Agriculture: Unsustainable Resource Depletion Began 10,000 Years Ago

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This is a guest post by Peter Salonius, a Canadian soil microbiologist.

According to Peter, humanity has probably been in overshoot of the Earth's carrying capacity since it abandoned hunter gathering in favor of crop cultivation (~ 8,000 BCE). The problem is that soil needs tightly woven natural ecosystems to properly recycle nutrients and prevent soil erosion. Earth's inhabitants have devised a whole series of approaches to increase the amount of food that can produced, starting first with hand-cultivation and culminating in the last century with the widespread use of fossil fuels. These approaches strip the soil of its nutrients and cause soil erosion. Even Permaculture cannot be expected to overcome these problems. According to the paper, eventually, to reach sustainability, the world will need to reduce its population to that of the hunter-gathers, and go back to living on the resources the natural ecosystems can produce.

Peter's paper begins below the fold.

Part 1: Life Before Agriculture

The major departure for humans as just another member of the global animal species assemblage came when fire was first used about 400,000 years ago by Homo erectus (Price 1995). The dynamic cyclical stability of complex systems has been shown for most animal populations, except top predators, to depend on predation to dampen overshoot and runaway consumption dynamics of prey species (Rooney et al. 2006). The ability to control and use fire removed the influence of wild animal predators as moderators of human numbers. The use of fire made possible the colonization of cold lands at high latitudes where fuel for heating shelters was available in some form such as animal oil, dried dung and wood. Even though their shelters became more complex and elaborate, they were, for the most part, temporary encampments whose main structural components could be transported across the landscape so as to benefit from variable food availability as the seasons changed.

The bulk of human history has been that of a culture of hunter gathers or foragers. They did not plant crops or modify ecosystem dynamics in any significant manner as they were passively dependent on what the local environment had to offer. They did however domesticate dogs as early as 100,000 BCE (Vila et al. 1997); these animals were useful as hunting aids, guardians, and occasionally as food during times of scarcity. Hunter gatherers maintained social organization and interdependence, and prevented the loss of food to spoilage by sharing the harvest among community members. These people lived in harmony with their supporting ecosystems and their ability to unsustainably stress and damage their environment was limited by the fact that if their numbers exceeded the carrying capacity of the complex, self-managing, species diverse, resilient terrestrial and aquatic ecosystems from which they gained their sustenance, then hunger and lower fertility exercised negative feedback controls on further expansion.

They used culturally mediated behavior like extended suckling, abortifacients and infanticide to keep their numbers far below carrying capacity, and to avoid Malthusian constraints like starvation (Read and LeBlanc 2003). Warfare between groups competing for the same resources, before the evolution of states, also appears have been a significant constraint on the growth of human numbers (Keeley 1996).

Part 2: The Evolution of Agriculture

The development of agriculture is of great interest to us because it produces most of our food and it was a prerequisite for the tremendous growth of human numbers, and also for the various complex societies that have evolved since this new culture began (Diamond 2002).

After the advent of agriculture, mortality rates, caused by conflict, decreased somewhat as local raiding by chiefdoms evolved into long-distance territorial conquest by states (Spencer 2003). These cultural and conflict behaviors that limited human population growth served to maintain balance between humans and other species during most of the historical record. Read and Leblanc (2003) suggest that humans, in areas of low resource density, tend to maintain generally stable populations, while high resource density, such as that produced by agriculture, decreases the spacing of births more rapidly than the increase in resource density, which results in repeating cycles of carrying capacity overshoot and population collapse.

<u>Nomads and Pastoralists</u>

The earliest movement from strict hunter gathering toward agriculture came when people noticed the changes in ecosystems that they burned to move game animals to places where they could be more easily killed; sometimes the post-fire vegetation consisted of an increase in the numbers of plants used as food, such as berries and bulbs and also vegetation assemblages, like the sparse oak parkland of the U.S. Pacific Northwest that produced acorns for both human food and for the deer that they hunted (Angier 1974; Oregon State University 2003), while in other areas grasslands were periodically burned to encourage the growth of tender vegetation that was attractive to game animals.

Even though some hunter gatherer/ foragers did modify the vegetation or successional state of vegetation assemblages in specific areas with fire, these areas seldom were productive enough to support year round occupancy. Thus began the first steps of humans as a ‘patch-disturbance‘ species (Rees 2002), whose expansion would ultimately extend to and modify almost all of the ecosystems on the planet.

Movement toward actual cultivation agriculture began with the domestication of cereal grains at a time when postglacial climate warming was interrupted by climate reversal, even before the beginning of the consistently warm conditions of the Holocene (Hillman et al. 2001). Diamond (2002) shows that plant and animal domestication first occurred in areas where the most valuable and easiest species to cultivate were native. These species were later moved to new and more productive areas by the migratory expansion of their cultivators who overran resident hunter gatherers. As people worked with and cultured wild species, the process of genetic selection began to produce more easily managed individuals with modified behavior. Diamond (1997; 2002) outlines characteristics of wild animals dealing with diet, growth rate, captive breeding, disposition, and social structure that make individual species either candidates for domestication or that make domestication very difficult.

Nomads, inhabiting grassland / prairie ecosystems, who had relied on hunting herds of herbivores, learned enough about the habits of these species to begin the process of controlling some of them. The resulting pastoral herding culture of such animals as camels, goats, sheep, cattle, yaks, alpacas and reindeer made locating meat much less chancy, and allowed the further developing use of secondary products from living animals such as blood and milk. This very early form of species domestication without cultivation provides considerable independence in the face of environmental fluctuations because herds are moved to different areas as the seasons change and during periods of drought. These people developed a culture that moved to adapt to the environment as opposed to forcing changes on the environment to accommodate a particular food production culture, even though they did burn land to rejuvenate pasture and prevent forest growth from encroaching onto grasslands.

Pastoralists, like hunter-gatherers maintained close social organization and interdependence, and they prevented the loss of food to spoilage by sharing the harvest among community members. Hunter gathering, foraging and pastoral lifestyles are often thought of as precarious and requiring very hard work, while both archaeological evidence and the health of the few groups that have not yet been displaced by farming suggests that they lived quite long and much easier lives with better health and diets than the first people who practiced cultivation agriculture in the same localities (Diamond 1987).

Pastoralists were subject to the same constraints as hunter gatherers; their ability to unsustainably stress and damage their environment was limited by the fact that if their numbers exceeded the carrying capacity of the complex, self-managing, species diverse, resilient terrestrial ecosystems from which they gained their sustenance, then hunger and lower fertility exercised negative feedback controls on further expansion. There have only been a few groups that have been able to maintain the hunter gatherer life style even as they have been displaced and forced onto marginal land by agriculturalists. Pastoralists may continue to thrive into the modern era because the semi-arid lands they utilize are usually inappropriate for cultivation agriculture.

Of interest is the move back to nomadic pastoralism in some of the Central Asian republics that has followed the demise of the money economy after the collapse of the Soviet Union during the 1990s. Modern grass-fed cattle and sheep ranching, although not a subsistence culture, has a lot of similarities to pastoralism except that it is carried on in a grander scale to produce commodities for markets.

<u>Beginnings of Cultivation Agriculture</u>

The evolution of agriculture appears to have been an accidental, ‘hit-and-miss’ development that almost certainly sprang, not from necessity (Diamond 2002), but from the propensity of humans to experiment. Selective harvest and replanting of specific races of food plants took place at an accelerating pace as the hostile and unpredictable climate at the end of the Pleistocene gave way to warmer and more predictable conditions (Richerson et al. 2001). Although some authors suggest that the growth of human populations during the last 10,000 years has resulted in pressure to produce more food to feed them (Boserup 2005), most see the increased food production by cultivation agriculture as the driver of population growth (Abernethy 2002; Hopfenberg and Pimentel 2001; Hopfenberg 2008).

Cultivation agriculture usually began with shifting or ‘slash and burn’ techniques that utilized the accumulated nutrients, built up under native forest or grassland, and also those nutrients in the ash resulting from burning native vegetation. Reasonable productivity for cultivated plants lasts for only a few years on upland soils under shifting cultivation. Permanent agricultural cultivation appears to have been possible in river valleys that were fertilized annually by new soil carried by floodwaters. When soil nutrients are depleted on upland soils, it is necessary to move to a new patch of native vegetation cover and repeat the 'slash and burn' process. After the abandonment of temporary fields, a considerable period of native vegetation regrowth is necessary before soil nutrient levels are again built up to the point where another short cycle of cropping and nutrient depletion is profitable. On better soils in tropical climates the period of early successional woody vegetation growth may only need to be a few years before the next cultivation cycle, because temperature-driven soil weathering rates are very high in these areas.

Shifting cultivation is usually labor-intensive and the small plots involved do not produce enough to support humans and horses, oxen or other draft animals that could assist with tillage. Year round multi-cropping in tropical climates on erosion prone slopes such as areas of the Philippines sometimes involved as many as 40 different crop species on the same field so that there was always enough plant cover to break the force of the rain and minimize erosion. Shifting cultivation is only viable if the population remains low enough that the next cycle of temporary cultivation is not required until native forest or grassland regeneration on abandoned fields has rebuilt the supply of nitrogen (by biological fixation) and levels of plant available phosphorus, potassium, calcium, magnesium and micronutrients (by soil weathering).

At the time of European contact in eastern North America, from mid continent and southward, much of the low altitude land had already been submitted to enough Amerindian shifting agriculture that the settlers discovered a landscape mosaic of cleared gardens, abandoned clearings returning to forest vegetation and maturing forest that was ready for yet another cycle of clearing, burning and temporary cultivation (Williams, 2006). European settlers, whose rapidly moving diseases had already decimated the Amerindians, were able to start farming on cleared land that had been prepared by the former residents.

Amerindians did utilize the nitrogen fixation capabilities of leguminous beans in mixtures with squash, corn and various other crops, and they did augment depleting soil nutrients with the placement of fish in planting spots. However at the time of European contact, Amerindian population dynamics were probably already on the same ‘increase and collapse’ trajectory as those of other populations, whose numbers increase to exceed carrying capacity as food production is increased by the adoption of cultivation agriculture (Costanza et al. 2005). Rees (2002-03) states, as did Malthus (1826), that unless there are constraints on animal (including human) expansion, all populations grow to the point that they destroy some critical resource and then they collapse.

Intensive cultivation agriculture provides adequate food to allow the growth of large scale, populous societies living in settlements with permanent dwellings that are near enough to the food growing areas to facilitate their management and that allow for the storage of food from season to season. The transition from the passive dependence on existing complex self-managing ecosystems by mobile hunter gatherers gave way to the greater control of food sources provided by cultivation agriculture on land in specific localities with radically altered ecology. Its practitioners were tied to the land, and they were vulnerable to environmental vagaries that could produce local crop failures.

Diamond (1997) suggests that the development of plant cultivation agriculture was a ‘trap’ that precipitated massive changes in the way we feed ourselves and in the social organization that is a natural product of land ownership and control of stored foodstuffs. The thinking with regard to this ‘trap’ is that, as populations rise to utilize the increased food supplied by cultivation agriculture, it is very difficult to revert to less productive food producing systems without incurring hardship and starvation.

The egalitarian food-sharing social organization systems of hunter-gatherers, pastoralists and shifting agriculturists, based on kinship, gave way to the class stratification of societies that rely on intensive cultivation agriculture. The stratum of society that controls the means of food production, and the land required for it, develops a hierarchy of property owners and leaders who are rich enough to thrive during periods of severe food shortages, while the less powerful, who are employed by them, suffer famine much more directly.

Eventually this social stratification and evolution of complex labor division proceeds to the point where merchants, craftsmen, military, clergy, bureaucrats, politicians and royalty occupy urban areas where food from the countryside is used, but not produced. A rich and politically powerful stratum develops absolute property rights that are accumulated as wealth and transferred to its descendants; this stratum, often doing very little labor, becomes more numerous and difficult to support as the ratio of elites to producers increases (Costanza et al 2005).

As economic class distinctions developed, the social changes usually included a decline in the status of women who were more equal partners in subsistence societies. While close to 100% of the people in foraging and hunter gatherer societies were involved directly in producing food, less than 60% of the population in non industrial agricultural societies may participate directly. In contrast, industrial, modern, mechanized agriculture that depends on non renewable fossil-fuelled machinery usually employs less than 5% of the population directly in food production.

The migration of foragers and hunter gathers to colder northern climates, the shift to more intensive food production systems that included increased densities of people living in the confines of enclosed permanent structures, the further migration of people into Asia, and the modern evolution of urban living conditions have all been accompanied by genetic changes in humans. The most well known of these changes are the adaptive development of resistance to "crowd diseases" spread from domesticated animals (Diamond 2002), food tolerances, the various blood groups we see in human populations, as well as the selection for lighter skin colors that has allowed people living in northern climates to use limited sunlight to accomplish the metabolic transformations of chemical precursors into Vitamin D (D’Adamo and Whitney 1996).

The transition to large-scale intensive cultivation agriculture in permanent fields often involved complex water management (irrigated rice) and the use of large animals such as horses, water buffalo and oxen to pull plows which turn up buried soil nutrients into the planting layer and aid in controlling weeds. Even though intensive cultivation agriculture did produce more food than subsistence food production on a specific area, severe local food shortages were not eliminated by the development of these techniques. Famine was caused by cyclic drought, climate cooling episodes and the natural propensity of humans to increase population numbers to meet then surpass any elevation of carrying capacity during benign conditions (Hopfenberg 2003).

Societies grew and prospered until soils were exhausted or as long as there was new land to cultivate, but they declined when they ran out of fertile soil options (Montgomery 2007). Temporary overshoot of carrying capacity has caused human numbers to fall back precipitously with some regularity throughout history (Stanton 2003), while less regular complete collapses of societies have been the norm since the advent of agriculture (Costanza et al. 2005).

Cultivation agriculture has resulted in a tremendous depletion of both soil mass by erosion (Montgomery 2007; Sundquist 2007) and plant nutrients in soil (Williams 2006; Salonius 2007). Plant nutrients are lost because of bare soil cultivation and the lack of the very efficient recycling that is a characteristic of diverse, deep rooted, nutrient-conservative forest and grassland / prairie ecosystems. Nutrient replacement with fertilizers is the process that allowed intensive cultivation agriculture to continue after all of the arable soils on the planet had been occupied.

The Agricultural Revolution and Beyond

The Agricultural Revolution was the first of several food production improvements that took place after 1700. Soils, whose plant nutrients would normally be depleted after a period of cultivation, were augmented in the earliest stages of intensive agricultural development by forest leaves, animal manures, wood ash, fish, seaweed, mud from tidal zones, and pulverized bones. As a complex transportation industry began to develop based on coal and then petroleum for railways and ocean going ships, long distance transport of guano, Chilean nitrate, limestone, potash salts and rock phosphate allowed depleted soils to produce enough crops for domestic use and export. The absolute necessity for including legume crops in crop rotations was circumvented after the Haber- Bosch process began producing ammonia using methane and atmospheric nitrogen 1913 (Vance 2001).

Science-based management of soil nutrients and fertilizer materials became necessary as crop fertilization had to become increasingly efficient. The guiding principle for crop fertilization was Liebig's Law of the Minimum that states that only by increasing the supply of the scarcest or most limiting soil nutrient would crop growth be improved. Later the emphasis shifted from crop fertilization to nutrient management planning which attempted to assess soil nutrients that would be released into solution during growth, the acidity of the soil as it effects plant nutrient availability, the nutrients contributed by manure applications and nitrogen fixing plants, and the possibility of environmental (especially to water) damage by nutrients that are not used by the existing crop or that are not held in the soil until the next crop begins to grow.

The next major increase in food production occurred as the Industrial Revolution began. Energy for manufacturing farm implements was first obtained from falling water. With the invention of the steam engine, energy from burning wood supplied power for the manufacture of farm machinery such as plows, mowers, diggers and threshers. The motive power to operate this machinery was provided by draft animals. Later these machines were pulled and operated by power obtained from internal combustion engines that slowly reduced reliance on draft animals such as oxen and horses, whose feed formerly came from the same arable land that grows food crops for people. Thus the Fossil Fuel Revolution began.

Since 1750 human society has increasingly augmented the solar energy that it relied on exclusively for most of its history with a progression of temporary supplies of non-renewable geological energy sources (coal, petroleum, natural gas and fissionable uranium). The profligate consumption of these energy subsidies has allowed tremendous increases in agricultural production and the global trading that removes the necessity for food to be produced in the region where it is to be consumed.

Thomas Malthus (1826) predicted that agricultural production increases would not be able to meet the requirements of a steadily growing human population. However he was not aware that the depletion of soils by the agriculture, that was feeding less than one billion humans in the 1700s, was already unsustainable in the long term. Malthus could not have conceived of the temporary increase of carrying capacity and food production that would be made possible by the use of non-renewable fossil and nuclear fuels during period after his death. The abandonment of the effective controls on human birth rates, exercised by pre-agricultural societies, and the decrease in mortality by warfare that followed the evolution of states have allowed the exponential expansion of human numbers to be fuelled by increased availability of food.

Human populations had grown very slowly until the advent of agriculture. Population grew rapidly in the context of both increased food security and the wealth that agricultural productivity created until the middle 1800s. During the latter part of this period, as soil productivity became seriously diminished by cultivation agriculture, and a scarcity of forest land that could be cleared for farming developed, migration to new lands such as North America and Australia was used to decrease the pressure on existing land. These new areas presented migrants with fertile land so that soil-depleting agriculture could continue (Manning 2004; Williams 2006).

This migration and exploitation of new lands continued the accelerating population expansion that increased agricultural food production makes possible. The historically unprecedented rapid exponential population explosion after 1800 was driven by the increased productivity that was made possible by the labor saving machinery of the Industrial Revolution in concert with the increasing access to cheap and abundant geological energy that characterized the Fossil Fuel Revolution.

Part 3: Our Current Agricultural Situation

The Green Revolution produced the last major improvement in food production during the latter decades of the twentieth century as new crop varieties were created by plant breeders. These new varieties depended on large inputs of fossil-fuel dependent fertilizers, irrigation, insecticides and herbicides. William Paddock (1970) warned, at the time of the beginning of the Green Revolution, that the increased agricultural productivity would simply produce more malnourished poor people if curbs were not applied to the increase in human numbers that would result from increased food availability. Global population growth since the beginning of the Green Revolution has borne out the futility of increasing food availability in the absence of measures to control human fertility (Diamond 2002).

Some forms of modern industrial agriculture, combined with the transportation necessary to ship food produced, use more than 10 calories of fossil fuel to deliver one calorie of food to the market (Younquist 1997). Montgomery (2007) states that before 1950, most increases in food production were the result of increased land under cultivation and better husbandry, but recently most of the increases have been the result of mechanization and escalating fertilizer use. Albert Bartlett (1978) has said, “Modern agriculture is the use of land to convert petroleum into food."
Salonius (2005) summarized evidence for the necessity that modern civilization must face the prospect of decreasing access to the cheap and abundant exhaustible geological energy that has served agriculture so effectively during the recent past. The cost of this energy is poised to increase and that eventually fossil fuel and fissionable nuclear energy will become economically unavailable.

The looming scarcity of fossil fuel resources will create great difficulty in continuing to supply fertilizer nitrogen for agriculture by the Haber-Bosch process. Inexpensive rock phosphate supplies are forecast to become depleted in as little as 60 years (Vance 2001). Dery and Anderson(2007) demonstrate peaking phosphorus production from several sources including the United States that follow the same trajectory as the Hubbert Peak for petroleum; these authors suggest that world rock phosphate production is already in decline and that future agricultural production will depend upon diligent phosphorus recycling.

North America has the largest reserves of potassium in the world that can be manufactured into fertilizer materials. Concerns about the stability of limited supplies as well as the increasing costs of transport, that are driven by petroleum scarcity, produced rapid escalation in the price of potassium fertilizer during the early years of the twenty-first century.

As fertilizer supplies and long distance transport are expected to dwindle in concert with fossil-fuel depletion during the twenty-first century, organic agricultural techniques are expected to replace the industrial agriculture that has been powered by fossil fuels and nourished by chemical fertilizers. The International Fertilizer Industry suggests that organic agriculture is only capable of producing one quarter of the protein produced when large amounts of inorganic nitrogen fertilizers are employed (www.fertilizer.org/ifa/sustainability.asp); however, Pimentel et al. (2005) have shown that weathering rates appear to be able to meet plant demand for nutrients when organic agriculture relies on nitrogen fixing by legumes on some soils.

Sustainability issues are becoming increasingly apparent to systems analysts who have begun to understand the dilemma faced by human populations that have overshot the carrying capacity of the ecosystems they rely on for the production of food and fiber. This understanding usually encompasses the looming current depletion of non-renewable fossil and nuclear energy subsidies, however more basic depletions are becoming recognized as having been sidestepped for the last 10,000 years.

The global human family has become dependent upon the enhanced food production made possible by temporary supplies of non-renewable geologically stored fossil and nuclear energy. The energy market, upon which present affluence levels are based, is a global one, and the availability of geological energy supplies cannot be maintained. As access to the energy upon which complex industrial societies are dependent becomes more expensive and less available during the twenty-first century, human population numbers will have to be brought into balance with the sustainable productivity levels of the local ecosystems upon which they rely for their sustenance.

The ecological deficits, that humans have sidestepped by migration to new lands, mining soil mass (erosion) and soil nutrients (leaching), and access to one-time supplies of exhaustible energy, will have to be squarely faced as the level of affluence diminishes. Food production per capita must fall as horses and oxen must again be fed from crop land and as access to fossil fuel dependent fertilizers diminishes.

Part 4: Intensive Crop Cultures Are Unsustainable

A growing number of commentators, such as Alan Weisman (2007), have begun to suggest that a world with fewer people would be far better placed to deal with climate change and the exhaustion of the dirty fuels of the industrial past. Many appear to think that high technologies such as nuclear energy and yet another agricultural revolution, this one supplying Genetically Modified crops, in combination with curbs on population growth, would begin to dampen the environmental disruption caused by human society that is becoming increasingly obvious. However the problem is even more serious than that visualized by these thoughtful individuals who are convinced that the neoclassical economic model of open-ended expansion and so-called ‘sustainable growth’ is a recipe for disaster.

William Rees (1992) originated the idea of the Ecological Footprint to measure the amount of land that people with different lifestyles both occupied and drew on for their sustenance. Wackernagel and Rees (1997) further developed this concept, calculating how many Earths would be required if all of the people on the planet lived at particular levels of consumption; they appear to believe that the human family overshot global carrying capacity sometime in the twentieth century. Regardless of the timing, we know we are in serious overshoot and that the total human footprint (whatever enormity it is) must get smaller.

As we run up against all of the renewable and nonrenewable resource depletions (oil, soil, phosphorus, minerals etc.) that will characterize the foreseeable future, we require an entire rethink as to how we do business, because the human enterprise has been living on borrowed time and resources for millennia. It is quite conceivable that most intensive crop culture is unsustainable and that it has been unsustainable since cultivation agriculture began.

It is reasonable to suggest that we begin unsustainable resource depletion (overshoot) as soon as we use (and become dependent upon) the first unit of any non-renewable resource or renewable resource used unsustainably whose further use becomes essential to the functioning of society. Each of the following has facilitated an increase in food availability and thus an increase in the human numbers that must continue to be fed whether the resources become depleted or not: the first tonne of coal, the first litre of oil, the first kilogram of fissionable uranium, the first barrel of fossil water for irrigation that exceeds the recharge rate of the aquifer being tapped, and the first hectare of formerly nutrient conservative native forest or grassland/prairie plowed.

The last item in the list, plowing of virgin ecosystems for cultivation agriculture, sets in motion unsustainable renewable resource depletion (excessive erosion and leaching/export of plant nutrients from arable soils, and more recently the excessive leaching and nutrient depletion that is associated with harvesting of nutrient-rich forest biomass) that has been looming over us, unseen, for 10,000 years (Salonius 2007). Some estimates suggest that nearly one-third of the arable soils on Earth have already been lost to erosion since cultivation began and recent moves to rely on agricultural crops as a source of biofuels (ethanol) are seen by some as trading a system based on mining oil for one based on mining soil (Montgomery 2007). We can expect that the unsustainable exploitation of soil will become increasingly apparent as the depletion of petroleum begins to affect the production of foodstuffs by unsustainable farming, and the production of fiber produced by unsustainable forestry upon which most of us are dependent.

Humanity has probably been in overshoot of the Earth's carrying capacity since it abandoned hunter gathering in favor of crop cultivation (~ 8,000 BCE) and it has been running up its ecological debt since that time.

Part 5: The Future of Food Production

In the context of depleting reserves of the fossil fuels that have supplied modern agriculture with motive power, machinery, fertilizers, insecticides and herbicides, it is expected that the way food is produced will have to change as the twenty-first century unfolds. 'Permaculture' (Mollison and Holmgren 1979), and other modifications of agricultural practice that seek self sufficiency, such as those put forward by proponents like the Post Carbon Institute's Relocalization program (www.postcarbon.org) include local food and biofuel systems, revitalization of local industry, and community cooperation.

These are good first steps that recognize global trade will wane as fossil fuel depletion gains momentum. They are also an attempt to wean people off the industrial food production that treats soil as a medium for fertilizer-dependent hydroponic agriculture, and simply a substrate to stand plants up in. These people are interested in popularizing organic agriculture, minimum tillage or no-till methods, solar powered tractors etc. that will make local economies less reliant on imported materials. However these alterations follow the cultivation agriculture model as a food production system, as they must in the short term.

All cultivation agriculture depends on the replacement of complex, species diverse, self-managing, nutrient conservative, deep rooted, natural grassland/prairie and forest ecosystems with monocultures or 'near monocultures' of food crop plants that rely on intensive management. The simple shallow rooting habit of food crops and the requirement for bare soil cultivation produces soil erosion and plant nutrient loss far above the levels that can be replaced by microbial nitrogen fixation, and the weathering of minerals (rocks and course fragments) into active soils and plant-available nutrients such as potassium, phosphorus, calcium, and magnesium on most of the soils on the planet.

Under natural grassland/prairie and forest ecosystems, erosion rates of soil mass are minimal, and the diverse and deep structure of the below-ground rooting community, with its microbial associates, makes the escape of plant nutrients entrained in downward-moving drainage (leaching) water to the ocean very difficult. Our ultimate goal, as we attempt to achieve a sustainable human culture on Earth, must be to move toward the sustainable exploitation of natural grassland/prairie and forest ecosystems at rates that do not cause the loss of physical soil mass or plant nutrient capital any faster than they can be replaced by biological and weathering processes.

Obviously, as we move back toward a solar-energy dependent economy based on self-managing natural ecosystems, we will no longer be able to run the massive ecological deficits that temporary fossil and nuclear fuel availability have allowed. Just as obviously the solar-energy dependent economy will not support the human numbers that have been able to exponentially increase slowly as a result of agricultural mining of soil mass and nutrient stores since ~8,000 BCE, and rapidly because of the availability of non renewable fossil and nuclear energy subsidies since 1750.

In order to lower the human population to levels supportable by sustainable exploitation of natural grassland/prairie and forest ecosystems we must begin to allow these ecosystems to reestablish on lands that have historically been devoted to intensive cultivation during our 10,000 year agricultural past. The best suggestion so far to produce Rapid Population Decline (RPD) is for the collective global human family to adopt a One Child Per Family (OCPF) 'modus operandi/philosophy'. Even with general acceptance of RPD and OCPF, the human population decrease that is necessary to achieve a sustainable solar energy-dependent culture, will take several centuries. Governments, as they become convinced that RPD is necessary, may choose monetary incentives, tax breaks and/or penalties to achieve general acceptance of OCPF or some other RPD program.

Part 6: Moving Beyond (Back From) Cultivation Agriculture

There are areas of the planet with such low rainfall as to preclude the growth of forest vegetation where a return to pastoral herding, with low stocking levels, will allow the reinvasion of native prairie vegetation. As we move toward the abandonment of unsustainable agricultural practices, it would be advisable to shift away from the cultivation of grains and forages that require bare ground cultivation on these lands.

As human numbers are contracting/shrinking under a OCPF/RPD or some other numbers reduction methodology, the extant population will insist on being properly nourished. The only way enough food can be produced for them is by cultivation agriculture that will further deplete most of the arable soils on the planet. During the centuries of transition, as we move toward a solar-dependent culture that again sustainably exploits natural grassland/prairie and forest ecosystems, we should be exercising as responsible agriculture as is possible on the shrinking arable land base where it is still practiced. During this transition, the growing amount of land that is abandoned will revert toward natural grassland/prairie and forest ecosystems very rapidly after we cease cultivating it (Weisman 2007).

Balancing of human numbers with the productivity of their supporting local ecosystems may be accomplished by planed attrition, much lower birth rates and the economic dislocations and hardships that a retreat from classical economic growth will incur, or the balancing of human numbers may be accomplished by a catastrophic collapse imposed by natural resource scarcity. The species with the large brain must make the choice between economic hardship and catastrophic collapse.

Cultivation agriculture must be relied upon for the bulk of the food required to support global humanity until we have reduced our numbers to a level that can be sustained by regulated exploitation/harvesting activities that fall within the
(now better understood) capacity of ecosystems to maintain diversity, to form soil and to replace soluble plant nutrients lost by harvesting or leaching.

The attractive aspect of moving toward sustainable co-existence with self-managing ecosystems is that the hit-and-miss process of evolution has already established how to make them work. Our responsibility (after our numbers have fallen to sustainable levels) will be to learn to live within the regeneration capacity of these restored ecosystems. The penalty for exceeding their regeneration capacity will be hunger and privation, as it was for our hunter gatherer, forager and pastoral ancestors.

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281 comments on Agriculture: Unsustainable Resource Depletion Began 10,000 Years Ago

Comments can no longer be added to this story.

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Selected comments only

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airdale on October 21, 2008 - 1:21pm

Engineer-Poet,

Your looking at 'it' thru the eyes of an engineer, I must assume.
The author as a soil biologist.

Me as a farmer. From early childhood when I was raised on farms, to farms I have held even though working in the IT industry, to now where I brought my present one in 1985 and farmed it and it was under intensive modern ag row cropping for much of my ownership in the 80s. Upon which time in the early 90s I stopped row cropping and resorted to grasslands and grassland management for the haying crops(made more money then).

Ok. It IMO takes a farmer who is close to the soil to see what has happened and I must agree with the author as to what I see.Though most farmers might see this they refuse to give it credence,IMO again.

My area has very good soils. It also contains much bottom land which requires no fertlizer inputs for the most part.

What I see and judge , viewing the past against the present is the vast amount of devastation. How the modern practices destroy the land.

A personal example then:

I noticed that the operators who put in my row crops had little real regard for the soil and land. They were destroying my farm as a result and they were the biggest in the county and the richest.

Yet when I dug 5 ft hole for the erection of a pole barn I was building I noticed that there was not a single earthworm to be found as I augered these holes. Right in the middle of a corn field. Looking over my farm which was BTW being No-Tilled..I discovered that I could find zero evidence of earthworms. Except in the nearby woodlands.

I also noticed plenty of gullies starting to form. I tried disking them and overseeding them with Ky 31 Fescue..did not good for they promptly sprayed weed burndown over them and planted right over them.

They had destroyed two of the ponds on the place by breaking the damns. Ponds that drained a lot of watershed. They pushed the fences into the ponds. Took me a great deal of work to resurrect the ponds after I discontinued the row cropping.

There is far more but the good fertile soil that was classified as Collins Silt Loam was being turned sterile over time.

I sowed it all down and it began to come back.

This has happened all over my county and other counties. The farmer thinks nothing of altering the land via dozers and trackhoes, which most now own. They destroy the topsoil and figure that as long as they can spread fertilizer on it then it doesn't matter at all.

Most farmers are IMO lousy stewards of the land!!!

I know a lot. They want the money,period. They will use what ever methods to ensure they have a cash flow in the positive.

Note that I have experience in more than one state as far as owning small and large farms. The lands of central Ky are entirely different and what works for one doesn't work for all.

So my view is that , yes we are fast destroying our precious soil and nature in the process.

One has to simply drive by a large paper/pulp mill or chip mill or charcoal making site to realize the enormity of what is transpiring , all in the name of a suburban family being able to cook meat outdoors. Or having cheap food, even though that food be fairly tasteless and void of much nutrition.

I think ag is our last frontier to destroy.
The oil is going.
Financials are in dire straits.
Ag is next to meltdown and believe me,it is ripe.

They, the farmers, have mostly forgotten how it used to be. How precious the land was when you sat on very good land and most of the us does not have good water, good growing seasons and good soil..all combined as we do in many areas nearby.

Illinois in the flat lands has been turned into a massive field of industrial ag. Thats about all it is.
Mining of coal may come back but intensive ag is about it.
Iowa,Indiana,upper Missouri and so on.

We are killing it and at a rather rapid pace.
Good thing that ethanol is now just a dream.

Bad that we grow grains that are used to foist junk food on the masses and enable them to continue the dreams of endless dreams of paradise on earth thru gorging themselves and endless driving.

Airdale

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And1 on October 22, 2008 - 9:14am

Re Airdale comments.
Going through the same cycle. Being in farming for 46 years and farming and engineering in parallel I support the comments in the paper and Airdale’s comments.
For future farming the major problem is the soil degradation that is compounded by the removal of biomass residues for biofuel, animal feed and energy production. The organic components in soil are steadily removed and have to be replaced with NPK fertilizer etc.
In future some fertilizer can be made from renewable energies, and this will ensure that crop yield do not drop to medieval levels. More biomass wil have to be returned to the soil which will put a strain on all the renewable – biomass based future resources.
There still is IMO a good case for not so intensive “industrial farming” especially if we manage Phosphorous well. This is no new issue. Already 1300 BC this problem has been identified in the UK.
http://www.bahs.org.uk/45n2a1.pdf

A few numbers that illustrate the issues:
Medieval harvest in Denmark 1600-1700 BC typically 5-7 “fold” (grown in 2/3 year crop rotation).
“Fold” means how many grains you harvest compared to what you sow.
For UK the literature gives a similar yield around 1800 BC of 20 bushel per acre ~7 fold ~ 1.25 ton per Hectare
http://books.google.dk/books?id=9XzxRXrIIo8C&pg=PA134&lpg=PA134&dq=crop+...
Present wheat harvest 40-55 fold and Barley 28-35 fold.
For grain yield nerds this English database is a must: “Three centuries of English crops yields “ 1211-1491. http://www.cropyields.ac.uk/project.php Yields of 3 “folds” or less are not uncommon in

those times.

/And1

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Peter Salonius on October 20, 2008 - 7:42pm

Far from abandoning all hope, we have the choice to orchestrate a reduction in our numbers during the next ciuple of centuries by planned reduction of the birth rate or having nature reduce our numbers by starvation.

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void_genesis on October 20, 2008 - 7:16pm

Formation of topsoil is primarily a biological process, not a geological one. It does not have to take millenia to occur, as has been demonstrated by Yeomans keyline system of agriculture. The key is allowing the decomposition of roots in place without excess soil cultivation in order to maximise the formation of humus from biomass.

I have found similar results in my vegetable garden by using regular green manure crops, leading to a deeper topsoil at a rate of about half to one inch per year. The green manures grow for half the year and are slashed repeatedly, encouraging roots to die in situ. The soil is never turned, but is instead deeply cultivated with a broadfork to allow the roots to grow deeper every year. No animal manure is necessary to boost soil carbon. Human urine is applied to the green manure to recycle basic food nutrients.

My field crops are grown with a permanent living mulch of low growing soft weeds along the style of Fukuoka. The density of these is managed by regular hand hoeing. No irrigation is applied, instead the soil is again occasionally deeply cultivated without turning to allow topsoil to deepen every year and increase rainwater retention. Small tree crops break up the fields into narrow rows. Erosion and nutrient loss are minimal, if anything moving food, biomass and soil uphill as a matter of habit works against the slow tendency for downhill movement. I have been reproducing Fukuoka's yields with a wide range of crops, giving a subsistence level of 2-10 people per acre (allowing for our variable rainfall here in Australia).

The key to the growth rate and yield of plants is the availability of nutrients. Plants can only access a certain depth of soil, but deeper microbial connections link the topsoil to the subsoil and geological strata. Every location has a base rate of sustainable nutrient extraction from the underlying strata. Plants will access the easy surface nutrients first before drawing up the deeper ones. The garden farm model is to use the strong growing field crops and trees to extract deep nutrients from the subsoil. These are then eaten as food, and the human wastes recycled and concentrated in the vegetable garden to produce high value foods. Inedible biomass is returned to the soil in a way that maximises the formation of stable soil carbon (humus) in order to shift the equilibrium of nutrients from the subsoil to the topsoil while minimising horizontal nutrient loss. In the modern world addition of bought food nutrients to the cycle further boosts the fertility of the land.

On a more general level I have to bring up the serious question of whether or not sustainability and stable societies are desirable, even if they are achievable. What is the ultimate purpose of a stable society, apart from the supposed amusement of its people? Nature itself does not tend toward sustainability- it is only our short attention spans and life-spans that prevent us from seeing that nature also favors boom and bust and constant succession. Every living thing ensures its own demise through its success. The benefit of this pattern, in nature and in human societies, is that there is a constant interplay of harsh selection of strength during the hard times, and a creative explosion of new experiments during the easy times. This is the way nature moves forward. Life is the opposite of sustainability. Sustainability is stationary and is equivalent to death. Life is by its very nature a dynamic disequilibrium. The key to success is to keep moving forward, through the good times and the bad. Most assuredly bad times are coming, but through that process new strengths will be found. Did you know that with a little genetic engineering scientists have managed to improve the rate limiting reaction in photosynthesis five fold? The stresses of the next few decades will most certainly lead to some creative and non-linear solutions to our problems. But in the mean time I will keep tending my little primitive garden-farm, protect my family, engage my community and watch the world unfold.

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Keith Akers on October 20, 2008 - 10:28am

Thanks to Peter Salonius for this intriguing discussion of population and soil erosion.

O. K., I'll bite: I see the argument for dramatic reduction in world human population, perhaps to 5% of current levels (about 300 million), but I do not see an argument (implied in Gail's introduction and that nice picture of hunter-gatherers) that we revert to hunter-gatherer mode of agriculture, which would seem to imply that we go back to a population of about 3 million, which as I vaguely recall was the population about 8,000 BCE. That would be a reduction to 0.05% of current population levels. To me the extinction of animals in pre-history, among other things, makes it quite difficult to believe that it is possible to support a population greater than 3 million on hunting and gathering. Or maybe the picture of those hunter-gatherers was just to get our attention. O. K., you've got my attention.

My understanding of soil erosion is that soil is being eroded about 10 times faster than it is being formed in the United States. (Actually, probably more than this, and it's worse still in parts of Asia and Africa.) That would imply to me that we cultivate only 10% of the potentially arable land, leaving the other 90% fallow. We should also take further measures to reduce soil erosion even further -- terra preta, no-till cultivation, small-time organic vs. large-time conventional, whatever as research indicates. I am conflating a lot of issues here into this "10%" figure, such as whether an organic agriculture can provide yields of current conventional agriculture, whether we can "police" soil erosion effectively (since soil is subject to the "tragedy of the commons" in agriculture), whether soil mass and soil nutrients are both included in "soil formation," whether soil formation on uncultivated land is as rapid as on cultivated land, and probably others, I'm just going for the ballpark view here.

Could we get by on 10% of current agricultural land, assuming that the world is pretty much cultivated to the max today? In the U. S., it would seem to be within the realm of possibility. You'd just put everyone on a strict vegetarian or vegan diet. About 80-90% of U. S. agricultural land (2/3 of the cropland, and obviously all of the grazing and pasture land) goes to livestock agriculture. But the U. S. is fairly well off in terms of agricultural resources and population, and this would still use 1/3 of current cropland, not 10%. So you'd probably need a vegan diet and population reduction, too.

Alternatively, you could include animal products and reduce population even further, but the population reduction for even a small amount of animal products is rather steep.

Anyway, this back-of-the-envelope type analysis seems to be to indicate an ultimate reduction to on the order of 100 to 500 million people or so, and I would not be convinced of the need to toss out agriculture quite yet. You are absolutely right, this requires a revolution in the human way of existence. Perhaps the current oil and financial crisis or collapse will provoke people to raise these additional questions as well, if we make it that far.

There's one source I've found helpful which I didn't see listed in your bibliography: "Soil Loss Tolerance: Fact or Myth?" in the Journal of Soil and Water Conservation, by Leonard C. Johnson, May-June 1987. I haven't found an online source for this. The article analyzes the U. S. government idea of 5 tons/acre of annual soil loss as the acceptable "soil loss tolerance." Johnson's conclusion: it's a myth, the true "soil loss tolerance" should be an order of magnitude lower, maybe 0.5 tons/acre/year.

Keith

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Henry on October 20, 2008 - 11:20am

Very informative survey of the human conflict with nature. Thanks for the post. So far humans seem to have demonstrated they have the upper hand, but beneath the surface I think mother nature has a few tricks up her sleeve to give us our comeuppance. One of these tricks is the imposition by nature of additional costs (declining EROEI) as we progress in our exploitation of resources (low hanging fruit principle).

If you look at the growth curves alone for human population, food production, energy usage, water usage, and any of the other critical components that determine the future of the human species, you might start to feel a little uneasy. It looks to me to be a somewhat heroic leap of faith to think that we will continue on these curves, upward and onward into infinity. How long can humans frenzy feed on the resources of the earth until something gives way?

At some point these growth curves fall of their own weight; the next sought after human solution, like the dream of nuclear fusion, does not come to the rescue, and the energy growth curve turn negative, so instead of facing a doubling period, we are facing a halving period. I think that experience has shown that when growth turns negative, that the outcome is not always smooth and there are catastrophic spurts downward. Just look at the financial news of today if you have doubts about the disorderly nature of unwindings.

I am more and more inclined to side with Richard Duncan in his view that civilization is in the long run temporary. Once the peak is reached, the decline phase should be characterized by sharp collapses, followed by periods of stability or even slight recovery, followed yet again by sharp collapses, etc., etc., etc.

Each transition from one level of technology to the next has required use of resources to build the infrastructure for the new way of doing things. During the long expansion phase, additional resources were available to facilitate these transitions. Once we enter the decline phase, we will be facing the need to build new infrastructure to do things a different, perhaps more primitive way, but without readily available resources to do so.

Maybe humanity can manage to fight back the forces of nature for a little longer and those of you who wish for, want and predict a dieoff free future will realize your vision of the future; and then again, maybe not. The risk certainly seems to be increasing.

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GreenEngineer on October 20, 2008 - 12:10pm

The author says:

> In the context of depleting reserves of the fossil fuels that have supplied modern agriculture with motive power, machinery, fertilizers, insecticides and herbicides, it is expected that the way food is produced will have to change as the twenty-first century unfolds. 'Permaculture' (Mollison and Holmgren 1979), and other modifications of agricultural practice that seek self sufficiency, such as those put forward by proponents like the Post Carbon Institute's Relocalization program (www.postcarbon.org) include local food and biofuel systems, revitalization of local industry, and community cooperation.
>
> [snip]
>
> However these alterations follow the cultivation agriculture model as a food production system, as they must in the short term.
> **All cultivation agriculture depends on the replacement of complex, species diverse, self-managing, nutrient conservative, deep rooted, natural grassland/prairie and forest ecosystems with monocultures or 'near monocultures' of food crop plants that rely on intensive management.** The simple shallow rooting habit of food crops and the requirement for bare soil cultivation produces soil erosion and plant nutrient loss far above the levels that can be replaced by microbial nitrogen fixation, and the weathering of minerals (rocks and course fragments) into active soils and plant-available nutrients such as potassium, phosphorus, calcium, and magnesium on most of the soils on the planet.

From this statement, it is quite clear that the Salonius knows very little about the theory, and nothing at all about the practical application, of permaculture techniques. The central premise of permaculture is to grow food in a fashion that avoids exactly those pitfalls he is describing. A related set of techniques allows one to actively build soil while producing meat using high-intensity rapid-rotation grazing (e.g. Joe Salatin).

Permaculture can produce substantially more food per acre than conventional techniques. The major limitation is that it requires much more involvement by the farmer, more physical labor per acre, and the farmer must have an uncommon level of skill and intimacy with the land. So current circumstances do not support these farming techniques in terms of economics or cultural expectations. But the limitation is not technical.

Given the author's profound misunderstanding of one of the major techniques for creating sustainable civilization, I think we can safely discount his defeatist, Oludavi-eque conclusions.

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GreenEngineer on October 20, 2008 - 4:21pm

Permaculture never plants monocrops. The entire point of permaculture is to mimic the "complex, species diverse, self-managing, nutrient conservative, deep rooted, natural grassland/prairie and forest ecosystems" substituting in some human food plants. A proper permaculture crop will be a mixture of plants that provide for human needs, plants that provide for the needs (food and habitat) of local helpful fauna, and plants that help protect and regenerate the soil.

Soil management is key. Stormwater is treated like the valuable resource it is, and is infiltrated on site. This minimizes erosion. Depending on soil type and rainfall level, this can lead to the formation of an underground "water lens" -- basically a small local aquifer -- to support plants through the dry season.

A thick mulch suppresses weeds and conserves water, and adds organic matter back to the soil as it breaks down.

A permaculture food production system will rely much more heavily on perennials, including trees, than we currently do. Perennials don't need to regenerate their structure every year, just their fruit, so they tend to be less depleting over time. Also, they have extensive root systems, which makes them less dependent on soil amendments.

When growing annual crops, you will plant more than one thing in any given place. Plants that have different growing cycles, nutrient requirements, and/or canopy and root zone space requirements are often good companions. Garlic and strawberries are a classic example: the strawberries cover the soil, while the garlic goes vertical. The three (or four) sisters (corns, beans, squash, and perhaps an insectiary plant) is another classic.

As a technique for backyard gardening, permaculture is actually much lower labor than most standard gardening techniques: good design, lots of mulch, and attention to the environmental needs of plants all help reduce the requirements on the gardener. But relative to standard farming techniques (where one human may "farm" hundreds of acres), the labor input is much higher (for annuals -- not so much with perennials). Partly this is because a polycultural crop does not mechanize well. Weeding tends to be by hand -- mulching keeps the weeds down, but you still wind up doing a lot of weeding on a big plot, if you're not going to use herbicides. Mulching is an ongoing process. And some of the techniques simply require frequent attention. The animals protocols, for example, typically have you moving your heard every day or two.

A capsule summary of permaculture is hard to do, because there are so many techniques that fall under the rubric. So this is not meant to be exhaustive.

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I stopped coecting coments here - ran out of time....

enddoc