The following is a compilation of notes and emails from Frederick W. Schueler.

November 8, 2006

Brian wrote:

> *The literature [on forest nutrient cycling] is already available. I just did a two minute search on Google and found articles that contain the following passages--*

* that's why the inhabitants of North America say the words "Hubbard Brook" with such reverence... **http://www.hubbardbrook.org/** We should wander through the educational pages at **http://www.hubbardbrook.org/education/HBEducationHomepage.htm** either before or during our meeting.

Limerick Forest, so far, has been all about nutrient retention: growing Pines to large size on sand, because the Pines and their mushroom symbionts have been able to extract nutrients so efficiently from precipitation. Forestry practices have changed to leave tops and slash on the forest floor, and much of the previous round of logging was done with portable mills that left slab and sawdust on the site, removing only the lumber.

If we're going to continue to be the 'artificially enhanced' forest that's implied by planting the Conifers in the first place, we've got to establish the ***diverse forest floor flora*** that's needed to hold nutrients in the fall and the spring, and to offset harvesting we'll have to ***import nutrients*** from sources that society regards as waste, both to help the forest along and to keep the 'wastes' from being spewed into surface and ground water where they constitute pollutants. And we've got to look out for ***invasives*** that may short-circuit locally native nutrient recycling, such as Earthworms and Garlic Mustard, and for ***regional effects*** like acid rain or neotropical migrant decline that may affect how the forest lives. I've appended some things I've written that bear on these questions.-- fred.

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Schueler, Frederick W. 1989. ***Feeding from the clouds: Net ombrotrophy as a measure of the health of landscapes.*** Trail & Landscape 23(3):122-125.

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Despite the fact that 'ecology' has replaced 'conservation' as the popular description of the activities of people who try to preserve the natural world, the conservation movement has borrowed remarkably few criteria from theoretical or applied ecology for its battles with government and environmental exploiters. The arguments of conservationists for environmental health remain fragmented: aesthetic, anthropocentric, or preservationist; we do not have any global measure of environmental health. If environmental concerns are to have the political importance that they deserve we must have a measure of environmental health that politicians can use in the same way that they use measures of unemployment or interest rates. The Opposition must be able to get up in Question Period and snarl "The Government's inaction has allowed the environmental health of the Sydenham Drainage to go down by 15 points over the last three years! Can the Minister tell this Legislature what action he is planning to reverse the damage to this biologically vital area of the Province?"

We now seem to be against everything: poisons, acid, sewage, tree-killing, intensive agriculture, highways, hunting, development, dams, and drainage; everything except birdwatching and wildflower photography. The fact that we are striving for a healthy, varied World, inhabited by moderate numbers of people who consciously live as a part of the World, emotionally and economically integrated with it, and managing the other species in it for stability on a geological time scale, is lost in the negativism of reaction to environmental abuse. We need a quantitative measure for both environmental health and sickness. If the problem with the management of the World is a general unconcern with the consequences of human activities, and if we need management programs that compensate for ecological damage done by economically necessary activities, then the measure of environmental health must be sensitive to a wide range of environmental disruption, must point out the damage done by historically condoned human activities, and must have a reasonably well-defined natural value that can be compared between areas. It must be quantitative, widely applicable, and based on theoretical understanding of the functioning of ecosystems.

One measure that the conservation movement has borrowed from theoretical ecology is the stability-diversity hypothesis, the idea that ecosystems made up of more diverse species will be more stable --- better able to withstand changes in its environment --- and thus more desireable than less diverse communities. This may or may not be true as an ecological theory. Diversity is usually taken to mean the number of species present, though its technical meaning is the 'information' gained by surveying the community --- the probability that the next specimen encountered will be of a different species than the last one. This is a useful criterion for comparing habitats for a single group of species, but it cannot be integrated across taxa or habitats. Vireos, violets, and mushrooms will not fit into one diversity statistic, nor will an entire landscape made up of many habitats managed for different purposes.

It is my contention here that the net retention of major mineral nutrients by a drainage area is an appropriate measure of environmental health, and that it ought to be used to evaluate the success of preservation and management of terrestrial ecosystems, both as a management tool, and as a challange to exploiters of the land.

Because of the influence of annual-based agriculture we are accustomed to think of nutrients as belonging to the soil, whereas in fact they are held by the community as a whole, and in ecologically mature communities a large percentage of the mineral nutrients are held in living organisms. The perennial root network holds and takes up mineral nutrients as they become available in soil moisture or, in association with myccorhizal fungi, even takes them directly from the decay of fallen litter. These root webs are most active in tropical rain forests, but at all latitudes fully developed communities are able to effect a net extraction of nutrients from rainfall, and it is this that I propose as a measure of the health of landscapes.

The ability to extract nutrients from the 'distilled' water of precipitation is most spectacular where entire communities are ombrotrophic --- feeding from the clouds --- communities that derive their mineral nutrients solely from the minerals in rainwater with a minimum of recycling, either because minerals are deposited in accumulating organic sediments or because the plants live on the exposed surface of rock or of other plants. In most habitats the rootless mosses and lichens, which lack structures to reach soil water, are the only regular ombrotrophs. In bogs, fens, and the epiphytic communities on the branches of rain forest trees the paucity of soil nutrients makes rooted plants dependent on nutrients in precipitation, and it is in these habitats that vascular plants with the most extreme adaptations for nutrient collection --- the fungal symbionts of orchids, the nutrient traps of insectivorous plants --- come to prominence in the vegetation.

The struggle for the greater nutrient resources of ordinary soil is just as intense. The fundamental finding of the study of nutrient cycling is that, on most substrates, mature communities allow so little of the major nutrients past their root webs that there is a net removal from rain water of the fixed nitrogen that builds protein, the phosphorus that holds genetic information in nucleic acids and organic energy in adenosine triphophate, and the potassium that balances sodium in the osmotic milieu of the cell. Since most of the outflow of nutrients is in drainage water, and the concentration of nutrients in river water and rain can easily be measured, the net flow of nutrients for the entire watershed can expressed by a formula of percent retention (positive) or loss (negative) of the nutrients in precipitation.

Almost every sort of environmental degradation results in the loss of mineral nutrients, because of stress to the root-web, deaths of organisms, the disruption of soil, or the introduction of concentrated nutrients that cannot be used by plants. Processes other than water flow which tend to export nutrients are often ecomonically favoured (agriculture, some kinds of air pollution) or actively combatted (wild fires), and nutrients may be sequestered in sediments in lakes or wetlands, or imported by migrating animals. On the whole, however, careless agriculture, soil erosion, paving of ground, clear-cutting, acidic precipitation, high concentrations (at least) of pesticides, and organic or inorganic water pollution all result in the release of nutrients into outflow water, and it may well be that this measure of environmental health will prove to measure the synergystic effects of a diversity of pollutants and stresses, since it measures the actual failure of the community to function as a whole.

The selection of nitrogen, phosphorus, and potassium is straightforward: they are the major nutrients, and are never, as calcium, magnesium, sodium, sulphur, or carbonate may be, present in excess in a natural community as a result of dissolution of bedrock or loading from precipitation. They are the familiar elements of garden fertilizer, so people who relate to fixed nitrogen only as the "first number" will be able to understand the ombrotrophy or nutrient retention index.

Forests absorb water into the soil, and use the nutrients in it so effectively that the groundwater that flows out of them contains less plant nutrients (nitrogen, phosphorus, potassium) than rainwater. Our lakes and rivers developed in forested landscapes, so any water, even pure rainwater, that is not filtered by a well-developed root network (sod or forest), increases plant growth and eutrophication, and must be considered a pollutant. This is true both of water that runs off the surface, and of ground water that originates below the surface (septic tanks) or in bare soils or immature plant communities.

Many popular activities stand condemned by this criterion, most noteablely the flush toilet and cultivation agriculture. Cultivation breaks the root web and allows nutrients to flush away under purely chemical forces until new root systems develop --- and the root web of an annual crop must always be an incomplete and haphazard affair compared to that of perennial plants. Even more direct than leaching is the erosion of soil into streams, which carries away nutrients bound to the finer soil particles, chokes aquatic communities and reduces their ability to use dissolved nutrients, and, by reducing the size of basins and channels, increases the frequency of flooding and drought. Moderate grazing or the harvesting of hay allow a perennial root web, and should be the method of choice for the feeding of agricultural animals, and all land should be zoned to prohibit cultivation near permanent or semipermanent streams. If agriculture is to be ecologically sound it must minimize the loss of soil and nutrients. The requirement of net ombrotrophy is made more difficult by the application of fertilizers, but is mitigated by the removal of nutrients in crops.

These same nutrients removed from one community by agriculture are flushed back into the same or another watershed as sewage, usually far downstream of the point where they were removed from the landscape. The conventional methods of treating sewage are designed solely to deal hygenically with human pathogens, and take no notice of the nutrient content of the wastes, except in cases where grossly excessive phosphorus would cause offensive algal blooms. The septic tank is no better than communal sewage treatment: nutrients are flushed into the ground water and lost to the ecosystem.

Nutrients that are not flushed into rivers or groundwater may be buried in landfills, burned in incinerators, or dumped in the sea. There is no conventional Western method of disposing of any kind of human waste or refuse that redisperses nutrients back onto the land except some forms of particulate or nitrogen-oxide air pollution. Even in these northern and temperate latitudes our culture sucks the life-building nutrients out of the land, and puts fertilizers made from non-renewable minerals only onto agricultural land, from which they in turn are eroded or leached from the soil.

The richest and most advanced human cultures have always grown up in conditions of high nutrient flow --- along the grinding glacial rockmills of the iceage, on the floodplains of silt-bearing rivers, at the centres of systems of imperial tribute, at the eroding edge of ecosystem-breaking frontiers, or, most recently, dependent on artificially fixed nitrogen and limited geological reserves of phosphorus and potassium. Now that there are so many of us, and we have occupied the entire planet, we must abandon this one-way flow of nutrients, which can now only deplete and impoverish the World and ourselves, and establish ecosystems with a high flux of long-retained nutrients that cycle through organisms many times before they make their way to the sea.

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Schueler, Frederick W. 2004. ***Non-Fibre Values: trapping nutrients in an ephemeral root-web.***
S&W Report 35 (Spring/Summer):15-16.

It's a truism that a forest is more than trees, but once we've grown trees on a site, we tend to take the resulting 'forest' for granted, without thinking about what more there might be. Scrounging across the internet recently, I found a paper from the Harvard Forest that addresses how much more there may be, and how long it may take for a second-growth forest to develop an herbaceous ground cover of ferns and spring wildflowers (Jesse Bellemare, Glenn Motzkin & David R Foster. 2002. ***Legacies of the agricultural past in the forested present: an assessment of historical land-use effects on rich mesic forests***[11]). Once we question whether young woods have their full complement of herbs, it's easy to imagine that the trees are growing a lot faster than herbs are recolonizing the blanket of needles under plantation Pines or the scrappy grey leaf-mould under a young stand of Ash. In many young forests that are far from seed sources, undergrowth plants seem to occupy patches rather than microhabitats, as if single ancestors have simply spread rather than competing for space with a full community of other species. The Harvard Forest study has actually measured the incompleteness of recolonization in forests more than a century old.

The authors studied forest vegetation in the towns of Conway and Shelburne in western Massachusetts. These towns are now 70% forested, with stands dominated by Sugar Maple (*Acer saccharum*, 61% of basal area), though they were only 20% forested in 1830. The forests were classified as either 'primary

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1 [1] Journal of biogeography [Oxford] Vol. 29. Nos. 10-11. October/November 2002. p. 1401-1420. http://harvardforest.fas.harvard.edu/publications/ pdfs/Bellemare_JBiogeography_2002.pdf (that break in the URL seems to be a real 'space' character).

forest' (forested in 1830), 'nineteenth century secondary' (open land in 1830, but forested in 1942), or 'twentieth century secondary' (open land or early successional vegetation in 1942). These different classes of forest had recognizeablely different patterns of vegetation, independent of the richness of their soil or other environmental factors. Herbs with no particular adaptations for dispersal and those with seeds dispersed by Ants are less frequent in secondary forests. Environmental differences between primary and secondary forests appear to be less important than age in influencing species' distribution.

When the forest of southern Ontario were cleared for agriculture, forest herbs were often eradicated by direct disturbance and burning, exposure and desiccation, competition with sod-forming grasses, and intense grazing and trampling. They will persist vegetatively through ordinary forest disturbances such as fire, blow-down, and logging, but must colonize second-growth woods by dispersal from existing populations. Often the first colonists are spore-borne Ferns and Clubmosses, or Lady-slipper Orchids (*Cypripedium*) with their spore-sized seeds. These are followed by species carried by the wind or Vertebrates, and only slowly by those without adaptations for long-distance dispersal.

Young woods can have a rich herb cover, if bedrock outcrops and steep slopes have provided refuges for the herbs during decades of deforestation. In the Sugar Maple-Paper Birch woods where the Bruce Trail doglegs out to the shore of Georgian Bay along Little Cove Road, the forest floor is as green as a lawn. Trout Lily *(Erythronium americanum*) covers the floor with a pelt of small leaves and nodding blooms of back-swept petals. There are low plants of Yellow Violet (*Viola pubescens*) with small leaves and constellations of small yellow blooms, Spring Beauty *Claytonia* with coy red-striped pink flowers among patches of small red-stemmed leaves, *Hepatica* tucked into the shelter of tree roots, the flowers open while the wooly leaves are still furled, and Blue Cohosh's (*Caulophyllum thalictroides*) strange blackish patches of purple-black leaves above the Trout Lilies. Wild Leek (*Allium tricoccum*) forms tall patches of broad green leaves that will grow, yellow, and wither before the flower-stems emerge.

Like all woods on the other Bruce Peninsula, these are less than a century old, and the largest Maples outline what must once have been unprofitable pasture, with limestone bedrock never more than a few centimetres from the surface. Mossy boulders are concentrated at the edges of what was the field, and nearby the bedrock opens into fissures 20-30 cm wide. Old sprawling leggy Apple trees are surrounded by whip-thin Maples, and a single Common Juniper bush is a survivor of the pasture (**Little Cove Rd/Bruce Trail,** Bruce County, 17 May 1997)

The Harvard Forest study found evidence that forest herbs had persisted in local refugia such as bedrock outcrops, rocky slopes and fencerows within the agricultural landscape. In 'nineteenth century forest,' plots within 50m of bedrock outcrops often had herb diversity comparable to that of primary forest, while plots farther from bedrock were significantly less diverse and often lacked species with limited ability to disperse.

As anyone who has tucked a few Trout Lilies or *Trillium* into a hedge knows, these ephemeral spring herbs often thrive in a wide variety of shaded habitats. And they are not just breath-takingly beautiful and (in the case of Wild Leek and Ostrich Fern) wonderfully delicious. Through the early spring their roots retain nutrients that might otherwise be lost to groundwater or runoff before the roots of the trees are actively drawing water from the soil. If we're to build up the nutrient status of our woods in the face of acid rain, a green floor may be as important as a green canopy. If we want the flora of young forests to mature within a century, we'll need to recognize and protect refugia where forest floor herbs persist, and perhaps transplant slowly dispersing species into the regrown woods.

<<add a description of Limerick woods in moccasin-flower season>>

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Schueler, Frederick W. 2006. ***Non-Fibre Values: Broken Networks with Garlic.*** S&W Report 43 (Spring-Summer):***11-12***

On the 6th of May 2006, as I patrolled the north slope of the Chatsworth Ravine, at the Lawrence Park School Complex, in Toronto, seeking the introduced snail *Arianta arbustorum*, I was appalled by the bareness of the silty soil, and the dominance of Garlic Mustard (*Alliaria petiolata*), green and tender, and just breaking into tiny while blooms. There were no native spring-flowering herbs. Only the bright golden eyes of Common Dandelions (*Taraxacum officinale*) were conspicuous among the mats of fallen green flowers of Norway Maples (*Acer platanoides*). I checked my revulsion at these alien plants, realizing that they weren't alien to the object of my search, but were rather creating a European ambiance in which a European snail might thrive. I wasn't focused on trees. This spring's leaves were just opening, and last year's fallen leaves had been eaten up by (alien!) Earthworms, but I felt a growing unease at my inability to recognize many of the small trees filling in the slope below the planted trees of the fenced yards, and the older native woods along the stream.[2]

This spring I have been surveying Chorus Frogs (*Pseudacris triseriata*), a nocturnal pursuit that left plenty of time to wander during the days, and everywhere -- from Windsor to Skunks Misery to Collingwood to Beaverton to Ottawa to Morrisburg -- there was Garlic Mustard, the soft rounded mounds of green foliage and the little balls of white flowers, displacing the native forest floor vegetation. Where it hasn't already completely taken over, that there is never any sign that there would be any limit to its possible expansion. In Europe, Garlic Mustard is abundant in forest edges, semi-shaded floodplains, and other disturbed sites, but it takes over both disturbed areas and forest understory across much of the United States and Canada, and has always looked like a blight in Ontario forests.

Anything that gives a plant an advantage in a new area can make it invasive. One such advantage is to disrupt the relationships among native species, freeing resources that the invader can exploit. In the case of Garlic Mustard the impression of blight turns out to be accurate: recently published research from John Klironomos Lab in the Department of Integrative Biology at the University of Guelph[3] has shown that chemicals secreted by the invader kill or suppress the symbiotic fungi on which native plants depend.

Soil on which Garlic Mustard has grown, or extracts of the plant, supress the growth of the arbuscular mycorrhizal fungi on which forest plants, especially, depend for their access to mineral nutrients. Garlic Mustard supressed the growth of seedling Sugar and Red Maple (*Acer saccharum* & *A. rubrum*) and White Ash (*Faxinus americana*) to the same stunted level as seedlings grown in sterilized soil. Spores of mycorrhizal fungi exposed to extracts of Garlic Mustard mostly didn't germinate. Among sixteen plant species Garlic Mustard had a much stronger effect on plants with high mycorrhizal dependency than those with less dependency, with the strongest effects on woody species most typically found in forested sites.

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2 I found a few shells of *A. arbustorum,* confirming this colony's persistance since 1970.

3 with collaborators: Stinson KA, Campbell SA, Powell JR, Wolfe BE, Callaway RM, et al. (2006) ***Invasive Plant Suppresses the Growth of Native Tree Seedlings by Disrupting Belowground Mutualisms.*** PLoS Biol 4(5): e140 **http://biology.plosjournals.org/perlserv?request=get-document&doi=10.1371/journal.pbio.0040140**

Mustards, as a family, don't form mycorrhizal relationships, so there is no loss to them in killing fungi that would be symbionts of their competitors. European forest fungi have evidently evolved a tolerance to Garlic Mustard, but North American fungi are apparently unadapted to these toxic chemicals. What's scary is that Garlic Mustard may well have long-term effects on the composition of a future forest by repressing the regeneration of dominant canopy trees, and by favoring weedy plants with low mycorrhizal dependency.The Dandelions (among the sixteen species tested for sensitivity), may have come into the Chatsworth woods on the chemical 'coat-tails' of the Garlic Mustard.

Unceasing vigilance would seem to be the only recourse: if you don't already recognize the dread *Alliaria* visit Toronto in order to learn to know it. If it shows up in your woods pull it before it sets seed. If it's widespread, eat lots of it as a tender and delicious potherb[4], and pull it through the season.

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Schueler, Frederick W. 2004. ***Non-FibreValues:Tamarack tangledup in hyphae.*** S&W Report 37 (Fall/Winter):18-19.

Non fibre-values: Tamarack bound up in hyphae.

On 15 October, 1.8 km SSE of Bishops Mills, in Grenville County, I was accompanying a group of home-schooling mothers and kids along trails through the woods as they picked up mosses, herbs, ferns, and fungi to plant in terraria. We encountered a few Leopard Frogs and Toads, and named the wood-decaying shelf fungi from the descriptions in Carolyn Seburn's copy of Barron's ***"Mushrooms of Ontario.***[5]" The only conspicuous mushrooms on the ground were a few yellow-pored *Suillus* of a species that isn't included in Barron's selection. The pressure of young terrarists kept us from careful study, or from retaining any as specimens, but the one thing we could note was that they were only found under the scattered Tamaracks (*Larix laricina*) in these tall young mixed woods.

Three weeks later, as I searched the woods with this column in mind, there were no remaining *Suillus*: the passage of the season and a night of -8C had seen to that. The scaly trunks of the overhead *Larix* were still hidden by low Cedars, but now they were made visible on the ground by a red-tan coating of fallen needles, like a dusting of snow, rather than by the risen fungal symbionts. There is a fair scattering of Tamaracks on this old Champlain Sea beach ridge, with about half of their needles still in the high narrow crowns, which were intermittently golden in brief intervals of sun. Many crowns were destroyed or crippled in the 1998 ice storm, and while those that dust the ground with needles have recovered, others are bare poles and food for polypores and Beetles.

Ectomycorrhizal fungi like *Suillus* are one of the underpinnings of our forests. They have a symbiotic relationship with trees, extending hypae through the soil into smaller soil pores than root hairs can reach, forming a sheath around the tips of roots, and thrusting a hyphal network between the cells of the root tissue. Introductory biology courses teach about root hairs, but most plants depend on these filaments of fungus to absorb much of the water and nutrients they need.

The fungus draws carbon and other essential organic substances from the tree and transfers water, mineral salts and nutrients to the tree. They're called ***ecto***-mycorrhizal because of the fungal sheath

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4 see **http://www.bbg.org/gar2/topics/kitchen/2002fa_garlicmustard.html**

5 George Barron, 1999. ***Mushrooms of Ontario and Eastern Canada.*** Lone Pine Publishing, Edmonton. 875 colour photo, 336pp.

outside the roots. Most of them fruit as mushrooms, and when the floor of the Boreal Forest or of a Conifer plantation explodes with autumnal mushrooms, we're seeing the long-distance reproductive effort of these otherwise-hidden partners in the lives of the trees.

Suillus is a genus of Bolete - mushrooms which bear their spores in a fleshy mass of tubes under the cap. It was formerly included in the old mega-genus *Boletus*, and its species are almost exclusively ectomycorrhizae of conifers. As you scan the pages of a mushroom guide, it's striking how many species of *Suillus* 'fruit under Larch.' They're mushrooms of modest size with caps that may be viscid or slimy, or dry and scaly. The mass of pore tubes is white or yellow, and the spore print is usually some shade of olive-brown. Then there's *Fuscoboletinus*, a small genus sometimes merged with *Suillus*, known mainly by its darker spore colour, lack of glandular dots on the stem, and its invariable association with Larch.

Most forest trees are highly dependant on their fungal partners and on poor soil could not thrive without them. Seedlings are quickly colonized by mycorrhizae, and shifting communities of fungal partners live on the roots through a tree's life. In older forests, the mycorrhizal community is often dominated by large fungal individuals, and a single *Suillus* can underlay a hundred square metres of forest floor.[6]

Tamarack typically dominates poorly drained sites such as swamps, bogs, and muskeg. The number of Bolete species associated with *Larix* suggests that they are critically important symbionts, and that Tamarack may be able to thrive only with the aid of *Suillus* and other fungal associates. Here the Tamarack is growing on a well-drained upland, sharing the canopy with Aspen (*Populus tremuloides & P. grandidentata;* also clobbered by the 1998 ice storm), on what was a nutrient-exhausted pasture half a century ago. This was marginal farmland, not settled until the mid-1850s, abandoned by the 1950s, and then colonized by the thickets that formed the present canopy. Probably we can't say whether the mushrooms are here because of the Tamaracks, or if the Tamaracks are here because of the mushrooms.[7]

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6 for a well-written exposition of the importance of mycorrhizae for forests, see **http://www.nifg.org.uk/ecto.htm** by the Northern Ireland Fungus Group.

7 Thanks to three generations of Grahams for the care they've taken of their land and its history, and for the trail system they've maintained for 35 years.