

- are fungi that colonize living plant tissue without causing any immediate, overt negative effects

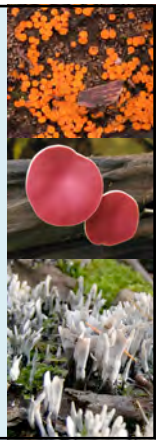
Hirsch, G., Braun, U., 1992. Communities of parasitic microfungi, in: Winterhoff, W. (Ed.), Fungi in Vegetation Science, Handbook of Vegetation Science. Springer Netherlands, pp. 225–250.

Endophytic fungi of non-grasses

- Many species & taxonomically diverse
  - mainly Ascomycetes (many inoperculate Discomycetes) or anamorph genera (many Xylariaceae)
  - some Basidiomycetes

Adapted from JK Stone, JD Polishook, JF White, 2004 (Ch 12). Endophytic fungi, in: Biodiversity of Fungi : Inventory and Monitoring Methods. Elsevier Academic Press, Boston, pp 241-270.

Photo top David Catcheside



Rainforest endophytes

- Up to 20 different species of endophyte were found in the leaves of one plant, the humble Wombat Berry (*Eustrephus latifolius*)*
  - Including *Phillipsia* spp.
- Tropical rainforests have even greater endophyte diversity.

Phillipsia subpurpurea

- Originally collected by Bailey near Brisbane, a specimen was described by Berkeley and Broome in 1882
- 1-3 cm discs with burgundy centers and white stem and flanks

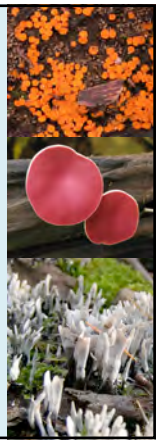
* Mapperson, RR and Dearnaley, JDW 2014 Molecular taxonomy of Australian endophytic Pezizales. In: 2014 Scientific Meeting of the Australasian Mycological Society, 21-23 April 2014, Brisbane, Australia.

Endophytic fungi of non-grasses

- **Non-systemic** variety of:

commensal saprobic → mutualistic fungi

- Quiescent* in 'normal' plant tissues without causing plant immune response



Adapted from JK Stone, JD Polishook, JF White, 2004 (Ch 12). Endophytic fungi, in: Biodiversity of Fungi : Inventory and Monitoring Methods. Elsevier Academic Press, Boston, pp 241-270.

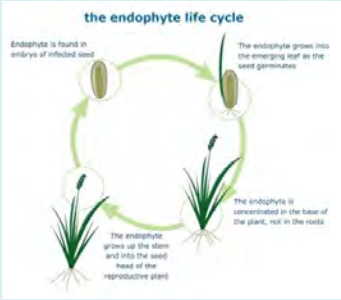
Photo top David Catcheside

Grasses Endophytes

1. Limited species numbers
2. Mostly *Neotyphodium* **anamorphs** of Balansiae (**Ascomycete: Clavicipitaceae**)
3. **Systemic** nonpathogenic symbiosis with extensive internal colonization & fungus is transmitted in the seed
4. Symptomless endophytes of *Lolium, Festuca* (mainly Poaceae)
5. Protection against herbivory and pathogens so increase their fitness

Adapted from JK Stone, JD Polishook, JF White, 2004 (Ch 12). Endophytic fungi, in: Biodiversity of Fungi : Inventory and Monitoring Methods. Elsevier Academic Press, Boston, pp 241-270.
http://commons.wikimedia.org/wiki/File:Festuca_rupicola1.JPG

Endophyte life cycle



http://www.grasslanz.com/understandingthescience/novelendophytetechnologies.aspx

Toxic grasses from endophytes

1. **Ergot alkaloids**, they induce various metabolic disorders that reduce reproductive rates and growth of grazing animals
2. **Paxilline alkaloids** they induce various stiff legged gaits (staggers) in sheep grazing
3. **Pyrollizidine-based loline alkaloids & Pyrrolopyrazine Peramine** reduce feeding by some insects

http://bugs.bio.usyd.edu.au/learning/resources/Mycology/Plant_Interactions/Endophytes/grassEndophytes.shtml
https://www.studyblue.com/notes/note/n/bio-101-study-guide-2012-13-whittaker/deck/9719514

Ergot poisoning

- *Claviceps purpurea* infects rye & other cereals
- "holy fire" = seizures, mania, dementia, gangrene, abortion
- this is an endophyte that fruits more in wet years
- Ergot alkaloids contain alkaloides including lysergic acid (ergoline)
- Ergotamine has been used in migraine medication like

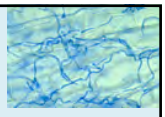
https://www.studyblue.com/notes/note/n/bio-101-study-guide-2012-13-whittaker/deck/9719514
http://salemdrugtrials.weebly.com/uploads/2/8/5/6/28565175/1855661_orig.jpg

Wise management

- Selective use of endophytes is being trialed to reduce bird strike by aeroplanes on runways
- Endophyte infected grasses like ryegrass and other *Fescue* species.
- The infected grasses are less palatable to grazing invertebrates (can deter white grubs, earthworms and caterpillars) and some vertebrates
- Less animals reduces the bird strikes

http://www.grasslanz.com/understandingthescience/novelendophytetechnologies.aspx http://news.ca.uky.edu/article/uk-entomology-research-hopes-prevent-bird-plane-collisions https://tokyobling.wordpress.com/2013/04/09/feeding-seagulls-in-yokohama/ http://imgarcade.com/1/plane-landing-at-airport/

Endophytes



Roles

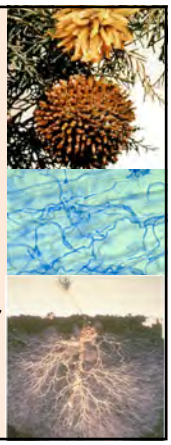
- Are present in many plant tissues
- Are poorly understood
- Have roles in:
  - disease and herbivore avoidance
  - improved drought tolerance
- Some may sequester stable carbon

Manage

- Diversity of "substrate & hosts"

Phillipsia subpurpurea

Ecological roles

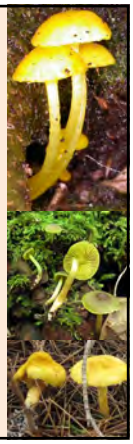


- Diseases like **rusts, smuts, galls** etc have a role in natural selection
- **Mycorrhiza** are necessary partners for most terrestrial plants,
  - mycorrhiza are important physical links in the ecosystem
  - diversity is important for ecosystem health and resilience
- **Endophytes** are present in most plant tissues, and have a role in disease and herbivory avoidance, some endow drought tolerance and some sequester stable carbon

Ecological roles

- Lichens capture carbon, some are source of nitrogen, are habitat for micro-fauna and may indicate declining air quality
- Decomposer fungi are important for nutrient recycling
- Fungal hyphae are important for good soil structure, water retention and nutrient availability
- Food for animals, particularly truffles macropods and hyphae and mushrooms, etc for invertebrates

Thanks to all involved



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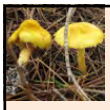

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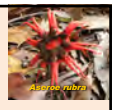

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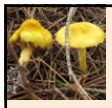

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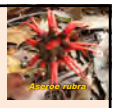

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