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«Soil as a living system»

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INTRODUCTION

Mrs Sauers's paper is oustanding from the RCW Technology point of view by the fact that she brings to light basic forest soil mechanisms for the real purpose of enhancing the quality of life of a forest stand instead of volume, quality and yield of wood productivity for industrial purposes. From this standpoint only, this paper is remarkable.

It is also noticable that Mrs Sauer is a landscape architect, not an agronomist nor a forester, both dealing with productivity of an «almost unknown system as such», but rather as a sort of an industrial plant design and fitted for production wheather maise, wheat or beech, etc. Basic ignorance of soil's biological, biochemical, chemical and physical mecanisms intertwined into a living system was until recently completly ignored. This paper is dealing with the fundalmental diffrence between agricultural soils based on bacterial activity while forested being based on fungal.

It clearly stresses the pathway of sustainability for both agrosystems and forestsystems. The RCW Technology is bringing new light and knowledge towards sustainability under temperate or tropical climates.

In this regard we have made many comments including our views on lignin roles and the whole world of polyphenols, long time ignored but fundamental and from forest orginin. We hope these comments to emphasize Mrs Sauer's approach to forest quality enhancement through soil, from biological origin, not nutrient availability only.

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Soil as a Living System[1]

by
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What most struck the woodland manager of New York City's Central Park when he visited the Adirondacks was a forest floor so soft he could plunge his hand into it. The ground was visibly alive and completely different from the dead, concretized soil of the urban forest in Central Park.

1- Soil wears its problems on the surface. Where trampling of high rates of decomposition prevail, the litter layer and topsoil are entirely absent. Until recently, the annual leaf fall in the woodlands of Central Park typically did not accumulate or even persist from one year to the next. With no litter layer, there was no nursery for the next generation of the forest.

2- Nearly a decade of woodland management is rebuilding the ground layer in Central Park's woodlands at the north end of the park. The site is becoming increasingly stabilized as erosion is controlled and bare areas are replanted. The many small saplings and seedlings that were planted or that volunteered after exotics removal help to hold the ground. During the icebound 1993-94 winter season, some remains of autumn's leaves persisted under the blanket of ice until spring. That was a turning point for the woodlands. The following winter was unsually mild and, by spring 1995, there was a relatively continuous litter layer.

3- In time, the organic litter on the forest floor will create humus, an organic soil horizon. Within it, most of the life of soil occurs. As organic matter is continually broken down into humus, it becomes incorporated into the mineral layers of the ground surface to

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[2]Leslie Sauer is principal landscape architect with Andropogon Associates, Ltd., based in Philadelphia, Pennsylvania, and adjunct professor at the University of Pennsylvania. This article is adapted from *The Once and Future Forest: A Guide to Forest Restoration Strategies,* which was developed by Andropogon Associates and is based on their approach to integrating environmental protection and restoration with landscape architecture and design. Their work on Central Park's North Woods is only one of many restoration projects. *The Once and Future Forest* is published by Island Press (800/828-1302 or ww,islandpress.org).

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build topsoil[3]. Soils are forming all the time and, like vegetation, integrate and express all of the ecosystem's processes. Soil is a reflection of climate, parent material, topography, vegetation and time.The layers of soil tell a more recent history than the rocks beneath.

4- The soil's abiotic, or non living, factors are generally the primary focus of conventional soil assessment. Much of our thinking in the past was oriented toward an "ideal" soil model that balanced sand, silt, clay, pore space, moisture, minerals, and organic matter. These standards determined whether a native soil was judged poor or good, and where soils did not conform to the ideal, soil amendments were used to modify texture, acidity, fertility or other characteristics. Many early mitigation, stabilization and restoration projects sufferd from the agricultural/horticultural approach. Standard soil specification, for example, call for routine topsoil stripping, fertilizing and liming even though many disturbed or made soils are already less acid than in their native condition because of the repeated addition of lime by means of concrete rubble and urban dust. Most regulations related to development sites, highways, landfills and abandoned mines require from three to six inches of topsoil spread over new soil surfaces before revegetating. That topsoil comes from somewhere, so restoration of one site frequently means the destuction of another. We need more research on alternatives to topsoils, especially those that reuse waste materials appropriately to amend local soils and that avoid environmentally-costly products such as fertilizers and peat. Even where topsoil has been stockpiled on a site before construction, the living organisms it contains die within days.

The soil Food Web

5- A food web is the structure of relations among the organisms within an ecosystem based on what each consumes. Primary producers consume water, minerals, carbon dioxide and a few other things to produce organic matter, which is consumed by most of the rest of creatures that are, in turn, consumed by still others. Some organisms have very specialized food requirements while others feed quite omnivorously.

6- Both soil and water are media in which plants and animal live and grow. And in a very real way, both are living systems. One of the most important contributions to the history of water management occurred with a shift in perspective that originated with Ruth

[3]Heading toward the good direction, the author do not discriminate between various basic process. Later on she refers to the soil under conifers in the same way as for deciduous climax forest soils, irrespectively of the basic difference between each of them. Each soil horizon has its own function. The surface horizon cannot be seperated from the others in the whole pedogenetic processus.

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Patrick and others. When one views water as a living system, its quality is measured by the richness of its biota instead of physical and chemical factors such as flood levels or biological oxygen demand. Its biological components are a defining measure of heath that reflect a more complex array of factors. This same kind of revolution is happening in our perception of soils.

> **7-** In 1968, **Ruth Patrick** wrote about aquatic food webs:
> "*The various pathways in the food wed and the various types of interrelationships of species to each other are two of the most promising avenues of research. Most food webs are composed of at least four stages [;].....the stages tend to be few because so much energy is lost between stages,....**diversity is expressed by many species forming each stage or level in the food web.** This srategy of many species at each trophic level has developed a food web of many pathways which seems to give stability to the system.....[W]e see there are many food webs within systematic groups as well as between groups. It should also be pointed out that the size and the rate of reproduction vary considerably in each of the major systematic groups. These types of variability in food chain, size of organisms and reproductive rates help to ensure the maintenance of the various systematic groups and in turn preserve the trophic stages of the food web of the whole community.*

8- Soil ecosystems are strikingly similar. Like aquatic systems, they have a great deal of redundancy. Very simple systems with simple food webs can be drastically altered by the appearance or disappearance of one or a few species. In more complex systems there may be multitude ways in which energy flows through the food web. Thus, the more complex systems are said to have redundancy and are not so dramatically changed when a few species change[4]. Many soil components even lie dormant until favorable conditions occur. The full soil structure is not required for most basic soil functions[5].

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[4]Here are some basic arguments in favor for primitive forest ecosystems which are composed of a limited number of species but have developed a great resilliance to competition. On the other hand, Angiosperm forests contain a great number species in the hypogeous as well as in epigeous ecosystems and a high degree of resistance to long periods of disturbance.

[5]Biodiversty enhances the dynamics where biological and biochemical balance faces a momentary rupture. Large numbers of organisms with the same function provide a relative stability to the plant-soil system. A much more complex reality in the Angiosperms deciduous forest makes climax forest possible.

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9- Rather than focusing simply on the non-living aspects of soils, restoration should enhance its living components, primarily bacteria, fungus and microfauna. Most of the work of forming humus is done by plant roots and by animal life in the soil, which depend on a permeable soil crust, stratified soil layers and appropriate amount of organic matter. There are up to three thousand arthropods per cubic inch of productive soil. A litter layer of leaves one-and-one-half inches thick and a yard square might contain five thousand miles of fungal filaments.

10- Plants are the primary producers of organic matter[6] in the forest soil system. Ants and other invertebrates initiate the breakdown of ground-layer litter. Soil microorganisms, including fungi, bacteria, protozoa and actinomycetes, continue this process of converting organic matter into soil minerals that in turn become available as nutrients to plants[7]. In food-web nomenclature, these organisms are "consumers". Primary consumers (herbivores) feed directly on the "producers", which are the plants; secundary and tertiary consumers are predators and parasites, which feed upon each other as well as upon herbivores. Food webs also contain other decomposers and detritivores that feed on litter, such as mites, woodlice and earthworms. Woodlands typically support more diverse assemblages of soil organisms than grasslands. If soil organisms are included in the species count, temperate rain forests are richer in biodiversity than tropical rainforests.

11- The soil food web performs the primary function of the soil, which is to cycle energy and nutrients, including nitrogen, sulfur and phosphorus[8]. Native soil systems are very efficient and succeed in recycling, for example, upwards of eight percent of the nitrogen in the system. The cycling of nitrogen is intimately associated with the cycling of carbon, which is tied up largely in organic matter. Nitrogen, in part, determines the rate at which carbon is broken down. Bacteria and fungi take up the nitrogen as they decompose soil organic matter, and some fix atmospheric nitrogen. This nitrogen too is released into

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[6] The author, like almost everyone, uses the term «organic matter». This term is an empty shell and its use is responsible for the scarcity of scientific knowledge related to basic soil genesis. We favor the terms evolving plant tissues or humic substances, where appropriate. It is on this basis that knowledge will improve and that the role of polyphenols and lignin within the enzymatic complex where Basidiomycetes are absolute masters, will be clearly established .

[7] This is a rather simple statement, but was an absolute belief throughout this century. Lignins, tannins, condensed tannins and a great number of various polyphenols must play a role in the stabilization of many plant nutrition aspects.

[8] Once more, the chemical view so typical of the 20th century seems to become of a minor importance because chemical nutrients are most of the time present in large quantity such as atmospheric nitrogen, but often non available for biologcal, biochemical or enzymatic reasons.

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the soil to be again available to plants[9]. Nitrogen's slow release from an organic to an inorganic form, which is available to plants, is called "mineralization".

12- The microbial community performs three major functions: as discussed above, conversion of organic nitrogen to a plant-available form such as ammonia, nitrification when ammonia is converted to nitrates; and denitrification when nitrogen is recycled into the atmosphere as a gas. The soil microbial community also contributes to soil stability, another vital function. Fungal hyphae knits bits of organic matter together to create a denser, stonger litter layer and upper soil horizon[10].

13- Not all soil food webs are the same. Fungi appear to dominate in forest soils, bacteria in agriculture soils[11]. Thus, soil communities change over time as the landscape succeeds to forest. The nature of the vegetation determines the nature of the fuel/food available for soil organisms. Grassland litter, a relatively easily decomposed herbaceous material, does not typically contribute all of the soil's organic matter. The extensive root systems of grasslands are also a major source of the soil's organic matter. The roots of grasses exude carbon directly into the soil as sugars, amino acids and other forms to feed soil fungal associates and activate bacteria and other microbes[12].

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[9]Here is another simplistic view upon soil's mechanisms. Once more taking into account mineral nutrients at stake does not explain anythings. Nitrogen chemical forms and origin discused here is used and stored as microbial proteins. As such, nitrogen exists within complex molecules which skeleton is made out of carbon, giving importance to carbon-nitrogen relations. This is made possible on molecules with aromatic rings in which nitrogen is stabilized. This makes polyphenols, ligins and their derivatives of a primary importance. These compounds are an important energy reserve to be used by the trophic web exchanges. Once more I would like to emphasize the fact that sugars and cellulose, in contrast to polyphenolic compounds, are easily and rapidly consumed and, therefore are not factors of stability in ecosystems. Stability is only possible with mechanisms regulating availability. These lay in synthesis and resynthesis of organic origin nutrients.

[10]This is one aspect of the physical side of stability. Biodiversity is far more important for biochemical diversity, and trophic web maintnance and evolution. We only begin to understand the importance of lignins and the role of Basidiomycetes which produce large number of enzymes and, while working on organic molecules, creates humic and fulvic acids, the real base for a dynamic and stable soil system.

[11]**For the first time in the literature, we see a clear biological difference between forest and agricultural soils. By extended meaning one can arrive to the conclusion that forest by all means preceeded agriculture which took place recently a result of human needs.** These few words should raise questions upon our actions and state of knowledge in the field of both agriculture and forest. **We carry on management of forest ecosystems by using agriculture rules all over this planet!**

[12] The author is making a good distinction between prairie and forest soils. Until now we did not tackle the lignin approach, but we must stress here that Monocotyledon grasses posses a differet type of lignin with no methoxyl groups, called hydrobenzoyl lignin. This lignin do not lead to the production of non-food and highly stable molecules. We must take into account that prairies form in areas where precipitations are rather low, such as the North American Prairies, Asian steppes, etc.

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14- As the landscape matures, the litter becomes more difficult to break down. While herbaceous litter is primarily cellulose, the litter of the forest becomes increasingly higher in lignin, the woody component of plants[13]. Tree leaves have more lignin than grasses[14], and the leaves of late successional species, like beech (Fagus grandifolia) and oak *(Quercus spp.),* typically have more lignin than ash *(Fraxinus spp.),* tulip poplar *(Liriodendron tulipifera)* and early successional species. In woodlands an important shift occurs as leaf fall and other litter become the most important sources of organic matter, rather than the direct contribution of carbon by the roots, as in the grasslands. There are also larger volumes of wood on the ground in the form of fallen twigs and limbs, which directly foster fungi because bacteria are unable to decompose lignin[15]. The mycorrhizal filaments from tree roots reach up into the old wood to extract the valuable nutrients. Insects, such as beetles and ants, are also able to break down wood. Wood, in contact with the soil and standing dead trunks, "snags", create many opportunities for various wood and soil invertebrates of the forest.

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[13] This statement is a good summary of what most scientists tought in the 70s. Knowledge has considerably evolved and we have now a much better understanding of soil structure and what soil physics, chemistry, biochemistry and biology is about. As the term of «organic matter» those of cellulose and lignins are hiding an extremely complex world. Throughout their own dynamics, lignins and other polyphenolic compounds will bring most answer to secular interrogations on soil. In order to understand better, one must go back to Gymnosperm versus Angiosperms models. Plants from the first group are rich in gayacyl lignin (with one methoxyl group -OCH3). While attaked by enzymes such as lignoperoxidases, it gives secondary polyphenolic compounds of which the role is to retain nutrients for plant growth and productivity. This is a selective proces based on the availablity of scarce nutrients. This process favors dominance of one or a few species in the ecosystem. In turn, woody Angiosperms have a larger proportion of another lignin, the syringyl lignin (with two symetric methoxyl groups) which under the same enzyme is giving a receptive soil, where a large biodiversy flourish. This allows soil to behave as a synergistic buffer, rich in nutrients and energy instead of being exclusive. Large quantity of energy and nutrients can be stored or released through activity of the trophic web. This set of mechanisms stabilises climax ecosystems and minimizes environmental variations. Hence, ecosystems dominated by herbs and grasses with such a poor support of lignins are not that stable through millennia and only depend on polyphenols throughout allelopathic mechanisms. On the other hand Gymnosperm forest ecosystems have a limited span of life even if individuals cans live much longer. They must keep their precious nutrients in their own living tissues instead of in the forest floor litter. These ecosystems are largely depending upon catastrophes for renewal, fire being the most common. It cleans allelopathic polyphenols inhibiting all biological renewal mechanisms. Angiosperm forest ecosystems reach the climax through biodiversity. There stability is derived from their rich biological complexity through which energy release to the trophic web is regulated. In turn, the trophic web supports a large biodiversity of plants making possible an «ever lasting» equilibrium into wich intermediary renewal stages are taking place. This system maintain a large biodiversity where individuals delevelop in harmony for long period of time.

[14]This theory does not hold when the type of lignin and polyphenols involved are taken into account. For example long lasting climax species such as oak, beech and maples contain much higher levels of syringyl lignin than the intermediate species of disturbed ecosystems such as aspen, birch...

[15] This statement is not exact. **Bacteria can degrade lignins with a special enzyme called laccase, but are unable to transform lignins into fulvic and humic acids.** Therefore, they are unable to act as a contributor to pedogenetic processus.

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15- The soil communities continue to change along with the vegetation communities. Over time, the cycling becomes less rapid[16]. In a humus-rich forest soil, the organic matter that remains the longest is the rather stable organic compounds that degrade much more slowly[17]. By then the humus is important more as a site for important chemical processes and for the physical qualities it gives the soil than as a stockpile of nutrients. The humus, for instance, increases the water-holding[18] capacity of the soil.

16- Another important role of dead wood is to serve as a water reservoir for the forest in times of drought. Dead wood, especially larger logs approaching a foot or more in diameter, soaks up water like a sponge and retains it for long periods. Old logs or stumps make great nursery by carrying vulnerable seedlings through dry spells. Salamander populations also depends on large logs for needed moisture, which is, in part, why they are absent so long after clearcuts and timbering, although they may number one or two per square yard in old-growth forests. Logs increase local stormwater retention as well by inhibiting overland flow and by absorbing water in place.

17- Fungi, in general, foster acid soil conditions, whereas bacteria increase alkalinity. The bacteria, and their predators in grasslands, help maintain the soil's pH and the form in which nitrogen is made available as well as nutrient cycling rates that work to the advantage of grasses. Where fungi are more abundant, as in natural forests, the nitrogren is converted to ammonium, which is strongly retained in the soil system. In bacteria-dominated systems, the bacteria convert nitrogen to nitrates instead of ammonium. Nitrate leaches more easily from soils than ammonium, however, the growing patterns of grasses tolerate this condition. But when woodland soils become bacteria dominated, rapid leaching may leave most native old-growth species poorly nourished while invasive exotics

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[16] This is true in Gymnosperm ecosystems or in monospecific artificial plantations of deciduous trees. The situation is completely different in Angiosperms climax deciduous forests where individuals differ in age allowing for a continuous replacement of individuals within a given structure. Therefore, changes in soil will take place with regard to individuals disapearance and replacement non over the entire ecosystem as in Gymnosperms.

[17] This can seem logical from a lanscape architect point of view. But the reality of natural systems is very diffrent. There are other dynamics and reversible mechanisms, wich are not likely to exist in the management of urban forests.

[18] Humus increases the water holding capacity of soils. This is one of the reason oligotrophic peat is so widely used today in both agriculture and horticulture. We must not overlook, however, the role of the microbial biomass in water retension. Fungal hyphae, more especially, retain a small but significant amount of water that is not accounted for in the chemical and physical soil "budget". They make that smaller water quantities much more efficient for life and plant productivity. The very efficient water use efficiency of fungi-dominated systems may explain at least in part, the observe benefit of RCW to crops yield. RCWs used on tropical soils have reduced by 50% the use of water with yields increases ranging from 300% to 900%. We also know from he literature that polyphenols play a major role in **biological active water regulation for plant growth**.

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and some early successional natives are flushed with nutrients. Some species are more sensitive than others to soil nutrition. Conifers do not grow in bacteria-dominated whereas agricultural crops cannot be grown in fungi dominated soils[19]. Indeed, in woodlands, a high ratio of bacteria to total biomass is an indicator of disturbance (**McDonnell, M.J., Pickett, S.T.A. & Pouyat, R.V. (1993)** «Application on the ecological gradient to the study of urban effects» in Human as Componants of Ecosystems. The Ecology of Subtle Effects and Populated Areas» ed. G.E. Likens and W.J. Cronon [New York Springer Verlag pp. 175-189]). These factors, which seem to depend on soil orgnisms, play a greater role in succession than previously recognized (**Ingham, E.R. (1995)** «Restoration of soil community structure and function in agriculture, grassland and forest ecosystems in the Pacific Northwest» Proceedings, Society for Ecological Restoration Conference [Seattle],31).

Damaged Soil Systems

18- Soils are far more damaged and damageable than we realize, but the problem is often hidden. The cumulative effects on forest systems and other environments of acid rain, nitrogen deposition, global warming, ozone thinning, unnecessary grading and stormwater changes have left a legacy of severely-altered soil conditions and totally-modified soil food webs. The consequences and remedies are still largely unknown.

19- Many of these changes are so pervasive that we take them for granted. Take earthworms, many non-native, which now are abundant throughout the urban forest system. In fact, they are not part of the historical community[20] of living creatures in native forests and are typically associated with more disturbed landscapes. Earthworms in general increase soil fertility by initiating the breakdown of organic matter[21], aerating and mixing

[19]This statement is oversimplified. Adding RCWs to agricultural soils increases fungi importance and give outstanding results. From this we come to the conclusion that soils dominated by a bacterial flora are artificial. Polyphenol derivatives and lignins being in short supply lead to soil degradation in agiculture. Coincidently, Basidiomycetes are lacking and are not the base of the food web. This is also true of natural prairie soils wich will always remain fragile and unable to support dense human populations. The transhumance of large wild heards made possible subsistance of buffalos. Only small human populations have ever been established in the Canadian Priaries, and this is still the case today.

[20]Some earthworm species were native to North America but following the last glaciation have retreated south. They have subsequently moved back north but did not go over the 45th parallel N. Earthworms found in the canadian climax deciduous forest ecosystems (oak, maple, beech stands...) and in agricultural soils are from european origin and typically associated to disturbed soils.

[21]In fact, nitrogen is retrieved from the plant tissues proteins strongly bonded to polyphenols. This operation is taking place into the earthworm digestive tract where small colonies of bacteria make this separation possible, but need thin coating of clay to avoid the same operation. Once more, polyphenols are basics as inhibitors,

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the upper soil and creating a micro environment that stimulates the bacteria that convert ammonium to nitrate. High earthworm populations also foster nitrification by supplying the oxygen necessary to convert ammonium to nitrates. They take a system already disturbed by added nitrogen and push it farther from normal by consuming the litter layer as fungi and converting excess food into nitrate[22]. The same kind of self-reinforcing cycle can be seen when aquatic systems fill with algea (**Nixon, W. [1995]** «As the worm turns» American Forests **101** (9) 34-36.). Each shift in the soil character will in turn ripple through the entire system. Unfortunately, in many woodlands that look mature because they have larger trees, there is a lag in the succession of the soil, which may still be dominated by earthworms and bacteria and impoverished in terms of types of fungi, invertebrates, and other more efficient paths for nutrient cycling.

Building Soil Systems

20- The object in restoration is to restore the nutrient cycling and energy flow of the historical soil system. First work is to protect existing soil resource and explore techniques to increase the overall biomass of the soil and to foster the diversity of native soil flora and fauna[23].

Recommendations

Identify, protect and monitor areas of native soil that are relatively undisturbed.

21- Most areas constitute places where there is less disturbed soil that can serve as a rough model of local soil conditions. Studying the more natural soils at the same time as remediation is being documented in a disturbed landscape will provide a standard for measuring the success of different approaches. The natural sites also serve as propagation sources for locally-adapted microorganisms[24].

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controling transformation of plan tissues and therefore playing a major biological role in humification, by controling bacteria populations and their free enzyme production (which have a proteic structure), responding to the plant demand for nutrient availability.

[22] We feel necessary to underline an unwanted mistake because fungi transform organic tissues into ammonium rather than nitrates.

[23]Actual knowledge about pedogenesis complexity do not allow such an optimistic conclusion.

[24]Here again, conclusions are somewhat prematured but have a rational basis. We now know that the soil is in a permanent biological, chemical, biochemical, physical and physico-chemical evolution. Transplantation of microoganisms from a balanced soil of one site to another disturberd one will not necessarly bring expected results. Once more, polypohenol biochemistry and reaction of the trophic web are responsible for the dynamics. RCWs are the very base of all these observed phenomena in the renewal of all these parameters. We now knoe that a period from 3 to 6 years is necessary.

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Reduce local sources of soil contamination, including added nitrogen.

22- Evaluate local air pollution impacts, especially those of automobile exhaust. Removing roads wherever possible is of paramount importance, especially in more natural areas. What is convenient, even to the restorer, such as easy access, may be lethal to the most jeopardized species. Educate the community about regional air pollution impacts. Many other management practices, such as pesticide use, also affect the realm of the soil. The most popular herbicide, for example glyphosate, which is often used to control exotics, enhance conditions for bacteria but makes a poor substrate for the development of forest fungi.

Recognize that the user is inseparable from the solution

23- No treatment of soil will make it impervious to compaction, erosion and other such disturbances. Confine all use in forests and other natural landscape fragments to designated trails to minimize degradation from feet, hooves and wheels. Prohibition alone never is enough. Users will stay on trails to the extent that trails create the elements of satisfaction that keep them there and provide access to desired destinations. The gradual building of the litter layer and the absence of bare soil off trail are hallmarks of success.

Minimize "working the soil"

24- Despite a lot of knowledge about the damage done to living systems by constant perturbation, there is still a tendency to overwork soil. Beyond the familiar structural damage - such as that caused by working a heavy soil while it is wet or by the erosion that accompanies any soil disturbance - the soil's level of microorganisms is also severely affected. For example, plowing and any mechanical disturbance to the soil will tend to foster the rapid growth of bacteria, which in turn generate exopolysaccharides, which cause the soil to slump in rain. Other substances make soils hard to wet, or hydrophobic. Cultivating soil is almost always deleterious to natural areas and constantly resets the time clock back to disturbance rather than allowing more complex, stable and diverse soil systems to develop.

25- We need to try new techniques, such as planting new seedlings in logs or stumps, to avoid soils disturbance while enhancing survival. Another technique is vertical staking, wooden twigs driven vertically into the soil. Vertical staking serves to aerate and loosen the soil without damaging the root of existing vegetation, and it avoids the need to

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completely turn the soil. In addition, it favors the development of fungi instead of bacteria because it incorporates wood into the soil[25].

Reevaluate the usefulness of current methods of stockpiling topsoil.

26- Harris, A., Birch, P, & Short, K.C. (1993) «The impact of storage of soils during opencast mining on the microbial community: a strategist theory interpretation» Restoration Ecology **1**:88-100, describe the progressive impact of stockpiling which is a frequently-used method to retain a site's topsoil during construction. The first phase is an instantaneous kill of many of the living creatures in the soil that occurs with the initial removal and stockpiling. During the next few months there is a flush of bacterial growth as well as fungi but only in the upper soil of the outside of the pile, the new "topsoil". During the next half year or so, the soil stratifies in layers. The primary distinctions reflect the amout of oxygen in the soil because of its depth in the pile or level of saturation with water. The developing layers consist of both near-surface aerobic and deeper anaerobic zones as well as a shifting transition area between them. When the soils are restripped and replaced elsewhere, there is another instantaneous kill of most living organisms followed by a flush of bacterial growth.

Experiment with alternative strategies that better preserve native soil food webs when moving soil is necessary

27- Experiment with methods that keep soil horizons intact, such as moving blocks of soil. Practitionners are using and modifying equipment like old sod forks and front-end loaders as well as developing new equipment for this purpose, such as the soil-mat lifter devised by John Monro (The tool, available in several sizes, was developed by Monro Ecological Services, Harleysville , PA and is available through Bently Development Co., P.O. Box 338, Old Route 22 Blairsville, PA 15717, 412/287-0671).

Reevaluate the addition of organic matter to enrich disturbed soils.

28- The continuous run of airborne nutrients onto soils in the form of acid rain and nitrogen deposition from air pollution raises serious concerns about many traditional management practices with regard to the use of organic matter as a soil additive and our almost automatic additions of nutrients to disturbed soils. Researchers have shown

[25]Not useful as a silvicultural technique in restoring forest and agricultural soils, this technique is appealing in urban forests restoration as we get closer to the RCW technology from the scientific point of view.

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repeatedly that fertilizer benefits weed species. Creating less-hospitable conditions in the conventional sense can actually enhance the performance of native species. Using elemental sulfur on test plots, Jean-Marie Hartman and his co-workers at Rutgers University (**Hartman, J.M., Thorne, J.F. & Bristow, C.E. [1992]** «Variation in old field succession» Proceedings [Design + Values] of annual meeting, Council for Educators in Landscape Architecture [Charlotteville VA] p. 55-62), lowered the pH and reduced nutrient availability in a mixed meadow to foster native species over exotics[26]. Many invasives, both native and exotic, are nitrophiles and do poorly under such conditions.

Reevaluate the use of mulch and soil amendments that are harvested from landscape communities other than those native to the site.

29- Because to a great extent soil organisms are what they eat, bringing in organic material from other sources, will not necessarily foster the growth of the same soil organisms as are in the desired native community. In an artificial soil such as made land or a highly-contaminated soil, it's not the addition of organic matter but what kind we use that will impact the nature of plant succession on the site. The more indigenous the existing landscape, the more important it is to minimize the use of dissimilar material.

Reevaluate the conventional management of brush, dead wood and leaves

30- Even where no additional fertilizer is added, it is important to modify our management of dead wood and vegetative debris to more closely mimic natural conditions. This sounds obvious, but how often is organic matter collected from a site, taken to another location to be composted, and then used at still another location when it is "well rotted"? Under more natural forest conditions, however, the major contribution of organic matter is not well-rotted compost but rather wood, twigs and leaves that slowly break down in the place where they fall. Adding wood and raw, rather than composted, leaves, more closely mimics the natural scenario.

Develop new ways of observing and monitoring soil health

31- Unfortunately, standard soil tests are of limited assistance to the restorationist. For example, nitrogen levels are poorly evaluated when they are measured only as concentrations at any one time rather than as total flux over time. Conventional tests also

[26]We cannot agree with this method only based on physico-chemical aspects. This technique is assessed as influencing only the nutrient availability but in reality the whole soil univers is profoundly disturbed. It is another chemical trick while we want to understand and evaluate the life as a whole.

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ignore the biotic component altogether. A number of researchers are working on new methods. One, **Jim Harris,** of the University of East London in England, who has been monitoring soil changes associated with restoration, has developed a set of techniques for measuring the size, composition and activity of soil's microbial community. These measurements can be used for comparison with a less-disturbed target community to assess the level of recovery of the soil system. He and other researchers have developed methods that, at least in England, have incresed fungal populations with significant beneficial impacts to soil development and nutrient cycling.

Build populations of soil fungi

32- As noted earlier, heavy nitrogen enrichment from air pollution and increased compaction, erosion, and sedimentation have tended to favor the growth of bacteria over fungi and invertebrates. Thoughtful management promoting the development of fungi through appropriate treatment of the soil, soil surface, and litter layer can help restore indigenous food webs in forest soils.

Management to Foster Fungi and Other Forest Organisms

33- Because only fungi can break down lignin[27], the woody component of plant matter, allowing dead wood and woody debris to remain on the ground layer, is a major component of the effort to rebuild soil fungi. Raw woodchips and small limbs on the soil surface provide an ideal matrix for the rapid development of a dense fungal network in the soil that, unlike bacterial decomposers, also provides surface stabilization[28]. The webby, sticky quality of the mycelia of fungi serve to knit the suface particles and litter to reduce erosion and conserve moisture that is vital to the life of forest soil. While a deep layer of woodchips can create a growth suppressing that later floods the area with nutrients, a very thin layer of woodchips stimulates the development of a more complex soil biota while limiting the overall rate of the addition of nurtients. Wood's slow rate of decomposition have accelerated dramatically. Because lignin has a very low decomposition rate, it is a more durable groundcover that promotes the development of a stable litter layer[29].

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[27]We take this opportunity to remind that Basidiomycetes fungi play a fundamental role in pedogenesis making possible depolymerization of syringyl and gayacyl lignins giving humic and fulvic acids without important cleaving of aromatic rings containing energy and also biochemical and chemical nutrients.

[28]Once more the author is making no difference between stemwood and ramial wood chipped or crushed nor between Gymnosperms and Angiosperms. More over he only pay attention to the physical impact of fungi mycelia on soil stabilisation.

[29] As evident as polyphenol action is, the author makes no reference to as well as biological and biochemical mechanisms fit for pedogenesis. Only the physical role of fungus mycelia is taken into account.

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34- Occasionally, it may be necessary to inoculate the soil or vegetation with mycorrhizal fungi[30], although in most cases local sources of inoculum are likely to be available from wind and animal dispersal. Where soils are high in nutrients it may be more important to manage nutrients and foster fungi that directly inoculate, especially if inoculation is not required to establish plant species. Small amounts of soil from analogous sites nearby or woodchips colonized by local mycorrhyzae may be used to inoculate sites where natural processes have not been effectual, where there is a substrate limitation, such as thin soil over bedrock, or where plant-specific requirements do not occcur.

35- Jim Harris recommends using thin blankets of fresh woodchips from one half to one inch thick, which create ideal surface conditions for the development of fungi[31]. Within weeks a network of fungi colonizes the surface so densely that the wood chip layer can actually be shaken loose from the soil by hand and moved elsewhere to inoculate an area nearby with local fungi. This method, local harvesting and dispersal of indigenous fungi, should become an important part of soil management programs and is preferable to using a mass-produced commercial inoculum[32] for restoration purposes.

36- We can also manage blowdowns better than by simply removing fallen trees, as is the current convention. Instead, we can minimize the hazard of a falling tree to area walkers while mimiking more natural processes of decomposition that encourage the growth of fungi and invertebrates in the soil by partially upending the stump. The upended root mass reveals a near-perfect seedbed for native species and maintains enough of the

[30]There is a deep confusion about the Basidiomycetes which are responsible for lignin depolymerization and mycorrhizal fungi even if some Basidiomycetes can be involved in mycorrhizal symbiosis with forest trees. The role of these two functional groups of fungi are very different from one another and we should be carefull not to be confused.

[31]No author came so close to the basis of the RCW technology, although only superficial observations were made. The author does not relate to the role of RCWs and confuses the value of stemwood and ramial wood. She overlooks fundamental mechanisms such as lignin biotransformation, the constitution of Gymnosperms and Angiosperms but states the reasons why fresh chipped wood is better than composted material.

[32] Once more we would like to point out the fact that Badisiomycetes are the first level of the trophic web in forest soils and fongivorous fauna form the second level. Therefore it is of utmost importance that Basidiomycetes be the first colonizers, otherwise bacteria and Actinomycetes will free the nutrients in the soil solution creating an non-stable and leaky systems with severe consequences for the natural flora which, it self, is part of the environment stability.

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tree's still living roots to maximize the extent to which its nutrients are passed directly to neighboring trees[33].

37- Commercially produced mycorrhizae have been very successful in reforesting drastically-disturbed lands, such as mine spoils, all over the globe. Sites in Kentuky for instance, where soils were extremely acid, with pH values 2.8, have produced pulpwood for harvest in just fifteen years from inoculated seedlings[34] (**Cordell, C.E., Marx, D.H. & Caldwell, C. (1991)** «Operational appplication of specific ectomycorrhizal fungi in mineland reclamation», unpublished paper presented at annual meeting of the American Society for Surface Mining and Reclamation [Durango, CO, May 1017 1991]). When considering such products, however, evaluate their potential impact on native subspecies of mycorrhizae. Like commercial plant propagation, this approach risks hastening the extinction of local varieties. We still need to develop appropriate procedures and protocols for disseminating fungi and other soil organisms as much as we do for larger plants and animals. Such techniques are well developed in the western states but have only recently been applied in the East.

38- Fire also acts as a stimulus to many wood fungi and invertebrates and reduces bacteria, which in turn fosters the growth of fungi. In a study of changes in beetle population following fire in boreal coniferous forests in Findland, scientists found a sudden appearance of a diverse group of beetles that feed on wood fungi, which in turn implies an even more rapid response by fungi (**Muono, J. & Rutanen, I. [1994]** «The short term impact of fire on the beetle fauna in boreal coniferous forest» Annales Zoologici Fennici, **31**: 109-121). These wood-fungi-feeding forest beetles are fire specialists and represent an important evolutionary adaptation at an ecosystem level to recurrent fires of the past; they are a side-benefit of restoring natural patterns of fire to the forest[35].

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[33]We do not know such a mechanism from the literature

[34]We believe that he author is switching into a very different environement using monospecific conifer plantations, probably with species poor in lignin such as those from the Betulaceae or the Salicaceae family. This is interesting in industrial terms but has no relation with forest restoration or building new climax, stable diversified and high yielding forests. This comparison is most confusing with regard to goal and ideas to be achieved.

[35]Once more the author lacks discrimination over various pedogenetic processes and do not distinguish between boreal Gymnosperm and tropical Angiosperm forests. These are based on fundamental different phenomena such as exclusion and catastrophe for Gymnosperm forests, and on harmony and mutual support in Angiosperm forests.

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39- Native soils conditions and biotic communities and processes need to be the models for our interventions in restoring native habitats[36]. The remaining remnants of native soil are, therefore, bioreserves for the richness that once characterized our soil heritage. The approach should be to restore, rather than replace, soils. Soil made in place is favored over the imported topsoils. Instead of reintroducing missing components with inputs from outside the environment, we should instead focus on fostering the restoration of remnant and indigenous communities of soil biota, which furthers the general goal of "restoring-in-place" to the extent feasible. By doing so, we also minimize the casual dispersal of local subspecies of soil microorganisms and exotic soil organisms. In the worse-case scenarios, such as areas where soil is completely depleted, some materials from outside will be needed, but even in these situations, the soil-building resources inherent to the site should be used to the maximum extent possible.

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[36]The future will be the results of succession dynamics and proceeds through options created by distrubance rather than by the spontaneous re-establishment of the previous system. The succession, however, will proceed in order to restablish the essential and secondary functions. In the computer network, the INTERNET is an example of a way to aliviate major network disturbance. Diversity has had for a long time this stabilizing function. In the biology of ecosystems, time has been the most bothering factor. Therefore copying the surface of eventual solutions using fast and artifical means, has been chosen by most.

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