Fungi and Sustainability

Ron Spinosa*

Fungi . . . are the primary governors of ecological equilibrium.
Paul Stamets, *Mycelium Running*

Abstract

The concept of "sustainability" is becoming ever more prominent in almost every area of human affairs, from individual households to the planet Earth itself. A brief history of the development of the concept of sustainability and its implementation is presented. The United Nation's Earth Summits have been especially important in creating programs to promote sustainable development in response to the global crisis that has resulted from a century of exploitation of the Earth's resources and exponential human population growth. Fungi can play a significant role in the pursuit of sustainability. For example, mushroom cultivation may be integrated into schemes for recycling agricultural waste as well as providing nutrition and income for peoples living in developing nations. Fungi are essential for the health and sustainability of terrestrial ecosystems. In the case of catastrophic destabilization of the earth's ecosystems by human folly, fungi will prepare the way for the future.

Keywords: Agricultural waste, Mushrooms, Mycorrhizae, Recycling

"How Mushrooms Can Help Save the World"—This is the rather sensational subtitle of Paul Stamets's superb new book, *Mycelium Running.* If you haven't yet read his inspiring book you might think that his subtitle is hyperbole, but he passionately believes that if we commune and cooperate with the mycelial networks beneath our feet—networks that form an essential component of the earth's ecosystems—there is hope for the survival of our species.

Stamets is not alone in his optimism about the future role of mushrooms (and other fungi) in human affairs. A number of organizations see mushroom cultivation playing an important part in moving our planet toward sustainability. I would like to introduce one of these organizations, Zero Emissions Research and Initiatives (ZERI), that is doing especially innovative work with mushrooms and sustainability, but first a brief overview of the history of the sustainability movement may make our discussion more meaningful.

Sustainability

The word "sustainability" has recently come to find itself pushed forward into the limelight and attached as a modifier to nouns with which it formerly had no more than a nodding acquaintance. "Sustainable development," for example, has been with us for some time, but more recent pairings are now commonplace: sustainable agriculture, sustainable design, sustainable energy, sustainable tourism, and sustainable living, to name a few. I'm sure you will come across the word at least once today.

The more this word appears in the current media, the more familiar we all become with the ideas behind it, and the more it reflects the growing shift in the way we view our relationship to the earth and all its species. It is the foundation of the Green Movement, for example. It represents one aspect of this shift of perspective and emphasizes the value of ecological preservation, maximization of biodiversity, and empowerment of local communities.

Ever since the Apollo missions gave us images on our TV screens of the pretty blue marble in space, the fact that we are all passengers on "spaceship earth" has been dramatically impressed upon our consciousness. With that image we could more concretely begin to view our species as only one in an intricately interdependent network. We could more easily imagine ourselves as one among millions of species living in a thin membrane, the biosphere, on the surface of our planet—planet whose resources are not endlessly exploitable. The philosophy of sustainability is a repudiation of the early 20th-century industrial model of the exploitation of nature, with its technology-driven economic growth and demand for ever-greater consumption of products and services.

The underlying ethic of sustainability was succinctly articulated in the 1987 United Nations report, "Our Common Future" (AKA "The Bruntland Report"): ". . . meeting the needs of the present generation without compromising the ability of future generations to meet their needs (www.un.org/geninfo/bp/envirp2.html.)

The report prescribed sustainability as a goal to be applied to every level of organization, from local communities to the entire planet. The Bruntland Report was the result of the work of the United Nation's World Commission on Environment and Development, chaired by former Norwegian Prime Minister, Grö Harlem Brundtland. (See United Nations Briefing Papers Home Page at: www.un.org/geninfo/bp/worconf.html.)

One of the principle conclusions of the Commission was that our critical global environmental problems are primarily the result of the enormous poverty of the South and the non-sustainable patterns of consumption and production in the North. This Com-

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mission was the impetus for the UN Earth Summit in 1992, where a global plan for sustainable development was first revealed. The plan became known as "Agenda 21" (the 21 refers to the 21st century). The next Earth Summit at Johannesburg in 2002 (The World Summit on Sustainable Development) called for full implementation of Agenda 21, along with the achievement of the "Millennium Development Goals" by 2015. Those goals are as follows:

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria, and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development

   (See Millennium Development Goals at www.un.org/millenniumgoals.)

The United Nations, believing that it is of vital importance for everyone to understand the concept of sustainability and the Millennium Development Goals, has declared a "Decade of Education for Sustainable Development," which started in January 2005.

The response to the UN's reports and initiatives has been overwhelming. Scores of organizations, both governmental and non-governmental, have arisen to work toward sustainability in all areas of human activity-economic, ethical, social, technological, and environmental. A list of some of those organizations is appended at the end of this article.

What Do Mushrooms Have to Do with Sustainability?

I am sure you recall seeing news reports about the mass slaughter of millions Asian chickens and other poultry as a measure to prevent the spreading of the deadly avian flu. In response to the crisis the government of Hong Kong declared a complete ban on the raising of poultry. Millions of chickens were exterminated in an attempt to kill all poultry in the province (Nowak, 2002; Young, 2002). This action has had a devastating effect on hundreds of small farmers, whose livelihoods have depended on raising poultry for generations. As a remedy for the plight of the poultry farmers, the Hong Kong Department of Agriculture is offering an alternative to poultry farming—mushroom cultivation. The farmers are being offered seminars to learn the techniques for mushroom cultivation and marketing (UPI, Hong Kong, Feb. 15. 2006).

There are a number of good reasons for promoting mushroom cultivation: Mushrooms are a crop that grows rapidly and yields high returns. For example, Oyster mushrooms can fruit in one month. Mushroom growing houses can be very simply made at low cost, using low tech methods, on small plots of land. A mushroom cultivation business can be managed by a family or small community. The prices commanded by mushrooms are much greater than for other comparable produce, and the demand for "gourmet mushrooms" is increasing worldwide. Mushrooms are quite nutritious, and they can be a potential food source as well as a marketable product in impoverished areas. In addition, mushrooms have significant medicinal properties, which makes them a potential health food commodity. Shiitake mushrooms, for example, are a source of the compound Lentinan, which is being evaluated as an anti-cancer drug. Even the ubiquitous polypore, *Trametes versicolor* ("Turkey Tail") is a source of " PSK," another substance with anti-cancer potential (Hobbs, 1995). Health food stores and upscale "whole foods" markets now have whole lines of "mycomedicinals." Paul Stamets (1999) is well known for his pioneering work in this area.

The most significant virtue of mushroom cultivation is that mushrooms can perform the alchemy of transforming agricultural and other organic waste into a nutritious and marketable product. Oyster mushrooms can grow on cottonseed hulls, cocoa hulls, banana leaves, coffee waste, straw, and even newspaper and cardboard. Shiitake mushrooms grow well on many different woods and forest waste materials. But that is not the end—once the mushroom harvest is over, the spent mushroom substrate has all the nutrients, protein, and medicinal compounds found in the mushrooms themselves. This makes it an ideal feed product for livestock, being both nutritional and medicinal (Adamovic et al., 1998). Alternatively it can be used as excellent compost for other plant or vegetable crops, again turning a waste product into a valuable resource.

ZERI and Mushroom Cultivation

ZERI <http://www.zeri.org/> is an international organization founded by the visionary eco-designer, Gunter Pauli. Pauli has been a pioneer of sustainability. He has a long record of achievements in this field starting in the 1980s. Pauli was selected as one of "100 Global Leaders of Tomorrow" by the World Economic Forum. He is currently traveling internationally to train and certify practitioners of his revolutionary eco-design principles. His students have gone on to initiate projects in both developed and developing nations (Pauli, 1996; 1997).

ZERI stands for Zero Emissions Research and Initiatives. The philosophy of ZERI in a nutshell is "Zero emissions means zero waste." It applies "systems thinking" which is holistic and considers feedback loops in complex dynamic systems, to design projects applicable to all human needs—food, shelter, livelihood, self esteem, community—in a sustainable manner.

The design principles of ZERI are modeled on the natural world, drawing instruction from the relationships among the five kingdoms of life on earth—bacteria, protists (e.g. algae), plants, animals and fungi. In the natural world we observe that the waste, or even the toxin, of one kingdom is often a nutrient or energy source for species of another kingdom. A prime example would be the saprophytic relationship between fungi and plants. Without fungi we would, of course, be smothered by mountains of dead plant material. The five kingdoms, working together harmoniously in a healthy ecosystem, process organic matter to maximize productivity, biodiversity, and the resilience of the system itself. An ecosystem endures indefinitely, as long as the climate and environment are stable. Resources do not become exhausted, nor does the ecosystem pollute itself into oblivion. It is, in other words, sustainable.

Beer, Bread and Mushrooms

Let's examine a ZERI project that will illustrate its design principles. The project was initiated in a small community in Tsumeb, Namibia, where a brewery was developed. In traditional breweries, the beer making process generates huge quantities of organic waste and lost energy for every unit of beer produced. In fact, only a small percent of the nutrients in the grain are utilized in the process. The protein in the grain is left almost untouched. The spent grain becomes waste, yet it contains a considerable amount potential nutrients. A traditional brewery would often dispose of the spent grain in a landfill. An obvious waste disposal solution might be to feed the spent grain to animals. The problem with that is that animals find it difficult to digest spent grain—and it gives them gas. The result is considerable amounts of methane, a greenhouse gas, emitted into the atmosphere. This emission represents pollution and wasted energy. To make maters worse, the runoff from manure produced by the animals may also pollute the watershed to further sully the environment.

In accordance with ZERI design principles, the Namibian brewery has found a way to turn waste into a resource, thus generating "value added." This is where the mushrooms come in. The spent grain is a prime substrate for the oyster mushroom, *Pleurotus ostreatus*. With a relatively small investment, a simple mushroom cultivation operation will yield a crop of nutritious and marketable oyster mushrooms, as well as more jobs for the local farmers. After fruiting and harvesting, the mushroom substrate has increased protein content, since it is loaded with mycelium. As it turns out, livestock find the substrate palatable, and the increased protein content means an increase in the growth of the animals and better quality meat. Another use for the spent grain is to incorporate it into bread, so there will be more bread to feed more humans—another example of "value added."

But that is not the end of the story. Other kingdoms need enter the picture. Wastewater from the brewing process can be used to flush manure and other organic mater from the animal pens. The run-off water, rich in organic content but also containing pathogenic bacteria, is then fed into an airtight "digester." The digester employs the services of anaerobic bacteria to produce methane that can be collected and burned to provide the heat needed to sterilize the spent grain for use as mushroom substrate. After the bacteria perform their magic, the pathogen-free but still nutrient-rich effluent is processed further in oxidation ponds, where algae process the rich brew via photosynthesis and flourish to produce more algal biomass. The algae, in turn, is harvested as a food for fish in an adjacent pond. Finally, the water from the algae pond, still nutrient-rich can be used to fertilize gardens and crops, thus yielding higher quality organic plant crops without resorting to synthetic fertilizers. There! I believe we have included all the five kingdoms of life (Mshigeni and Pauli, 1997).

All of this information is nicely summarized by the following flow diagrams in Figures 1 and 2 from the ZERI web site (http://www.zeri.org/index.cfm?id=projectBrewery).

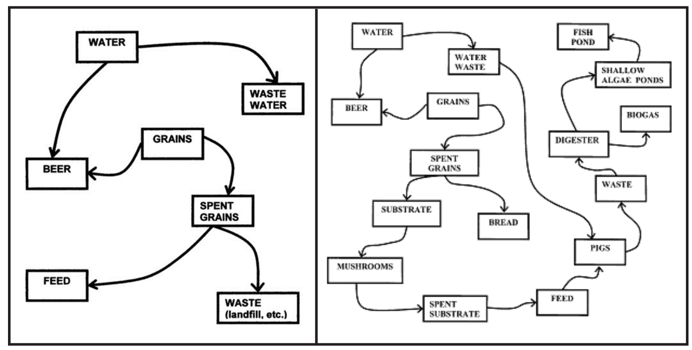

Fig. 1: Traditional Brewery Process Flow Diagram; Fig. 2: ZERI Brewery Process flow diagram (with permission of Gunter Pauli).

An interesting variation on the system described above was explored by ZERI trainee, Mary Appelhof (AKA Wormwoman). I was sad to learn the Mary had passed away after this article was written. Mary was associated with Sustainable Communities/ZERI-New Mexico (SCZ-NM), one of the first ZERI projects in the USA, located near Santa Fe, New Mexico. Mary was a believer in worm-power! Gunter Pauli also extols the virtues of earthworms. Ms. Appelhof was implementing one of a number of ZERI projects that utilize the potential of earthworms. In her scheme, spent mushroom substrate is fed to earthworms that then transmute the mushroom mycelium into more worm biomass. The worms then become food for fish or chickens, and the remaining substrate becomes "vermicompost," a nutrient rich natural fertilizer and soil conditioner. The humble earthworm has yet even greater value as a source of useful enzymes. If you are the unfortunate victim of a stroke, mycelium-munching earthworms may come to your rescue! Lumbrokinase is one of the important enzymes, which is extracted from earthworms. It is a potent fibrinolytic enzyme that dissolves blood clots and is being used to treat strokes and coronary thrombosis (Mihira et al., 1991). Once again the ZERI system yields a value-added product from waste. For more on "worm power" see Mary Appelhof's Web site at: www.wormwoman.com.

Sustainable Communities / ZERI-NM: Mushroom Projects SCZ-NM (www.scizerinm.org) is a vital and creative enterprise working under the auspices of the U.S. Forest Service Collaborative Forest Restoration Program in New Mexico. One of the SCZ-NM missions is the reduction of fire hazard in overgrown National Forests. The thinning of forests and clearing of underbrush reduces fire hazard but creates mountains of woody scrap in need of disposal. A SCZ-NM solution, along the lines described above, is to use the woody refuse as a substrate for mushrooms such as oyster or shitake mushrooms. As it turns out, even wood digested by mushrooms can be incorporated into a digestible feed for cows, sheep, bison, and as we have already noted—worms.

A related SCZ-NM project, initiated by SCZ cofounder Lynda Taylor, is the establishment of a long-term New Mexico native fungal culture bank. Native fungi are being collected and maintained on agar plates. Various fungi in the bank are being tested for their ability to grow on the various species of small diameter tress (ponderosa, piñon, and juniper) and on invasive species (salt cedar, Russian olive) and other tree "wastes" that are being thinned in the process of forest restoration.

The SCZ-NM forestry projects are excellent examples of what Paul Stamets calls "mycoforestry" in *Mycelium Running*. In fact, he devotes a whole chapter to the subject. Matching native fungi to native tree species is one of the principles of mycoforestry that Stamets emphasizes. Stamets also advocates chipping the woody debris, left over from clear cutting and thinning of forests, and inoculating those chips with fungi. He has devised an ingenious way to give the fungi a jump—mix spores into the oil used in chain saws and wood chippers. Only Paul Stamets could wax so eloquently about mycelium and woodchips:

> Mushroom mycelium is the grand demolecularizer of plant fibers (lignin and cellulose), creating soil as an end consequence. My goal is to make use of fungi's appetite for wood chips to increase soil depth so that the soil has a greater carrying capacity for the tree successions that spring from it. I see wood chips as valuable ecological currency that should be reinvested into forest's ecobank to enhance sustainability. (*Mycelium Running,* p. 73)

Stamets discusses other practical uses of myceliated wood chips in his chapters on "mycofiltration" and "mycoremediation." Clear-cutting forests and incursions of logging roads often cause problems of erosion and loss of topsoil as a result of water run off. If depressions and roadside ditches are filled with chips and inoculated with mushroom spawn, mycelium binds the substrate into a densely bound mated network that serves to reduce erosion and silt flow. This is a promising strategy that SCZ-NM is employing in their forestry project.

One of the SCZ-NM mycological consultants is Carmenza Jaramillo López from Columbia. Ms. Lopez is conducting a project in Chinchina, Columbia, which is in a coffee growing region. The coffee growers there are mostly low-income peasants, whose livelihoods are precarious due to volatile coffee prices. Just as in the beer making process described previously, the final product, in this case the coffee beans, represents only a small percent of the agricultural starting material. Traditionally, huge amounts of coffee waste products were simply thrown away. The Chinchina project is utilizing the considerable biomass of coffee waste as a substrate to grow Shiitake mushrooms. The Shiitake mushrooms are produced at a Biological Efficiency of an amazing 75%, and they provided an additional source of income and nutrition for the poor coffee growers. Here we have another example of the use of mushroom cultivation to reduce poverty (Jaramillo et al., 2004).

Fungi and Ecosystems

ZERI projects have amply demonstrated that "zero emissions" in many human endeavors can in fact be achieved by the judicious recycling of organic waste from one kingdom to another. Their projects are models of sustainability. We have seen how mushroom cultivation can play a role in transformation of agricultural waste into a delicious, nutritious and marketable product and as a tool for restoring and sustaining forest communities.

Let us now consider sustainability on a larger perspective, namely on the level of ecosystems, and ultimately the entire planet. The importance of fungal biodiversity in sustaining ecosystems is becoming increasingly clear. We now know that 90% of all plants have symbiotic relationship with fungi via mycorrhizae. As Mycophiles we are well acquainted with the mycorrhizal relationships of many mushroom species with trees. Another class of fungi, which are invisible to the naked eye, but even more important as symbionts with plants, are the vesicular-arbuscular mycorrhizal fungi (VAM), of which *Glomus* is one of the better known genera. VAMs account for a considerable amount of the fungal biodiversity in soils (Van der Heijden et al., 1998).

The fungi in the soil of terrestrial ecosystems comprise a vast network of hyphae in complex relationships with many organisms including bacteria, nematodes and arthropods. This living zone is now being referred to as the "rhizosphere," and it is absolutely essential for the well being and resiliancy of the entire ecosystem (Curl, 1986). As Paul Stamets points out in a 2005 article in *Resurgence Magazine:* "[fungi]. . . serve as primary healing agents for land and ecosystems . . . mycelia are the great soil builders of our planet: they create habitats . . . the complexity of the fungal kingdom gives soils the ability to respond to catastrophes."

And in *Audubon* magazine: "Where there are catastrophes in nature, we find that the solutions are literally underfoot" (Woodsen, 2002). Paul speculates that the fungal rhizosphere is a living Internet that possesses sentience, intelligence and inherent ecological healing properties. He believes that the similarity in the decentralized, networked architecture of hyphal networks, the neural networks in our brains, and the World Wide Web is more than a coincidence. Mycelia in soils serve as a communication network within an ecosystem, sometimes over vast distances; it supports biodiversity and resiliency of the system as a whole; it builds soils; and gives habitats the ability to respond to catastrophes—natural or man-made. (See rhizosphere links at http://ic.ucsc.edu /~wxcheng/wewu/links.html.)

Fungi and the Future

As a result of our "addiction to oil," we seem to be witnessing a man-made catastrophe in the making—global warming—which even staunchest conservatives are now taking seriously. It is clearly imperative that we focus our efforts toward the goal of a "sustainable planet." The United Nation's drafted the "Kyoto Protocols" in response to the impending climatic planetary catastrophe (which only the USA and Australia failed to sign).

Of course, we pray that it is not too late to "save the planet." But what if, God forbid, the worst-case scenario should occur—a thermonuclear holocaust, followed by a "nuclear winter," and collapse of all of our planet's ecosystems? The science of Paleontology informs us that the planet has survived much worse catastrophes. They are recorded in the fossil record as the major extinctions that mark the boundaries between major geological ages. Every schoolgirl knows about the great K-T extinction, brought on by the massive meteor impact at Chicxulub, that led to the demise of dinosaurs as well as much of the plant life on land. The greatest extinction in earth history occurred at the end of the Permian age, when 90% of all living species became extinct. The meteor impact associated with the Permian extinction has recently been discovered beneath a mile of Antarctic ice (Gorder, 2006).

What is not so well known is what happened immediately after these meteor impacts. Paleontologists Vivi Vajda and Stephen McLaughlin (2004) found the answer by a careful study of the sediment layer immediately above the famous iridium layer deposited by the K-T meteor impact. When their findings hit the popular science press, the headline announcing the discovery read, "A World Ruled by Fungi" (*Terra Daily*; Mar. 8, 2004). What Vajda and McLaughlin found was a layer devoid of all plant life but rich in fungal hyphae and spores, the layers above the fungal one showed an orderly succession of plant life. So the story goes: after the great impact, fungi thrived on the massive amounts of dead plant material to become the dominant life form on land. It was mycelia that then prepared the way for the return of plants—new ecosystems, new niches, new adaptive radiations, and naked apes. The same pattern of fungal dominance followed by a succession of new plant life has also been found following the Permian extinction, but then it was the dinosaurs who inherited the earth (Monastersky, 1996).

I hope our little paleontological digression has demonstrated the importance of the fungal kingdom in maintaining and restoring ecosystems. We can only hope for the best in our goal of achieving a sustainable planet; however, if the worst should occur, we can rest assured that fungi will rescue our planet again, perhaps even preparing a suitable habitat for future intelligent life.

Acknowledgments

I would like to thank our editor, Britt Bunyard, for his encouragement and suggestions for refining this article. The visionary ideas of Gunter Pauli and Paul Stamets served as an inspiration for the writing of my article. In addition I want to thank Gunter Pauli, Linda Taylor, Craig Gilbert, Jeremy Davis, and an anonymous reader for reviewing the manuscript.

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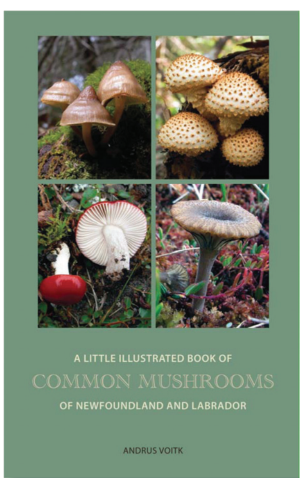
BOOKSHELF FUNGI



A Little Illustrated Book of Common Mushrooms of Newfoundland and Labrador, by Andrus Voitk. 2007. Published by the Gros Morne Cooperating Asso. 272 pp. ISBN 978-0-9699509-4-3 (PB). Color illustrations of almost 400 species

Here is a surprisingly nice book out of that remote little corner of North American that fondly refers to itself as "The Rock." Newfoundlanders are proud of the fact that they were first to be settled in the New World, and they're quickly becoming leaders in the world of mushroomology, thanks in large part to the author of this book. (Who, by the way, is also an authority on wild orchids and has previously published a wonderful little field guide to them as well!)

The annual Foray Newfoundland has become one of the larger and better organized of the numerous forays that occur from coast to coast each year. I was lucky enough to attend last year; you can read a report on that foray elsewhere in this issue of *FUNGI*. This guidebook arrived, literally hot off the press, just in time for attendees to reap its benefits. I quickly realized that this book would be suitable for any mushroomer hitting the woods in the northern half of North America. And in many ways it's superior to what's already being used for many regions, and I'll tell you why.

First off, *Common Mushrooms of Newfoundland* provides very current information—for instance, it's the only book I know of that cautions against picking *Pleurocybella porrigens* ("Angel's Wings"), and cites a recent spate of poisonings in Japan). Many species of mushrooms that occur across much of North America, and which you won't find mentioned in other guidebooks, are given their due here, including the spectacular *Catathelasma ventricosa*. And *Amanita wellsii*…what a stunner! The book, while just the right size to fit in your back pocket, is packed with beautiful high resolution photos.

Does the genus *Cortinarius* leave you scratching your head? You're not alone. Corts abound in Newfoundland, and *Common Mushrooms of Newfoundland* does a great job of breaking them down for the beginner. Also abounding in Newfoundland are species of lichenized mushrooms. Andrus is a big fan of these often overlooked little gems; his book gives them their due with fantastic pictures and descriptions.

The book is not laid out like most other guidebooks out there, which give a formulaic breakdown of the mushroom: description of morphology, spore size and color, habitat, and a list of other factoids. It took a minute or two to get used to, but I soon came to enjoy reading beyond the description of the mushroom I was holding at arm's length, trying to identify.

While the book is easily worth the cost simply for its photographs and concise descriptions of mushrooms, it's a must-have for the warm and folksy humour (note spelling!) characteristic of the author. I highly recommend this book to all mycophiles.

—Britt Bunyard

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