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.

Nomads and Pastoralists

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.

Beginnings of Cultivation Agriculture

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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