Hover cursor on speech bubble to see Presenter's script

Fungi for Better Health and Environment

David Moore

School of Biological Sciences

The University of Manchester

Some people think fungi are plants...

Photo by Jo Weightman

Image from *Growing Gourmet and Medicinal Mushrooms* by Paul Stamets, Ten Speed Press

Image from *Texas Mushrooms: A Field Guide* by Susan Metzler & Van Metzler

… but no, they're **NOT**!

Fungi are fungi!

There are three major Kingdoms of eukaryotes

- *Eumycota, 'true' fungi;*
- *Plantae, all green plants;*
- *Animalia, all multicellular animals.*

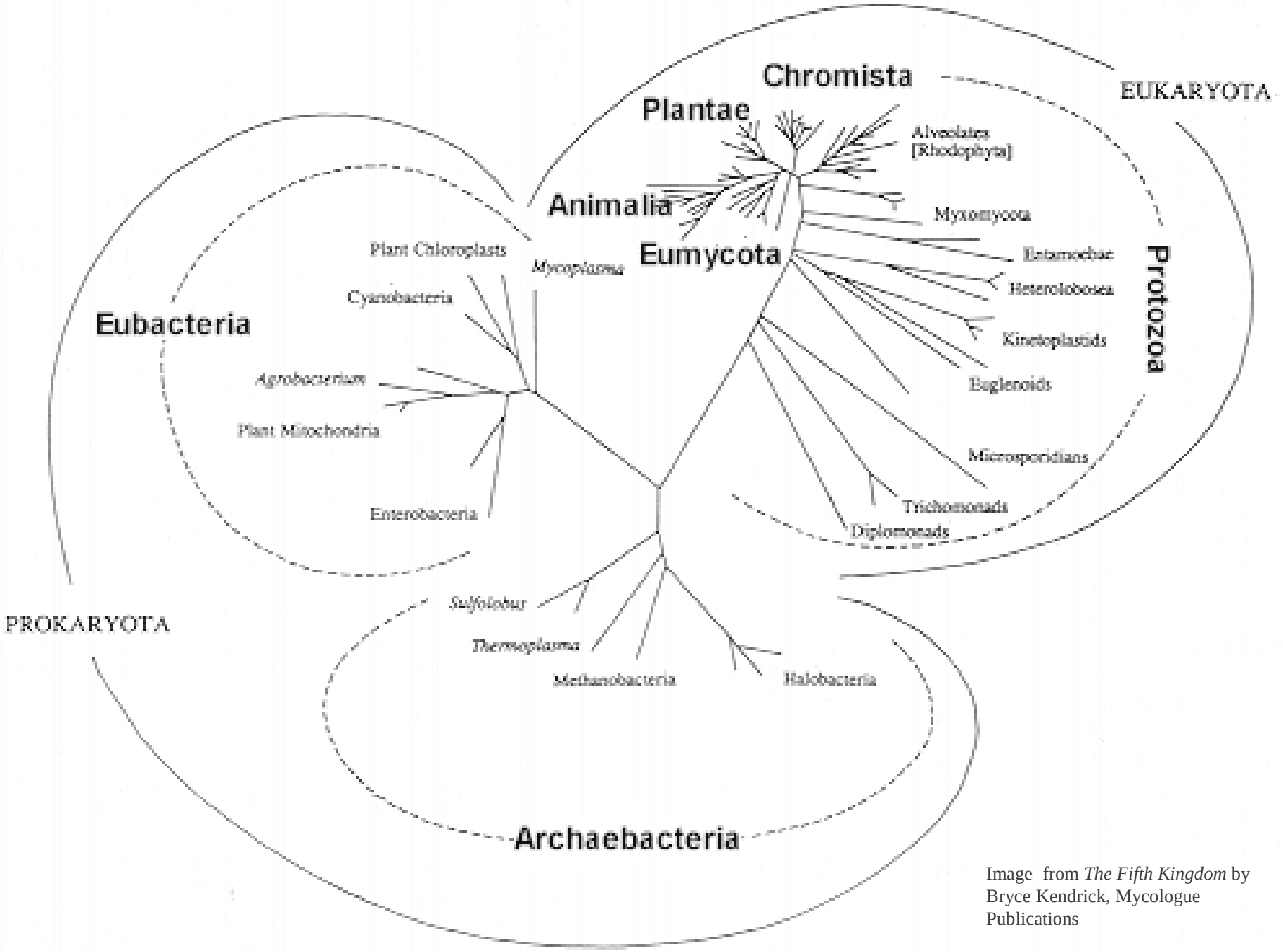


Image from *The Fifth Kingdom* by Bryce Kendrick, Mycologue Publications

Fungi are fungi!

"...This classification scheme...requires changes in social organization of biologists, many of whom as botanists and zoologists, still behave as if there were only two important kingdoms (plants and animals)...".

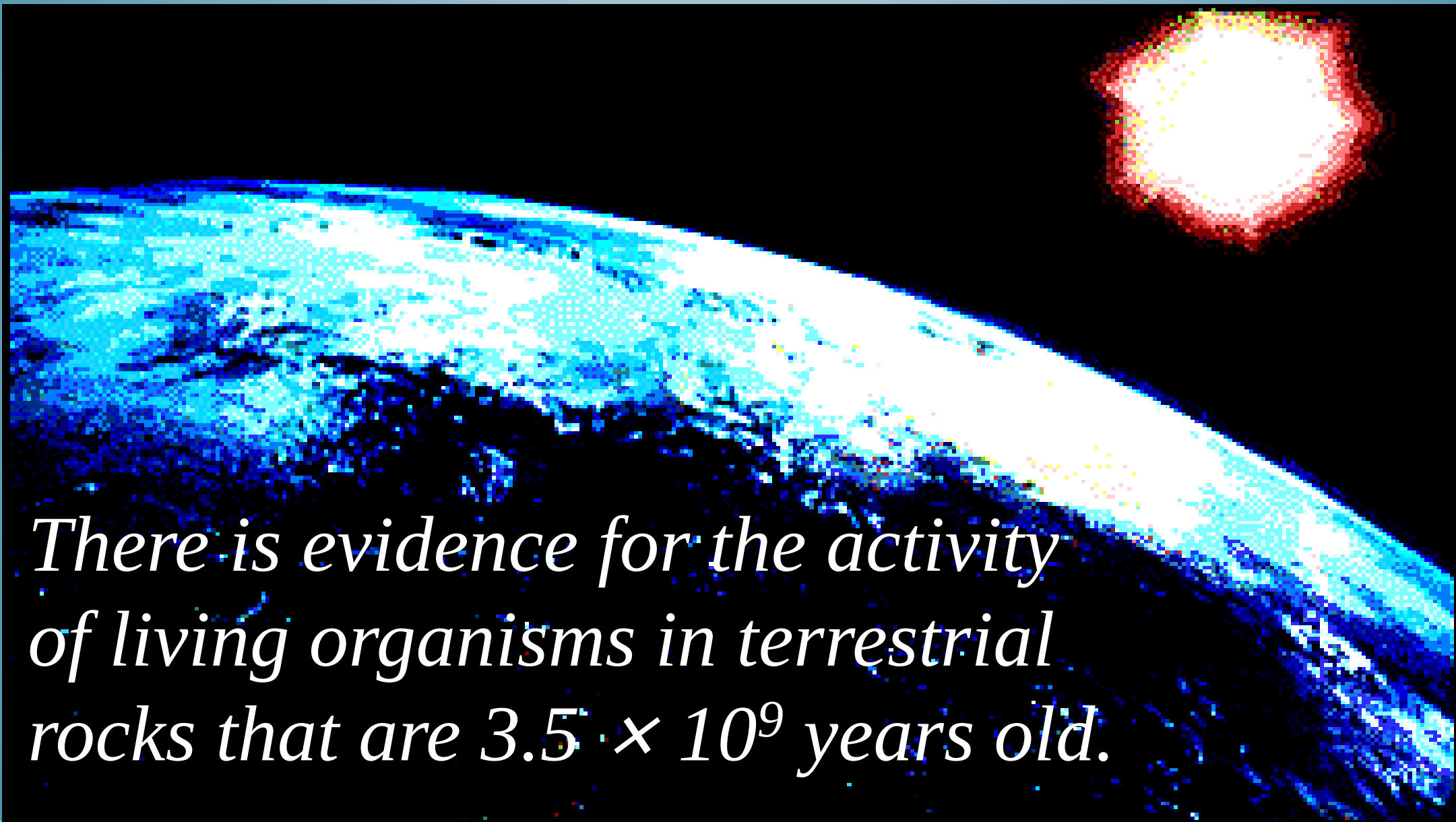
Margulis, L. (1992). Biodiversity - molecular biological domains, symbiosis and Kingdom origins. BioSystems ***27****, 39-51.*

Fungi are fungi!

"... animals and fungi are sister groups while plants constitute an independent evolutionary lineage...".

Baldauf, S. L. & Palmer, J. D. (1993). Animals and fungi are each others closest relatives - congruent evidence from multiple proteins. Proceedings of the National Academy of Sciences of the U. S. A. *90, 11558-11562.*

3.5 billion years ago



There is evidence for the activity of living organisms in terrestrial rocks that are 3.5 × 10^9 years old.

2 billion years ago

Eukaryotes and eubacteria last shared a common ancestor about 2×10^9 *years ago.*

1 billion years ago

Eukaryotic kingdoms diverged about 1×10^9 *years ago.*

Doolittle, R. F., Feng, D. F., Tsang, S., Cho, G. & Little, E. (1996). Determining divergence times of the major kingdoms of living organisms with a protein clock. Science *271, 470-477.*

Been there! Seen that!

Remains of two mushrooms have been found in amber which is 90 to 94 million years old.

- *They bear a strong resemblance to the existing genera Marasmius and Marasmiellus yet when they were preserved the dinosaurs still ruled the Earth …*

Hibbett, D. S., Grimaldi, D. & Donoghue, M. J. (1995). Cretaceous mushrooms in amber. Nature *377, 487.*

…so the mushrooms YOU see when you trek through the forest ...

…are almost identical to those seen by dinosaurs in their forests

Be thankful they've gone ...

This kind of encounter ...

.. Can be more than alarming!

Videostill from *The Making of Walking With Dinosaurs* © BBC MCMXCIX

Been there! Done that!

'...evidence accumulates to support the long-held view that the history of fungi is not marked by change and extinctions but by conservatism and continuity…'

Pirozynski, K. A. (1976). Fungal spores in fossil record. Biological Memoirs *1, 104-120.*

Been there! Done it all!

In other words:

if it works,

… don’t fix it

We all know what mushrooms look like

Image from *Texas Mushrooms: A Field Guide* by Susan Metzler & Van Metzler

We all know what mushrooms look like

Videostill from *Journey to the Center of the Earth*, a Twentieth Century-Fox production

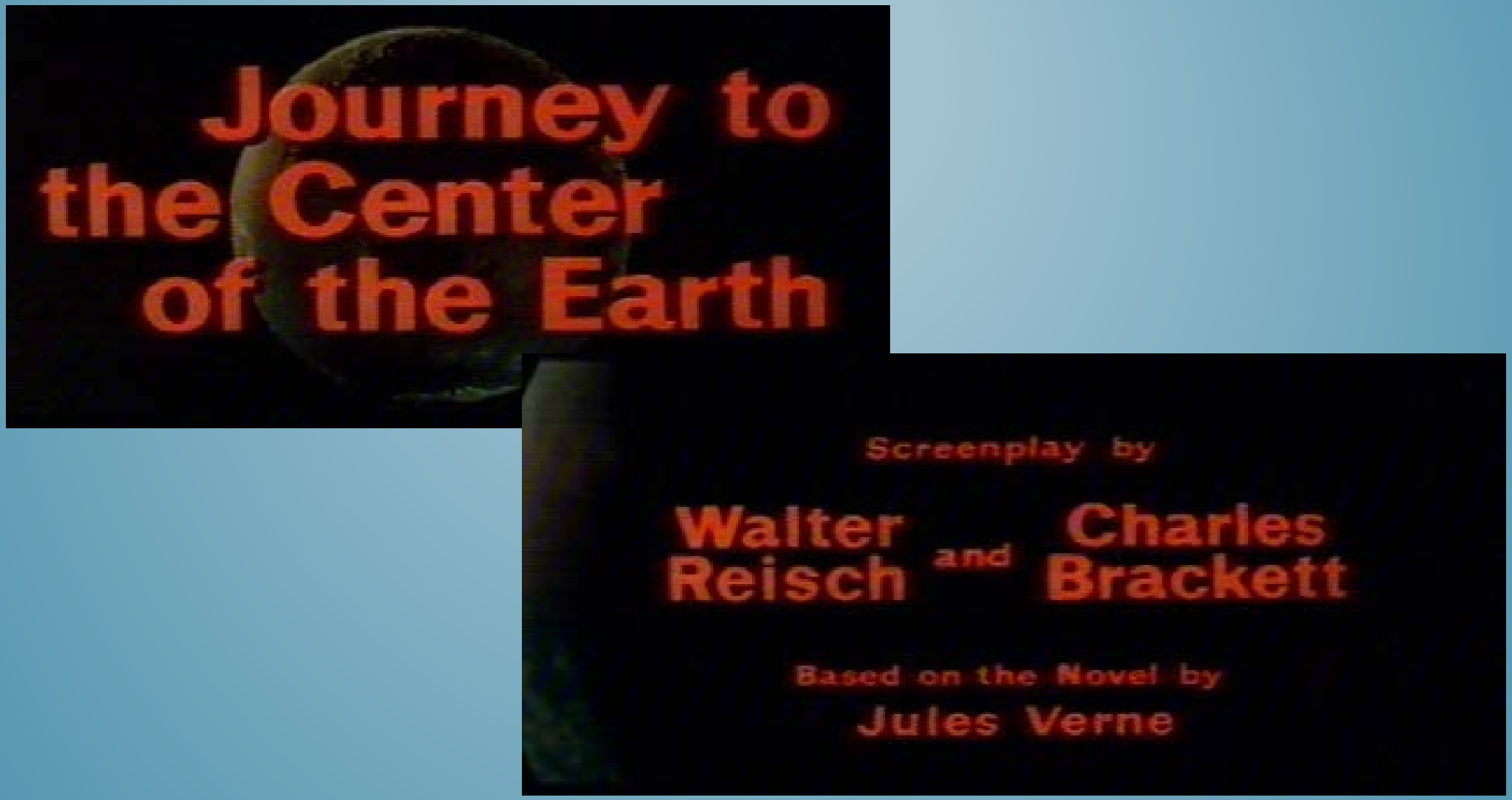
Maybe ancient mushrooms were gigantic…

Videostill from *Journey to the Center of the Earth*, a Twentieth Century-Fox production

…like ancient reptiles were gigantic?

Videostills from *Journey to the Center of the Earth*, a Twentieth Century-Fox production

Of course, it’s all fiction!



Videostill from *Journey to the Center of the Earth*, a Twentieth Century-Fox production

Or is it? …

A press cutting from **The Bangkok Post …**

Strangers in a strange land

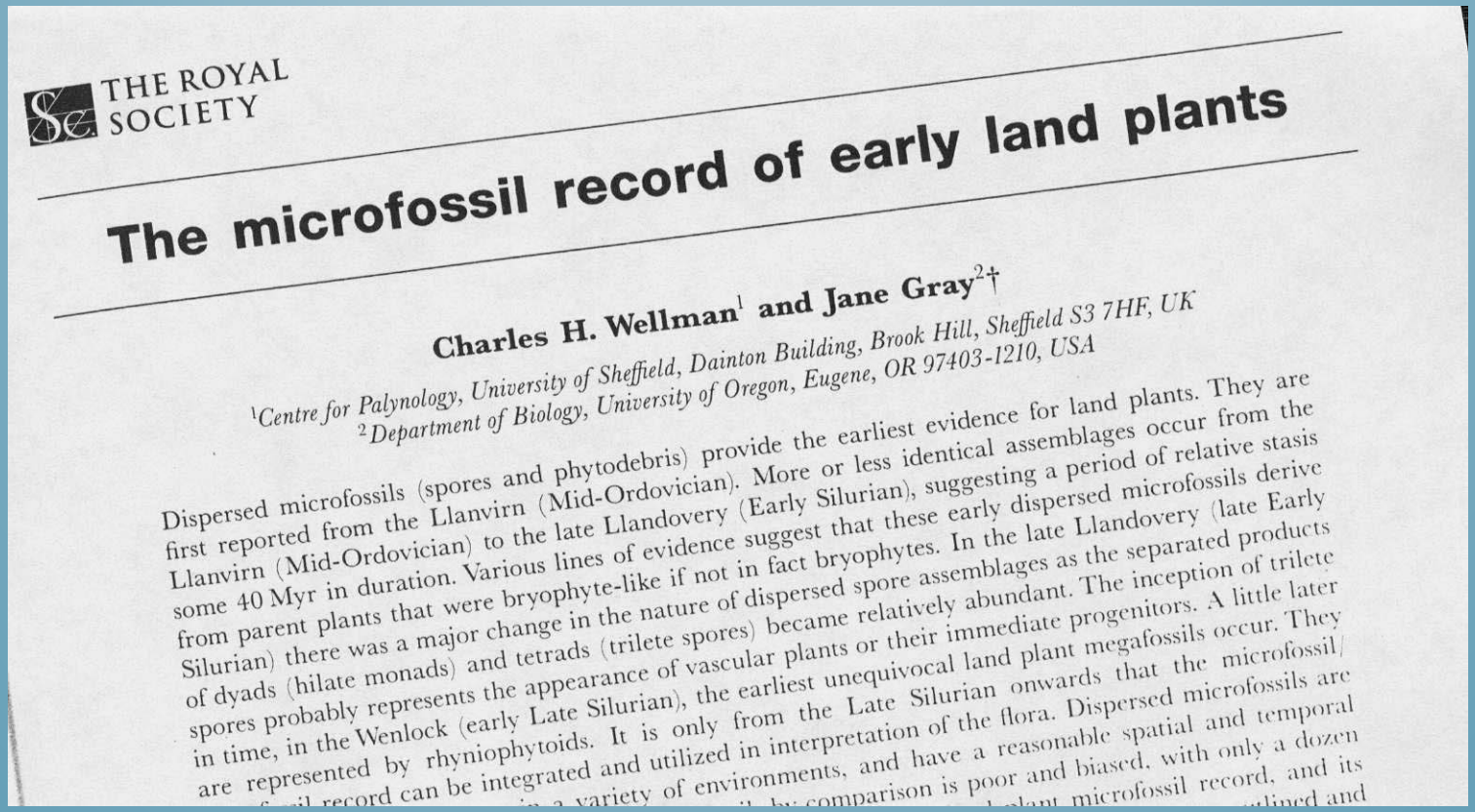
Could the earliest forests have been dominated by tree-sized fungi?

HENRY GEE
Nature News Service 2000

fungi … have domi- … this world seems in comparison to the … terious smile hanging in the air.
… earliest forests … vegetation of today. … Gray and Wellman think that the earliest … liverworts alive today.
sts the last paper of Jane … In the mid-1980s, conventional wisdom had the colonisation of the land occurring in the Silurian and Devonian periods (from around 439 million years ago). Gray presents evidence for a far earlier colonisation, in the mid-Ordovician, around 450 million years ago. … land plants may have been similar, or related to, present-day mosses and liverworts. … Writing in *Philosophical Tra… the Royal Society of London*, Gra… lman also discuss the natu… nematophytes. These are fossi… totally different from anythin… today. Once abundant, these… bundles of tubes could have bee… fungi.
versity of Oregon.
d at the beginning of this
f the prodigious talent of
he study of fossil plants.
in the colonisation of the
ore than 460 million years
Today, the earliest spores of land plants come from rocks 470 million years ago, and … True vascular plants (the group that includes ferns, horsetails, clubmosses, gymnosperms and flowering plants) appeared later: the earliest certainly-known vascular plant was Cooksonia, a tiny, frail thing that grew in Scotland … There are fossils of one ne… species, the trunk-like *Prototax…*
st work, co-authored with
of the University of Shef…

… *dated July 31, 2000*

… or do you prefer the Philosophical Transactions of the Royal Society of London?



THE ROYAL SOCIETY

The microfossil record of early land plants

Charles H. Wellman[1] **and Jane Gray**[2]†

[1]*Centre for Palynology, University of Sheffield, Dainton Building, Brook Hill, Sheffield S3 7HF, UK*
[2]*Department of Biology, University of Oregon, Eugene, OR 97403-1210, USA*

Dispersed microfossils (spores and phytodebris) provide the earliest evidence for land plants. They are first reported from the Llanvirn (Mid-Ordovician). More or less identical assemblages occur from the Llanvirn (Mid-Ordovician) to the late Llandovery (Early Silurian), suggesting a period of relative stasis some 40 Myr in duration. Various lines of evidence suggest that these early dispersed microfossils derive from parent plants that were bryophyte-like if not in fact bryophytes. In the late Llandovery (late Early Silurian) there was a major change in the nature of dispersed spore assemblages as the separated products of dyads (hilate monads) and tetrads (trilete spores) became relatively abundant. The inception of trilete spores probably represents the appearance of vascular plants or their immediate progenitors. A little later in time, in the Wenlock (early Late Silurian), the earliest unequivocal land plant megafossils occur. They are represented by rhyniophytoids. It is only from the Late Silurian onwards that the microfossil record can be integrated and utilized in interpretation of the flora. Dispersed microfossils are in a variety of environments, and have a reasonable spatial and temporal by comparison is poor and biased, with only a dozen plant microfossil record, and its outlined and

Quotations:

*'…It has been suggested that some of the nematophytes (*Prototaxites*) were terrestrial fungi… (specimens of* Prototaxites *over 1 metre wide have been reported)…' [and they were up to nine metres high!]*

Wellman, C. H. & Gray, J. (2000). The microfossil record of early land plants. Philosophical Transactions of the Royal Society of London, Series B *355, 717-732.*

Prototaxites was the largest organism in its ecosystem

A painting by Geoffrey Kibby depicting the landscape of the Devonian Period

Fungi make a crucial contribution to our ecosystem

The part played by fungi in nature make them crucially important to the maintenance of life on Earth.

Fungi help the balance of nature by nutrient recycling

- *Fungi decompose things.*
- *Importantly, fungi are about the only organisms that can digest wood.*
- *Lignin digestion is a fungal specialty.*

Images from *The Fifth Kingdom* by Bryce Kendrick, Mycologue Publications

Fungi make a crucial contribution to our ecosystem

Fungi make up 90% of the total living biomass in forest soils.

The total length of hyphae in grassland soil has been estimated at over 1 km g^{-1}.

Fungal mycelium in food webs

Fungal mycelium in most soils makes a major contribution to food webs, being eaten by numerous vertebrates and invertebrates including insects, mites, molluscs and nematodes.

Fungal fruit bodies in food webs

Fungal fruit bodies in food webs

Top predators, like birds of prey, eat small mammals that subsist almost entirely on fungal fruit bodies, and are themselves indirectly dependent on the fungi of the soil.

Fungal mycelia act as sinks of organic carbon and nitrogen

In many forests, a lot of carbon fixed by photosynthesis ends up in fungal mycelium because of the mycorrhizal symbiotic association in which the fungus assists the growth of forest trees.

Images from *The Fifth Kingdom* by Bryce Kendrick, Mycologue Publications

Fungi exude polysaccharides

These are important in gluing soil particles into aggregates that improve soil aeration and drainage.

This is a critical contribution the fungi make to soil structure because most terrestrial organisms are so strongly aerobic.

Even fungal plant pathogens enrich the natural environment

Plants killed by disease provide organic matter for nutrient cycling.

Dead branches or heart rot in live trees create cavities for nesting animals.

Gaps in stands of dominant plants create species diversity and diversity of food for animals from insects to elk.

… but not always …

Images from the website of the *Coalition to Save the Elms* at the URL http://www.savetheelms.mb.ca

This is what Dutch Elm disease does to the ‘urban forest’.

Why not use pathogens in Biological Control?

Weeds might be controlled by fungal diseases.

This policy has an overall success rate of 67%.

Image from *The Fifth Kingdom* by Bryce Kendrick, Mycologue Publications

More aggressive Biological Control?

Maybe use fungal diseases in the drugs war?

Fusarium oxysporum *against cocaine plantations.*

Videostills from *Panorama: Britain's Secret War on Drugs* © BBC MM

More aggressive Biological Control?

Pleospora papaveracea *against heroin poppies.*

Videostills from *Panorama: Britain's Secret War on Drugs* © BBC MM

Biological Control can be used against other pests

Weevil killed by Metarhizium

Metarhizium *kills spruce budworm larvae*

Mycar *is a mycoacaricide used to prevent the build-up of populations of citrus rust mite*

Images from *The Fifth Kingdom* by Bryce Kendrick, Mycologue Publications

Humans have been using fungi for many thousands of years

Image from James M. Deem's website *Mummy Tombs* at http://www.mummytombs.com

Ötzi, the Ice Man, carried three separate fungal products for his trek across the Alps.

Today's fungal metabolites

Alcohol (including biofuels)

Citric Acid

Penicillin

Cyclosporin

Mevinolin-derived compounds (Pravastatin, Simvastatin and Lovastatin, for example).

Some other fungal products

Most of the steroids in clinical use today are modified during manufacture by using fungi to make specific chemical transformations.

There is promise in immunomodulators - making the immune system more active against the cancer cells.

Mushroom cultivation

This is the most obvious way in which we exploit fungi.

Mushroom cultivation in the final quarter of the twentieth century

- *By the mid 1970s* Agaricus *accounted for over 70% of total global mushroom production;*
- *today, it accounts for 30% even though total production tonnage has more than doubled in the intervening years.*

Mushroom cultivation in the final quarter of the twentieth century

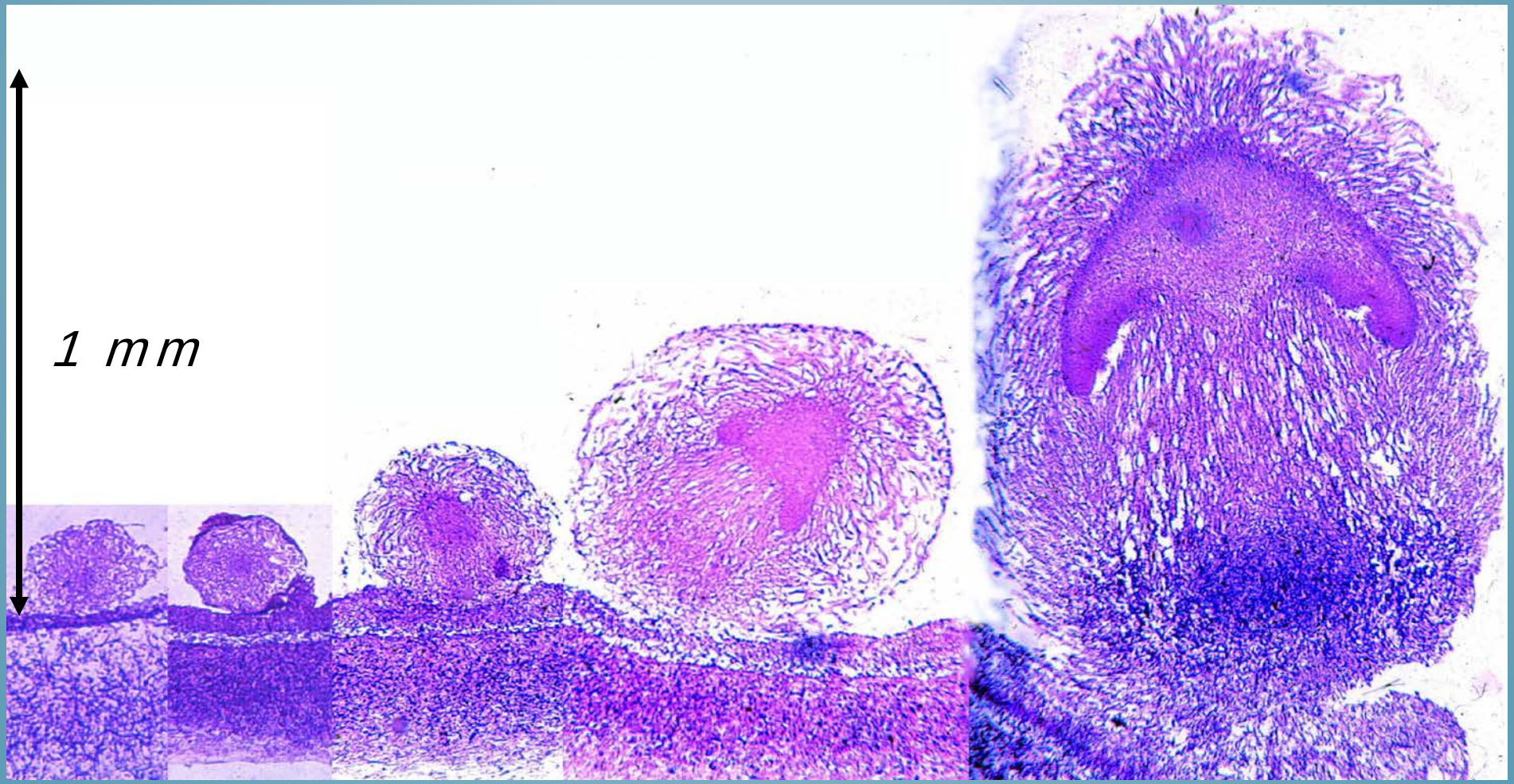
World production of mushrooms in 1996 was estimated to be 5.8 million metric tonnes.

Overall annual point-of-sale value is in the region of 30 billion US-dollars.

Market mushrooms

*‘Exotic’ mushrooms (*Lentinula *and* Pleurotus*) are now routinely found alongside* Agaricus *in supermarkets around the world.*

‘Embryology’ of *Coprinopsis*



Fungi are modular organisms

Fungi are 'modular organisms', like clonal corals and vegetatively-propagated plants.

Mushrooms are appendages of their mycelium, not individual organisms.

Andrews, J. H. (1995). Fungi and the evolution of growth form. Canadian Journal of Botany *73, S1206-S1212.*

Harper, J. L. et al. *(1986).* The Growth and Form of Modular Organisms*. The Royal Society: London.*

Mushroom morphogenesis

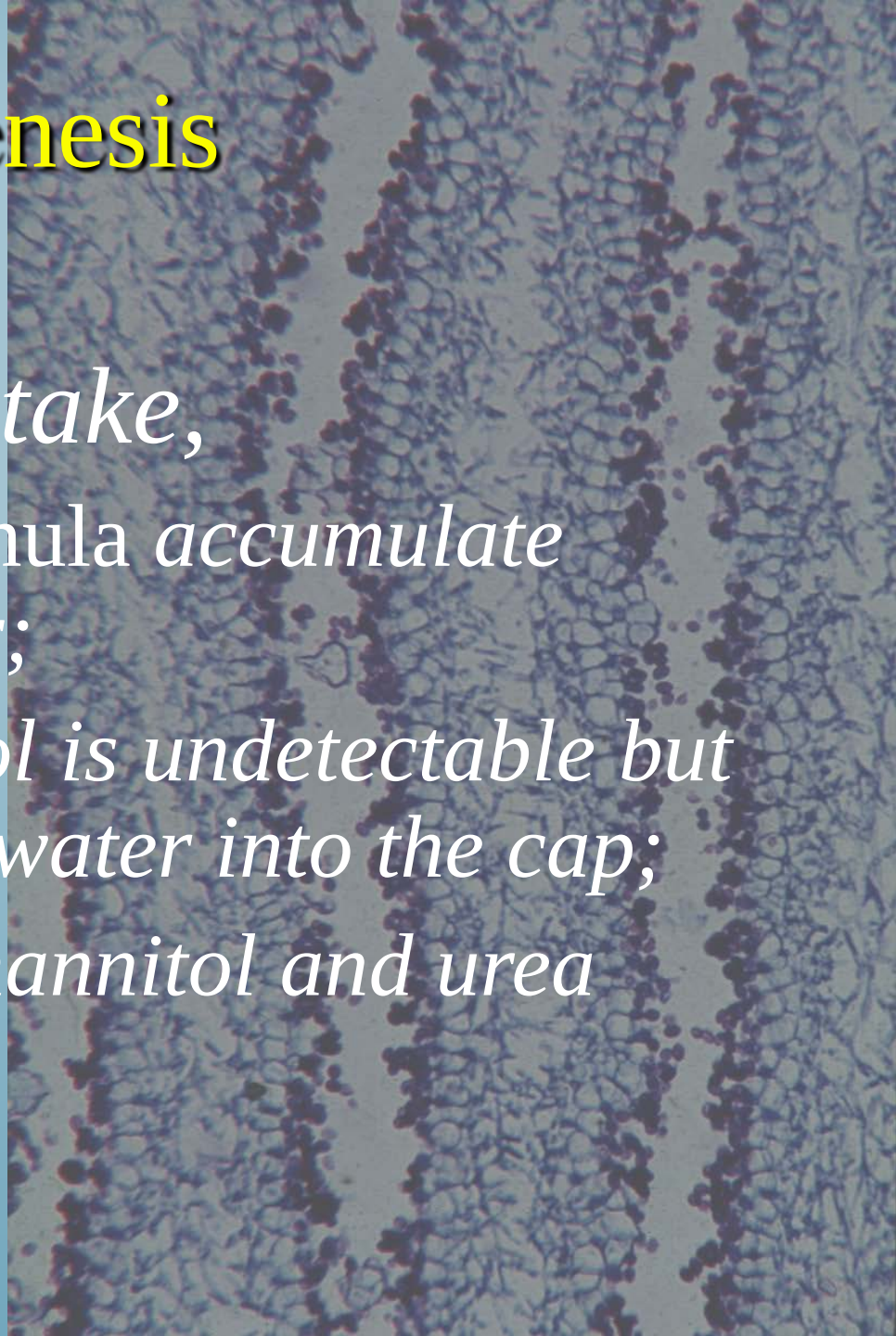
What we do know indicates complex relationships. For example:

- *expansion of the fruit body cap in* Lentinula edodes *and* Pleurotus pulmonarius *occurs by hyphal multiplication;*
- *the same process in* Agaricus bisporus *and* Coprinopsis *occurs by hyphal inflation.*

Mushroom morphogenesis

Both require water uptake,

- *but* Agaricus *and* Lentinula *accumulate mannitol as osmoregulator;*
- *in* Coprinopsis, *mannitol is undetectable but urea accumulates to drive water into the cap;*
- *and in* Pleurotus *both mannitol and urea accumulate in the cap!*



Mushroom morphogenesis

More studies of basic physiology and basic histology are essential to understand how shape and form arise.

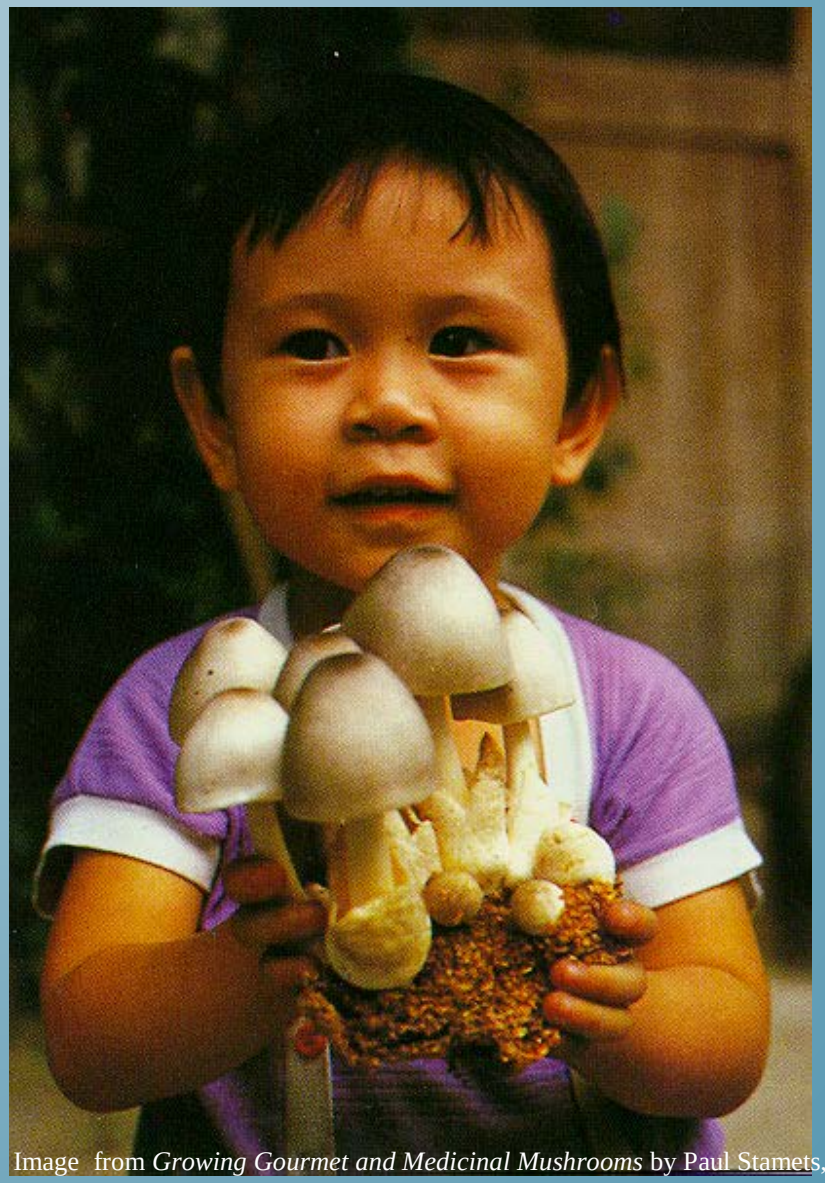


Image from *Growing Gourmet and Medicinal Mushrooms* by Paul Stamets, Ten Speed Press

Normal morphogenesis is made up of developmental subroutines

- *subroutines for hymenophore, hymenium, stem, cap, etc.,*
- *subroutines can be put into operation independently of one another,*
- *under separate genetic control,*
- *under separate physiological control.*

Developmental abnormalities

Twin fruit bodies of Clitocybe nebularis

Triple fruit bodies of Melanoleuca melaleuca

Twin fruit bodies of Clitocybe nebularis

Photos by H. van der Aa, from *Mycologist*, volume 11, part 2 (May 1997), p. 81

Developmental abnormalities

Photo by H. van der Aa, from *Mycologist*, volume 11, part 2 (May 1997), p. 81

Volvariella bombycina

Volvariella bombycina

Abnormal fruit bodies still produce spores.

For the full story ...

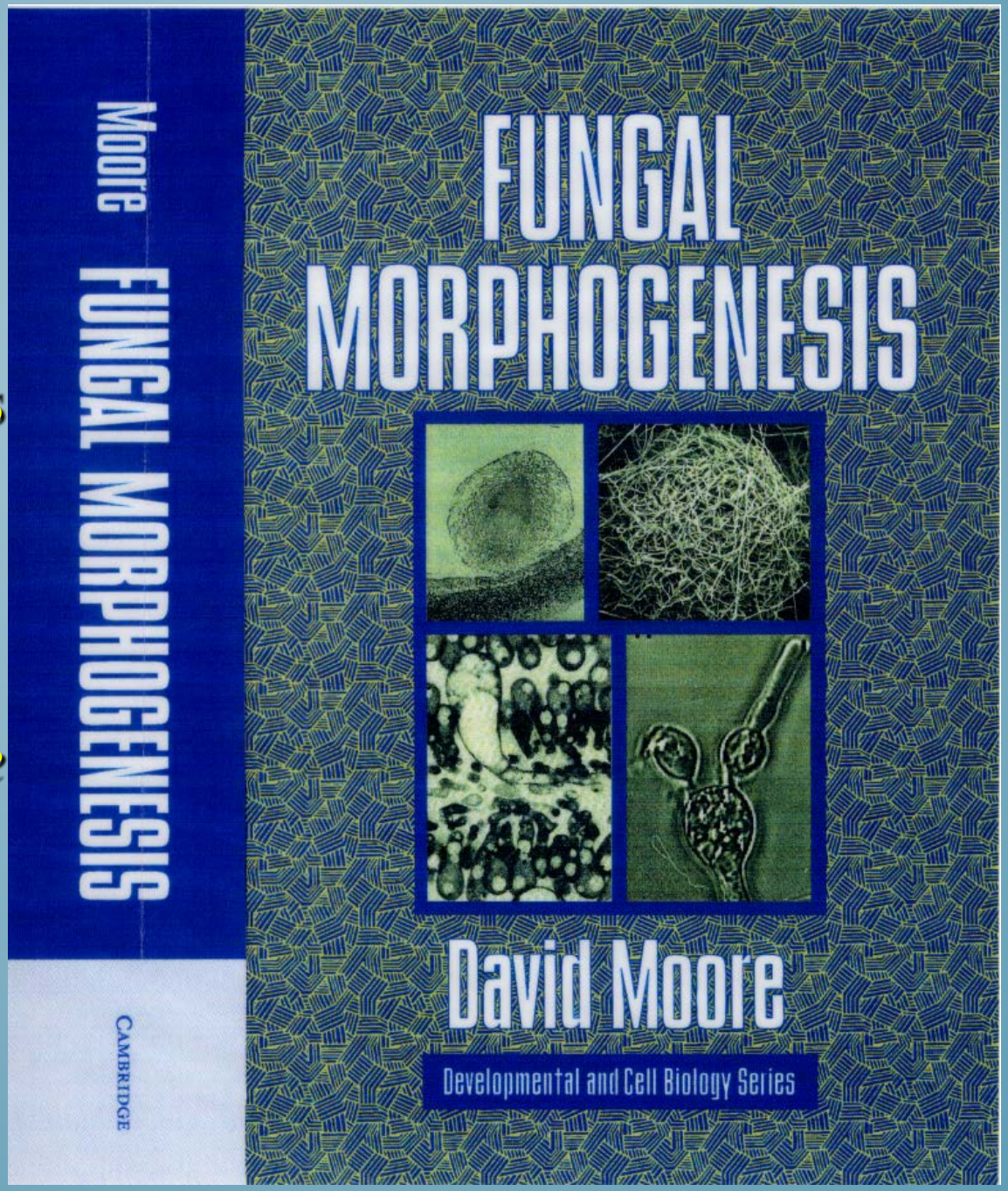
Fungal Morphogenesis

by David Moore

Published by Cambridge University Press, New York Office

xiv + 469 pages

ISBN 0 521 55295 8



Fungal Morphogenesis

The book brings together for the first time the full scope of fungal developmental biology, providing a coherent account which will be the basis for research in the future. The treatment also releases fungal morphogenesis from the confines of mycology, showing how and why this eukaryotic Kingdom deserves to be in the mainstream of developmental research. The author's view is quite simply that if you are ignorant of fungal morphogenesis then your understanding of developmental biology is incomplete.
The book is aimed at all biologists. Throughout, the author blends together physiological, biochemical, structural and molecular descriptions within an evolutionary framework, combining the older literature with the most recent. A comprehensive description of fungi is not attempted, though sufficient information is provided about fungal biology to give the general reader a rounded view of the mycological context within which fungal morphogenesis is played out, without obscuring the broader biological significance. Jargon is avoided, technical terms demystified and a reader with knowledge of basic biology should not need to bring any other knowledge with him/her, nor need to refer elsewhere, in order to appreciate fungal morphogenesis.

Fungal Morphogenesis

CONTENTS

The first chapter is an overview of the evolutionary origins of fungi and the central role they played (and still play) in the evolution of life on Earth. The second chapter introduces hyphal growth, the essence of the fungal life style, and identifies features which are crucial aspects of morphogenesis. Chapter 3 summarises fungal primary and secondary metabolism, necessary here because adaptation of primary metabolism and exploitation of secondary metabolism are both critical to fungal morphogenesis. In chapter 4 the impact of physiology on morphogenesis is discussed, with the genetic components of differentiation and morphogenetic change being dealt with in chapter 5. The development of form and structure is the main theme of a lengthy chapter 6, and the ideas developed here are brought together and summarised in the final chapter 7.

Fungal Morphogenesis was well received on publication (indeed, it appeared in the Top-ten Best Sellers list in the Professional Titles, Biology category produced by Yankee Book Peddlers for the 4th quarter of 1998).

YOU CAN ORDER the book from the publisher, Cambridge University Press, at this URL:
http://www.cup.cam.ac.uk/Scripts/webbook.asp?isbn=0521552958

Fungi as food

- *Good content of protein (20-30% of dry matter) that contains essential amino acids,*
- *chitinous walls as a source of dietary fibre,*
- *contain B-vitamins,*
- *low in fat,*
- *virtually free of cholesterol.*

Quorn™ myco-protein (*Fusarium venenatum*)

Quorn™ myco-protein fermenter

Two of the world's largest continuous flow culture systems are used to produce the Quorn™ myco-protein. Each fermentation tower is 50 m tall and 155,000 litre capacity. Installation was completed in May 1994.

Quorn™ myco-protein products

Fusarium, *Agaricus* and yeast!

Ultimate fungus food?

INDIVIDUAL PIES WITH A SHORTCRUST PASTRY BASE FILLED WITH QUORN MYCOPROTEIN AND MUSHROOMS IN A CREAMY SAUCE, TOPPED WITH PUFF PASTRY

INGREDIENTS: Wheat Flour, Water, Margarine (Vegetable Oil and Hydrogenated Vegetable Oil; Water; Salt; Emulsifier: Mono- and Di-Glycerides of Fatty Acids), Reconstituted Whole Dried Milk, Quorn Mycoprotein Product (7%) (Mycoprotein; Water; Egg White; Flavouring), Mushrooms (7%), Whipping Cream, Hydrogenated Vegetable Oil, Onion, Modified Maize Starch, Salt, Lactose, Milk Protein, Maltodextrin, Potato Starch, Raising Agents (Disodium Phosphate, Sodium Bicarbonate), Flavouring, Sugar, Yeast Extract, Nutmeg, Parsley, Pepper Extract, Sage Extract, Dextrose, Colour: Beta-Carotene, Flour Treatment Agent (L-Cysteine Hydrochloride).

WARNING: This product may contain traces of nuts.

Suitable for Vegetarians

Ganoderma is naturally variable

Ganoderma is cultivated, but not as a food ...

Ganoderma is used for medicinal purposes

Opportunities for the twenty-first century

- *Fungal protein foods can compete successfully with animal protein foods like meat on health grounds.*
- *Because fungal foods can be produced using waste products as substrates, they should also be able to compete successfully on grounds of primary cost.*

Industry produces wastes

Oyster and paddy straw mushrooms grow well on cotton waste of textile and garment industries.

All of agriculture produces wastes

Typically, 80 to 90% of the total biomass of agricultural production is discarded as waste.

Agriculture produces wastes

From this entire field of rape (canola) only the oil from the seeds will be used.

Agriculture produces wastes

This is an unacceptable loss of primary production but we could grow a lot of fungi on agricultural residues and convert wastes into food, animal feed, pharmaceuticals and other products.

Traditional Lentinula cultivation in China ...

… still the most widely used method though it is devastating hill forests.

Opportunities for the twenty-first century - themes for exploitation

- *Use of substrates that are waste products from other industries;*
- *combining bioremediation with mushroom crop production;*
- *sustainable use of a wider range of the biodiversity evident in natural populations.*

Sustainable cultivation of Lentinula

… uses 'artificial logs' made from hardwood chips and sawdust packed into polythene bags.

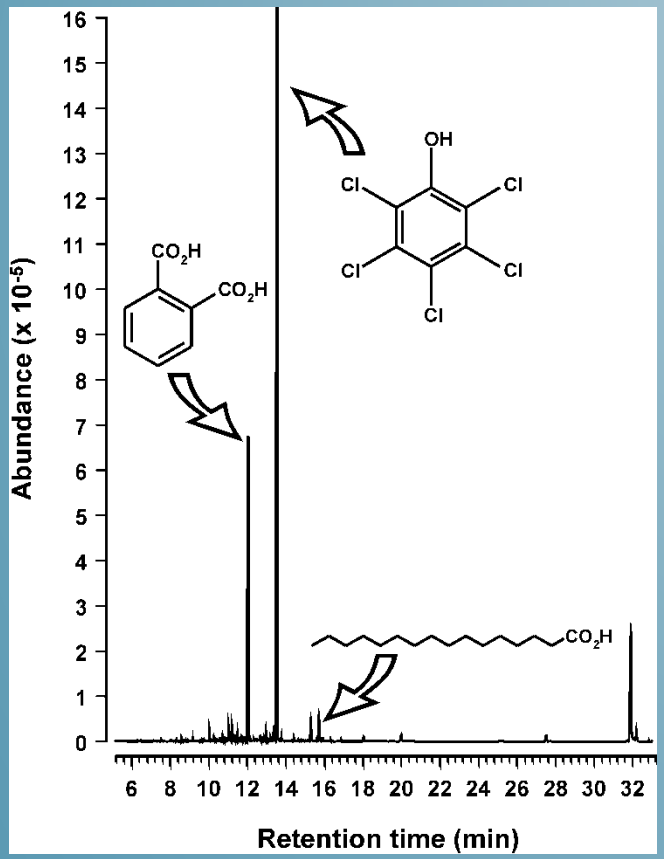
Bioremediation with fungi

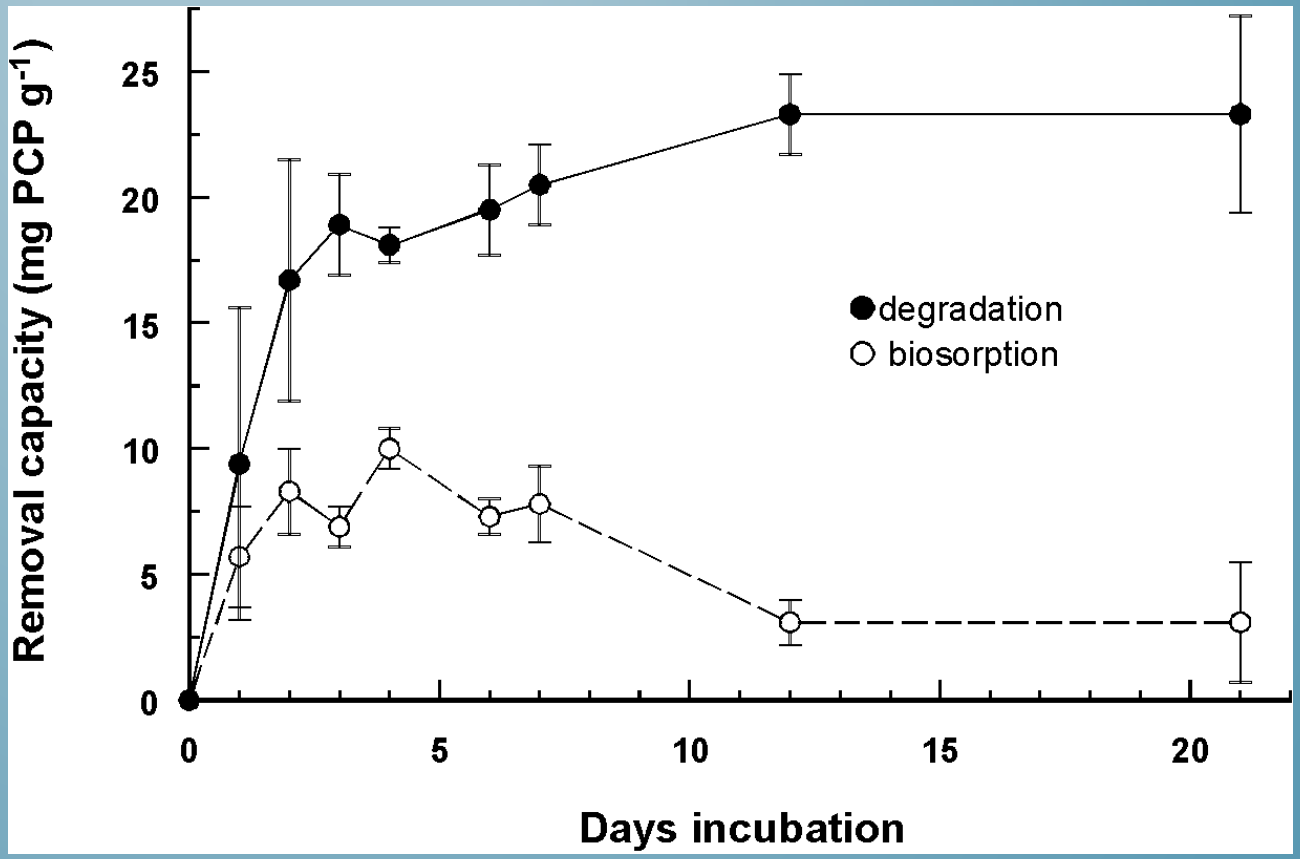
Many wastes are hazardous because they contain tannins and phenolics, toxic to plants and animals.

- *residues from extraction of oils such as cotton, rape, olive, palm oils;*
- *fruit processing residues, like citrus wastes;*
- *wastes contaminated with pesticides.*

Bioremediation with *Pleurotus*

The spent compost is able to remove the biocide pentachlorophenol (PCP) very effectively.





Bioremediation with *Pleurotus*

PCP has been the most heavily used pesticide throughout the world; it is very persistent in the natural environment and a common cause of soil contamination.

- *Using spent mushroom substrates in landfill sites combines soil conditioning with degradation of organopollutants as an effective strategy for bioremediation* in situ.

Heavy metal warning ...

Care is needed because mushrooms accumulate metal ions.

- *Wastes gathered from industrial sources for use in mushroom compost may be contaminated by heavy metals.*

The non-green revolution

On average, agriculture currently loses 40% of its primary production to pests and diseases and then throws away more than 70% of what's left because the crop always represents so little of what is grown.

That works out to an overall 18% efficiency, at best.

Wake up to fungi!

Today fungi range from amongst the smallest to the largest individuals on Earth.

Yeasts are amongst the smallest, yet we use them to make enough alcohol every year to refloat the Titanic.

Wake up to fungi!

In the Malheur National Forest in eastern Oregon ***the largest organism on Earth*** *dwells.*

It covers an area of 890 hectares, weighs in at around 150 metric tons and is at least 2,400 years old.

It is, of course, a fungus, a clone of a tree root pathogen known as Armillaria ostoyae.

When all that's left of the primates are their buildings and artifacts ...

the buildings will crumble, but ...


… the fungi
will still be
here … .. ...

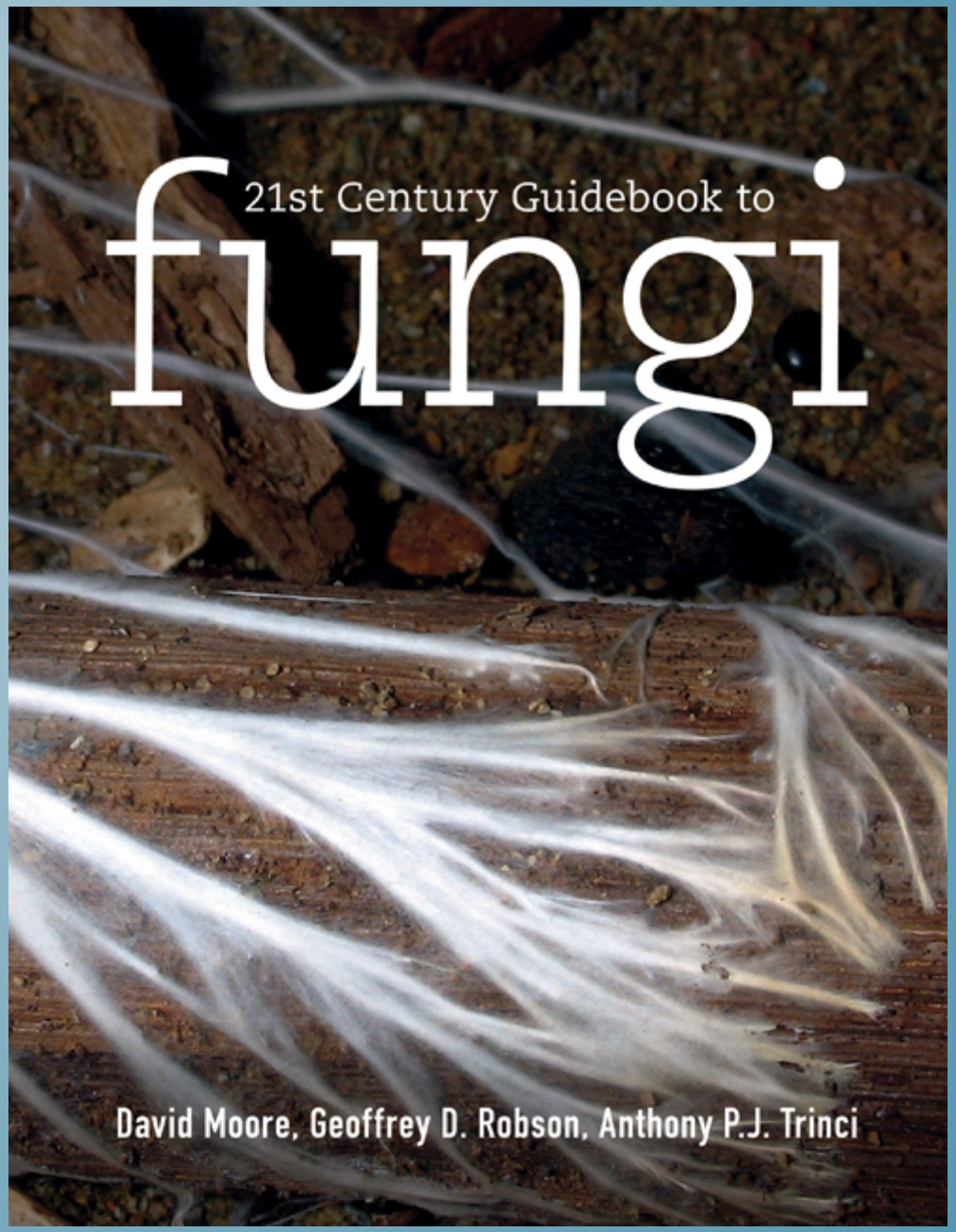
Wake up to fungi!

A new textbook for serious study of fungi:

21st Century Guidebook to Fungi *by David Moore, Geoffrey D. Robson and Tony Trinci.*

Published by Cambridge University Press

ISBN: 9780521186957



21st Century Guidebook to Fungi

by David Moore, Geoffrey D. Robson and Tony Trinci

Fungi have their own unique cell biology and life cycle, but also play critical roles in wider biological systems. This textbook provides an all-round view of fungal biology, ranging in scope from the evolutionary origins of fungi and other eukaryotes more than a billion years ago, to the impact fungi have on our everyday lives. Bringing mycology teaching right up to date, this unique systems biology approach emphasises the interactions between fungi and other organisms to illustrate the critical roles that fungi play in every ecosystem and food web. With more than 60 colour figures, examples of computational modelling and resource boxes directing students to areas of interest online, this uniquely modern textbook gives students an appreciation of fungi both at the organism level and in the context of wider biology. A companion CD features a hyperlinked version of the book and the fully integrated World of Cyberfungi website complete with the Neighbour-Sensing interactive fungal growth simulator program.

Publication date: July 2011; 640 pages + 406 b/w illus. + 57 tables

ISBN: 9780521186957