Taken from *Slayers, Saviors, Servants, and Sex: An Exposé of Kingdom Fungi* by David Moore; published by *Springer-Verlag, New York: 2001,* ISBN 0387950982.

Chapter 10 The cavalry is coming. Fungi to the rescue

There's a general feeling around that human activities are making a mess of this, our one and only planet. We pollute our air. We pollute our water. We pollute our food. For short-term gain, we cause long-term damage. The only face-saving aspect of it all, is that for most of the time our technology has been reshaping the planet we have been unaware of the damage we have been doing. Like children playing a game we have wrought a civilization with no appreciation of the harm the activity involved has been doing to the fabric and holistic life of the Earth. If there is anything special about the human animal it is that we have the ability to set our own constraints. In nature competition, predators, disease and available resources constrain populations. It's our technology, and our ability to devise it, which makes us different from other animals. Strip us of our technology and send us naked into nature and we are not very special. Without the tools that enable us to punch above our weight, nature once more imposes on us a balance determined by outside forces. But our technology allows us to step outside the biological constraints and impose our will upon the world. This 'technology' I'm thinking of here is not at the nuclear power and rocket science end of the spectrum. Once this primate discovered fire, a single human/ape creature could level a thousand-year old forest into scattered smouldering embers. Invent flint axes and arrow heads and he can inflict death and destruction on the most fearsome predators. Give him the wheel and a lever and he will move mountains. Domesticate the horse and the primate can roam over tens of thousands of miles in a single life-time. When the primate invented agriculture the climax vegetation stopped being forest and became whatever he wanted to grow, be it cereal grasses, tobacco or poppies.

We have been modifying nature systematically since we lived in caves and chased mammoths. The only possible defence we can offer for our adverse impact on our environment is that for most of the time we were ignorant of the extent of the damage we were doing. Indeed, even ignorant of he fact that we were inflicting damage. We know about it now. Our damaging activities cannot be excused, let alone denied. But we face conflicting demands. We now depend on continuation of our current technological activities. We can't consider the prospect of even slowing down our present industrial-commercial civilization because there are six thousand million of us. Admittedly, a lot of those people don't get their fair share of the resources available. But we would not be able to support a fraction of one percent of that population without the much-reviled industrial-commercial machine we have created. We cannot live without it; equally, the planet cannot live with it. At least, cannot live with it in its present form. The paradox is that we cannot afford to stop and we cannot afford to continue. The resolution of the paradox is that we *could* change *how* our industrial-commercial machine works its magic for us. A compromise must be established and over recent years the name of that compromise has become 'sustainable development'. Arising out of world environmental commissions and finally the UN Earth Summit in Rio de Janeiro in 1992, sustainable development has become a priority for the world's politicians and policy makers. Its foundation is the recognition that it is not possible to return to a natural lifestyle but the unnatural lifestyle we have created for ourselves must be managed in such a way that future generations can continue to enjoy it. Like it or loathe it, but a commercial analogy summarize it best: the Earth must be managed in the way good managers would run a company if they were intending to pass a going concern on to their children. It's a good analogy, because that's exactly what we have to achieve, isn't it?

Having recognized that a problem exists; the policy makers have tried first to estimate how much it will cost to deal with it. In Europe it's been estimated that improving waste management will cost three hundred thousand million Euro, half that again to ensure good quality drinking water, and almost four hundred thousand million Euro to counteract the greenhouse effect. The equivalent figures for these three programs in the USA are two hundred and seventy thousand million, one

© David Moore 2001

hundred thousand million, and three hundred and seventy thousand million US dollars respectively. Estimates of other, this time global, costs are: over one hundred thousand million US dollars to protect the topsoil on agricultural land, over thirty thousand million US dollars for renewing forests, one hundred and fifty-five thousand million US dollars to slow the rate of human population growth, two hundred thousand million US dollars to raise the efficiency of energy usage and one hundred thousand million US dollars to develop renewable energy resources. These are the estimates of likely costs *at the start of the program* but you know they are bound to rise.

As you can see from the nature of the programs listed, what we are facing is a biological problem. The animal that is called 'human' is, through a variety of its activities, causing biological damage to its environment. If the problem is biological, then its solution can be biological too. We can see this in some of the programs that have already been started. We are used to hearing about renewable energy sources, for example. Water and wind-driven power generation seem to be at the top of this list, but biotechnological alternatives to fossil fuels could become important too. Now these might include materials like alcohol; produced, say, by fermentation of some industrial waste product like molasses. Sadly, after twenty-five years of development, Brazil and North America are still the only regions producing large quantities of fuel-alcohol, from sugar cane and maize respectively. Unfortunately, even here it is only tax credits that make fuel-alcohol commercially viable because oil prices are so low. It may not be all 'doom and gloom', though, because tax considerations may encourage the use of fuel-alcohols in aviation. The airline industry is one of the fastest growing sources of greenhouse gasses at the moment because of its rapid expansion and dependence on kerosene produced from crude oil. A report in the London *Observer* for 27 February 2000 described how British Airways, Rolls Royce Aerospace and several UK Government ministries were co-operating in a venture to assess whether planes can be fuelled with a kerosene alternative produced by fermentation of straw and wood pulp. Although an expensive alternative at the moment, such fuels are likely to become viable alternatives as increasing taxes are imposed on oil-derived fuels following international agreements based on 'the polluter pays' principle.

It may seem perverse to go to such extremes to replace one burning fuel with another, but it's not. Even direct burning of wood, or some more rapidly produced plant biomass that can be burned as a fuel, better for our environment than burning coal or oil. Providing appropriate steps are taken to minimize direct pollution from smoke and particles in the flue gases, it is more eco-friendly to burn wood than it is to burn fossil fuels because burning fossil fuels increases the atmosphere's content of carbon dioxide. Burning wood produces carbon dioxide, too, but the point is that when you burn something that grew over the past few years you are simply recycling the carbon dioxide that was already in the atmosphere during the past few years. So the removal of atmospheric carbon dioxide as the wood was formed, and its sudden release as you burn it are just minor perturbations in what amounts to the 'present day' carbon dioxide level of the atmosphere. When you burn oil or coal you are releasing into today's atmosphere carbon dioxide that was used in photosynthesis three hundred million years ago. In effect, burning oil and coal short-circuits the natural carbon cycle, reinjecting into the atmosphere chemicals that were removed long, long ago. This disturbs the natural balance of the atmosphere and has resulted, as we all know, in the greenhouse effect problem we have now.

Fungi could certainly help us to cope with at least some of these problems. Since the problems we have created for ourselves are biological ones, there are many areas in which application of biotechnology might provide solutions. For example, in terms of improving food production, creation of renewable resources, and dealing with waste materials. In all of these, fungi have a great deal to offer. There is no way that I can set out a comprehensive recipe for solutions here but I do want to describe a few topics where I believe current thinking patterns amongst the experts are too narrow and risk losing opportunities which the fungi offer. Let's look at food production first.

© David Moore 2001

The underlying food production problems are widely seen as resulting from the rapidly growing human population and the damaging environmental effects of today's most efficient agricultural production systems. The most uncomfortable statistic from which conventional experts start is the fact that approximately forty percent of crop production world-wide is lost to competition with weeds, and to pests and to pathogens. The experts see a number of potential remedies, in which biotechnology can be involved. Among these are the need to focus attention on the production of more food on the same area of land, with the aim of reducing the pressure that continues to expand agriculture into the wilderness or forest areas which are the natural reservoirs of biodiversity. Obviously, there is also a perceived need to reduce losses of harvested crops and so effectively increase crop yield, and to replace conventional fertilizers and pest control agents (which are resource and energy-demanding) with more environmentally friendly alternatives. And finally, encouraging replacement of environmentally damaging agricultural practices with more enlightened crop management techniques.

It seems to me that there is another statistic that needs to have some attention paid to it. This is that so little of what agriculture produces is actually used. Our agricultural efforts produce more waste than anything else. This cannot be allowed to continue; yet it is a feature that rarely appears in the policy maker's deliberations. That's worrying because the wrong decisions have been made before. The so-called green revolution in the 1960s involved the introduction of new high yielding varieties of cereal crops like corn and wheat in order to increase the world food supply. Unfortunately, the new varieties required good irrigation and application of large amounts of chemical fertilizers and pesticides which were costly to produce and expensive to buy. Inevitably, only the richer farmers were able to benefit from this alleged 'revolution' and the increased applications of chemicals damaged the environment. The approach was completely wrong though there was so much misguided political conviction behind it that it took thirty years before the green revolution started to die away. We cannot continue to expect the Earth to produce more and more, what we must do is make better use of what the Earth already produces. Over seventy percent of agriculture and forest production is not useful or is wasted in processing. Just think of a field of flowing corn - only the seeds are used. All of the plants that you can see rustling in the breeze are waste and contribute to the three thousand million tonnes of cereal straw wastes we produce each year. The same astonishing level of wastage applies to every cereal crop. Or consider fibre production from sisal; the extracted fibre is only two percent of the sisal plant - the other ninety-eight percent is thrown away as waste - tens of millions of tons of waste every year. Palm and coconut oils represent only five percent of the total biomass grown on palm and coconut plantations, all the rest is waste. Sugar cane is better. As much as seventeen percent of sugar cane plants emerges as sugar; so only eighty-three percent of what is grown is wasted.

Apart from agricultural and forest wastes, there are growths of weeds, especially in Africa, which cause problems. Water hyacinth is the prime example. It is widespread on the surface of most tropical African rivers, dams and lakes. In some places it produces so much biomass that it prevents navigation of water channels and damages fisheries as well as transport. Growth of water hyacinth consumes production resources to an astonishing degree - several African countries produce millions of tons of water hyacinth biomass. All of these waste materials squander the materials and efforts put into growing the crops to a scandalous degree, and they become an embarrassment in their own right. They are wastes for disposal by burning on site, burying, or dumping in landfills. So, not only are we making barely marginal use of the primary production of the Earth but we are creating a waste disposal problem for ourselves in the same process.

There's got to be an alternative approach, and maybe we should start by recognizing that these agricultural waste materials, which are abundant and ready available in every corner of the world, especially in tropical and subtropical regions, are resources because they are potential substrates for

© David Moore 2001

mushroom cultivation. Concerted use of agricultural and similar wastes could produce millions of tons of edible mushrooms for table use; and millions of tons of organic fertilizers from the spent composts. The approach can be applied at the 'cottage industry' or peasant farmer level or at the more industrial level. The mushroom industry already has most of the technology that is needed for this. What is required is proper promotion and active support by the private sector as well as governmental organizations. Stated in these direct terms - 'we should all grow mushrooms' - it might well sound a bit nutty, but it's not. So bear with me for a moment and I'll explain why mushroom fungi are particularly useful and suggest a range of different things we could use the mushrooms for.

The great significance and promise of mushroom fungi lies in the fact that they belong to a group of fungi that can degrade woody materials. They have spent a hundred million years or so evolving the ability to secrete enzyme complexes that are able to convert various woody materials into nutrients suitable for fungal growth. Not just timber, but stems, leaves, roots and all the other large and small bits of vegetable matter that accumulate as plants grow and die. They are almost unique in their ability to digest woody material completely. A very few bacteria can make some effort in this direction, but these mushroom-related fungi are responsible for degrading by far the greatest proportion of waste plant materials in nature, so why not utilize that natural specialist activity to deal with our agricultural and other wastes? It seems perverse, to me, that various laboratories around the world are spending millions of dollars trying to genetically-engineer bacteria for a job the fungi have been doing since before the dinosaurs appeared. Microbial degradation of woody materials is difficult by design - by the design of the plants! The chemicals that make up wood contain several phenol-derived compounds with the specific purpose of protecting the plant tissues against microbial attack. Remember that wood is made up from the walls of plant cells. And the phenolics are put into those walls to protect the plant cells from invasion by microbes. They are natural antiseptics. The fact that so few microbes can digest wood is a measure of how effective the plants have been with all that evolutionary self-protective effort. The fact that the fungi have breached those plant defences is a tribute to the fierce competitive edge of the fungi. They have found a way to use a resource that is resistant to attack by other organisms. They do this by producing enzymes that produce and use highly active oxygen molecules. To all intents and purposes the fungi rip the wood molecules open in a precisely controlled burning reaction. These are the allies we should use!

Alright, so on biological and chemical grounds the more advanced fungi - especially the mushroom fungi - are the ideal candidates to degrade the waste vegetation that we produce through our agricultural activities and which, like water hyacinths, grow as weeds in regions that are not cultivated. But their usefulness is not limited to getting rid of waste vegetation. Not only do we have large amounts of wastes, but some of them are polluted with pesticides which are chemically similar to the complex phenolic compounds found in wood. Since the fungi can decompose the wood, they can also be used to degrade the environmental pollutants, both in soils and in liquid effluents. Things like industrial waste-water discharges such as those produced by the paper pulp industry, but especially pesticide-contaminated wastes. Many of the mushroom fungi and their relatives can degrade environmental pollutants you may have read about such as chlorinated biphenyls, aromatic hydrocarbons, dieldrin and even the fungicide benomyl. They don't just degrade these materials, leaving other possibly dangerous substances behind. No, they completely mineralize the pollutant so that its chemical constituents are returned to the atmosphere and soil as carbon dioxide, ammonia, chlorides and water. The oyster mushroom is particularly good at this sort of thing. We've recently found that several mushrooms degrade chlorophenols, which have been commonly used as disinfectants and preservatives for several years, and pentachlorophenol (more commonly known as PCP) has been the most heavily used pesticide throughout the world. It

© David Moore 2001

has been used in the United States mainly as a wood preservative and enormous amounts (about six million kilograms each year) have been sprayed over vast areas of central China to kill the snails that carry the schistosomiasis parasite. Although it's illegal to use PCP in most countries today, the chemical is very persistent and most of what was released in the environment is still there. It's toxic, cancer-inducing and has been declared a priority pollutant for remediation treatment. The conventional remediation strategy for PCP-contaminated is excavation and incineration or land filling. Such methods are expensive, obviously destructive to the environment and ineffective for anything other than 'point source pollution'. Bioremediation is a very promising alternative, using biological systems for the environmental clean-up. And by far the most promising technique seems to be to use the spent mushroom substrates remaining after harvesting mushroom crops. Ironically, these are often discarded as wastes themselves, but the spent compost left after oyster mushroom cultivation does two crucial things. It absorbs, immobilizes and concentrates PCP so it can be transported away from the contaminated site. But it also digests PCP completely, providing an integrated approach to remediation. You also get a crop of mushrooms!

Mushroom cultivation is a common practice all over the world and the idea that hazardous waste materials could have their pollutants removed *and* produce a mushroom crop at the same time is exceedingly attractive. But the idea is not free of problems. We have found that oyster mushrooms can concentrate the metal cadmium (a common industrial contaminant) to such an extent that by eating less than an ounce (dry weight) of the most contaminated samples you would exceed the weekly limit tolerated by humans. Cadmium is so toxic that this situation could pose a public health hazard. There are no worries about conventionally-cultivated oyster mushrooms. The point is that if the mushroom is grown on composts that might be mixed with industrial wastes (in remediation programs, for example), then it would be advisable to monitor the heavy metal contents before mushrooms are marketed for food.

Actually, the ability of mushrooms to absorb metals opens up yet another potential area of fungal biotechnology. More and more attention is being given to using fungal tissue to take up metal ions from solution. The aim of this is removal of polluting heavy metals (even radioactive ones) from effluents using the adsorptive capacity of living or dead fungal tissue. It's the fungal wall that makes it possible. It has evolved over the years to attract and accumulate metal atoms that might be needed for the fungus nutrition. It's a chemically reversible binding reaction, so that the fungus could take up the metal from its own wall, probably in exchange for a hydrogen atom. But the different metals have lots in common so a wall evolved to accumulate a common metal which is important in nutrition can also accumulate the less-common metals which escape into the environment from our industrial processes. These polluting metals can be removed from waste waters or other liquids by passing the effluent through a column containing the fungal material. Not only can you clean up polluted effluents this way, but you can also recover precious metals from industrial wastes (like the silver from photographic waste solutions and the gold from electronic chip industries). Current practice is to use ion exchange resins for metal recovery but the effectiveness of resins is reduced by the (very common) metals calcium and magnesium, and they are not good at adsorbing minute quantities of metals from large volumes of effluent. These are exactly the situations that the fungal wall has evolved to cope with and metal binding to fungal tissue is not greatly influenced by calcium and magnesium and is capable of accumulating metals from solution that are present in only trace amounts. Once metal ions have been adsorbed it is commercially essential to release them so that the fungus material can be reused and the metal recovered. This can usually be done quite easily by treating the fungus with solutions of sodium bicarbonate or ammonium carbonate. This adsorption desorption cycle can be repeated pretty often. As you might expect, efficiency of metal removal differs between different fungi - it's presumably linked to the life style and ecology of the fungus. I mentioned cadmium accumulation by oyster

© David Moore 2001

mushrooms before. Our experiments showed that you could recover thirty kilogram of the metal per metric tonne of mushroom. This is in the same ballpark as commonly used exchange resins. Experiments with other fungi have given recoveries of just under two hundred kilogram of metal per metric tonne and that level of yield is at least twice the uptake capacity of the best exchange resins. The message seems to be that there's bound to be a fungus able to recover the metal you are interested in from whatever metal-rich effluent you have to dispose of. It's worth the research effort to find it.

If you are pouring some effluent through a bed or column of fungal material in order to remove metals, you'll find that the solution that percolates through will be clarified. This is because fungi are also very good at adsorbing insoluble particles from solutions. Most fungi can adsorb almost any particle with which they are challenged. Again, it's related to their life style and ecology. In nature, fungi explore their surroundings in a search for food resources. When they find a resource it gets stuck to their wall and they produce the necessary enzymes to digest it. That's fungal nature. If you exploit their ability to trap particles you find that they quite readily adsorb metal particles (like colloidal gold), elemental sulphur, insoluble sulphides, charcoal, clays and even magnetite (so you can make magnetic mushrooms, if you like). Imagine using this ability to remove particles from waste streams to clarify them before discharge into rivers. Unfortunately, despite all the research devoted to the possible use of fungi to recover metal ions and remove particulates, no large-scale industrial process has yet appeared, even though the fungal process can perform better than most conventional chemical and physical techniques of effluent treatment. One reason why biological processes are consistently ignored is that chemical engineers are uncomfortable with anything that's really new. The industry is accustomed to handling established chemical-physical systems, the customers are confident about buying them and the whole unimaginative cycle is closed off to biological innovation. The vision is there for those with eyes to see.

A few pages back I suggested we must make better use of the Earth's primary productivity. We cannot continue to accept an agriculture that loses forty percent of its production to pest and disease *and then throws away more than seventy percent of what's left* because 'the crop' always represents so little of what is grown. Work through that little equation - we only take sixty percent of what we try to grow through to successful production and we use, at most, thirty percent of that - so the bottom line is that we make use of no more than eighteen percent of the Earth's primary productivity. Eighteen percent! Of the six billion people on the planet, one and a half billion don't have enough to eat. Yet we congratulate ourselves on a world-wide agricultural industry that can manage a magnificent eighteen percent efficiency. It's time we tried something else.

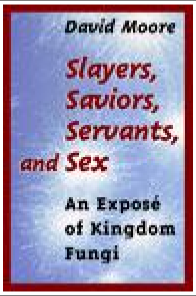
A good friend of mine, Shu-Ting Chang, who recently retired from the Chinese University of Hong Kong, has suggested that the something we should try is a 'non-green revolution' that makes use of that part of the primary production which is not used for mushroom cultivation for mushroom production and, *importantly*, mushroom products.

Remember, that in nature there are mushrooms everywhere. They grow on trees, they grow on grass. They grow in arctic snow, desert sand and tropical rain forest. They have spent several hundred million years evolving to exploit every terrestrial habitat. More than two thousand species of mushroom are considered good to eat, but up to now attempts have been made to cultivate only about one hundred species. Indeed, despite the fact that mushroom cultivation is a world-wide industry (about equal in value to the coffee crop), only about thirty species are commercially cultivated and only seven are cultivated on what could be described as industrial scale. So there's plenty of scope. Scope for finding mushrooms able to use any of the waste materials available. Scope to operate on small, medium or large scale farming; subsistence or high-technology. Scope to cultivate mushrooms for new markets or old markets. Mushrooms are highly nutritious foods but

© David Moore 2001

they are under-exploited. Mushroom tissue could be used as a meat substitute in processed ‘ready-to-eat’ meals - if it can be done with Quorn, it can be done with mushrooms. But it’s not just a matter of mushrooms for the table. Mushrooms for industry makes sense, too. Mushrooms to be used in bioreactors for metal-recovery and effluent filtering. Mushrooms to be used as a source of biologically active compounds for use in the prevention and treatment of human disease. And then there’s the used mushroom compost. It makes a good animal feed. Plant proteins are deficient in amino acids essential to human (and animal) nutrition. Fungi are not deficient in those amino acids, so a compost full of fungal cells is a better feed for the animals. Animals can’t digest the woody parts of the plants they eat, but if a mushroom fungus is grown on woody, twiggy material it digests the wooden parts and when the animals eat it they can make better use of a greater proportion of the feed. So on two counts, used mushroom compost can make good animal feed. It also makes good soil conditioner. If you can think of nothing better to do with it, plough it into land-fill sites. It’s got the structure and constitution that can only improve the soil *and* it can digest those persistent organic chemicals and pesticides we use in industry.

The non-green revolution offers employment, economic growth and protection and regeneration of the environment. And the mushrooms taste good! It’s all there waiting for us. Come on world. Wake up to mushrooms!



Did you like what you’ve just read? Then, why not buy the whole book?

Online orders from http://www.springeronline.com/ can be shipped within 2-3 days.

Order details:
Slayers, Saviors, Servants and Sex. An Exposé of Kingdom Fungi by David Moore (2001), vii + 175 p. 11 illus., Softcover: ISBN: 0-387-95098-2.

© David Moore 2001