Adaptive Cycle Cultivation --
A New Model for Sustainable Agriculture
Based on Traditional Mayan Practices and Modern Ecology

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Why we need to consider changing the way we produce, process, transport, distribute, and store food.

A brief review of the systems of modern agriculture within the context of sustainability and planetary woes.

Unless there are dramatic changes to "business as usual", this century will see human beings and many, many other species facing unprecedented challenges to their survival, quite literally, as a result of stupendous environmental, economic, and geopolitical turmoil driven by global climate change, the rapid decline of petroleum and mineral reserves, the rapid decline in uncontaminated freshwater, and quite possibly, world-wide ecosystem collapse. The agricultural sector is by no means immune to these challenges which are independent of any future gains in agricultural productivity from precision farming, transgenic crop modification or any of the other new, highly-touted agribusiness technologies (the so-called, "second green revolution"). These looming global crises will surely have a very direct (and undoubtedly detrimental) effect on our food supply (Brinkman et al. 2010; Deffeyes 2008; Foster 2002; Lenton et al. 2008; Lovelock 2010; McKibben 2010; Olson and Dinerstein 1998; Pachauri and Reisinger 2007; Sala et al. 2000; MEA, 2005).

This raises the specter of one humanity's oldest concerns-- How will we feed ourselves?[1] Many would answer that the large-scale systems of modern agriculture that have enjoyed such immense quantitative successes since the 1950s will continue to feed the world (Gillis 2009; Pauly 2007). Here, the term *systems of modern agriculture* includes large-scale terrestrial farms, large-scale ocean harvesting and aquaculture, plus the modern systems of food processing, storage, distribution, and preparation. Large-scale terrestrial farms and large-scale maritime aquaculture farms are synonymous with Altieri's (2001) definition of *agribusiness*,

1 In this context "we" refers to the 8,000 million people expected on earth by 2025 (WWF, 2010).

> "...the application of a reductionist scientific paradigm focusing on high yielding varieties that depend on purchased packages of chemical, mechanical and energy inputs. Yield maximization, uniformity of genetic resources and crop varieties, and simplification of [these] farming systems have, for decades, driven technical innovation. There are political and economic forces influencing the trend to devote large areas to monoculture, and in fact the economies of scale of such systems contribute significantly to the ability of national agriculture to serve international markets."

But as early as the 1960s there were concerns that these systems of production and extraction were beginning to cause unintended environmental consequences (Carson 1962; Wharton 1968). Now, in the 2010s, there is clear evidence of severe environmental and social damage caused by these systems of modern agriculture and there is the real possibility that these systems, if unmodified, will undergo catastrophic failure rather than a more gradual (panarchical) creative destruction (Altieri and Nichols 2001; Diamond 2010; Gunderson and Holling 2001; Hoekstra 2010; Horowith 1985; Jowit 2010; Pretty et al. 2001; Shiva 2004; WWF 2010).

There are four main reasons why these systems of food production are unsustainable (on the time-scale of centuries), will not be able to meet the food needs of people over the next few decades, and are likely to undergo catastrophic failure at any time in the next few years. First, the systems of modern agriculture are absolutely dependent on massive inputs of fossil hydrocarbons -- petroleum, natural gas, and coal. Large-scale farms require fossil hydrocarbons for the production of increasingly sophisticated equipment, for the production of agrochemical feedstocks and pharmaceuticals, and for the production of the energy needed to actually farm and to haul materials, whether on land or at sea. Likewise, the modern systems of food processing, storage, distribution, and preparation (post-farm activities) also require massive quantities of energy. Bomford (2010) has estimated that the U.S. food system consumes about 3 x 10^{15} (quadrillion) Btu on-the-farm (as inputs of fuel, fertilizer, and the machinery to farm and to haul materials) and about 7 x 10^{15} Btu off-the-farm (as inputs of fuel and materials to process, package, sell, store, and cook food). Noteworthy in Bomford's analysis is the fact that on-the-farm energy use in the U.S. peaked in 1978 and has fallen 30% since that time suggesting that U.S. farmers have made impressive gains in energy efficiency. Meanwhile, off-the-farm energy use has continued to rise so that today, one calorie on the plate requires seven to ten calories to get there! Underlying the evaluation in energy use in systems of modern agriculture is the fact that the sheer amount of energy used is increasing regardless of the gains in efficiency in different sectors. This seems to be a direct validation of Jevons Paradox (Foster 2002) and leads to a thought-provoking (if humorous) analysis by Murphy (2011) who, by extrapolating global power demand under a sustained 2.3% growth in energy consumption, finds that in 400 years we would require all of the sunlight hitting the earth (assuming that our solar panels cover the entire planet and have 100% conversion efficiencies). In 2450 years, we would use as much energy as all hundred-billion stars in the Milky Way galaxy! Even is we discover controlled fusion power, the continued growth in energy consumption coupled with thermodynamic realities would mean that the surface temperature of the earth would rise to the boiling point of water (100^0 C) in about 450 years and exceed the surface temperature of the sun in just over 1000 years! As a major contributor to the energy demands of humans on earth, systems of modern agriculture are obviously unsustainable. This is made even more evident by factoring in the ultimate exhaustion of planetary petroleum reserves, which are likely to be forms of non-substitutable natural capital because of their immense energy density and unmatched plasticity as precursors in chemical synthesis.

The second reason why the systems of modern agriculture are unsustainable, cannot meet the demands of the world's increasing population, and are likely to undergo catastrophic failure is that they produce massive environmental and social damage. A partial list of the environmental damage would include

- deforestation
- soil erosion
- loss of soil productivity
- destruction of soil food webs
- loss of natural biocontrol mechanisms for pests
- destruction of heirloom cultivars and crop progenitors by genetically modified organisms
- soil salinization and alkalization
- contamination of soils/waters with agrochemicals, pharmaceuticals, and biowastes
- loss of biodiversity
- loss of pollinators
- creation of ocean dead zones
- creation of "superweeds" and "superpests"
- ecosystem disruption by transgenics
- ecosystem disruption by severe outbreak of pests from monocultures

And a partial list of the social damage would include

- loss of small farms and rural culture
- farmland transfer to multinationals
- increased acute and chronic exposure to agrochemicals, pharmaceuticals, and biowastes
- increased burden of debt for farmers
- concentration of farmland ownership
- loss of nutrition (micronutrients) in food
- increased incidence of food-borne disease
- creation of new, aggressive viral strains

In large measure these damages are not reflected in private agribusiness accounting because they are externalities that have been transferred to the (global) public sector. Foster (2002) and Kovel (2007) argue persuasively that the blame for these damaging externalities lies not with the farmer or even with the agribusiness corporation, but rather with the system of neoliberal capitalism that imposes profit as the only measure of value and creates a structural immorality where the right to make money trumps all other considerations, environmental or otherwise.

The third reason for calling into question our systems of modern agriculture is that crop yields and ocean fish yields appear to have peaked and are, in fact, faltering or declining. Specifically, the world's best grain belts already are experiencing saturating yields per hectare of cereal crops regardless of the quantities and types of agrochemicals applied or of the new technologies employed (Altieri and Nicholls 2001; Ruttan 1999). Tilman et al. (2002) report that “[grain] yields have been stagnant for 15–20 years in those rice producing regions of Japan, Korea and China where farmers were early adopters of green-revolution technologies” and similarly the yield potential of maize has “barely increased” over the last 35 years. Terrestrial yields in many cases seem to have reached the point of diminishing returns offered by the applications of synthetic nitrogen and phosphorous. And even if new cropland can be appropriated, putting such low-yield, rain-fed environments of marginal agricultural quality into production is unlikely to sustain high yields because the soils in such areas typically have poor resistance to, and resilience from, ecological perturbations so that these soils will rapidly degrade (Welch and Graham 1999; Schjønning et al 2004; Diamond 2010). Likewise, Pauly (2007) reports that yields from global marine fisheries have been in steady (often sharp) decline since the 1980s. Most global marine fisheries are already over-exploited and are in real danger of crashing, just like the collapse of the northern cod of Newfoundland and Labrador (Finlayson and McCay 1998). Finally, there is serious concern that yields (and nutritive value) will be reduced by global climate change because of substantial changes in precipitation and temperature patterns, changes in pest ranges, and increases in extreme weather events (Olesen and Bindi 2002). Noteworthy in this regard is that today's commercial cultivars are critically dependent on a narrow band of stable and predictable local climate in part because they represent a very limited gene pool of the species.

Fourth, and perhaps most importantly of all, the systems of modern agriculture are based on a doubly-flawed paradigm: that of maximization of yield driven by profit. In systems of modern agriculture, the metrics of “yield” are invariably expressed quantitatively as the mass of a single agricultural product per unit of area or per unit of time. Thus "maximization of yield" means first, that agricultural activity must become increasingly specialized and standardized with as much energy as possible invested in the production of a single crop, and second, that the concept of agricultural productivity becomes very narrowly defined by a single metric. Scott (1998) notes that the pursuit of maximization of yield has led to the "radical simplification" of modern agriculture through the application of mechanization and agronomic science. A related approach, maximum sustained yield in fisheries resource management, has "simplified" the world's oceans by eliminating trophic levels (Pauly 2007; Finlayson and McCay 1998). Clearly, the myopic focus on maximum yield not only ignores other valid metrics (as, for example, the total food calories produced per hectare per year, the total usable biomass produced per hectare per year, or any qualitative evaluation like flavor), but more importantly, ignores critical feedback. Agricultural systems exist (spatially and temporally) within larger ecosystems. Ecosystems are dynamic, complex systems that have evolved characteristics of resilience and adaptability by embracing a suite of opposites: stability and uncertainty; connectedness and randomness; build-up and release; fast and slow. Holling (2001) has proposed that these opposites are dynamically balanced in the *adaptive cycle* which provides the mechanism for the (natural) sustainability of many complex systems. According to Holling, in ecosystems these adaptive cycles are nested (like so many Russian dolls) into a *panarchy:* "a term that ... capture[s] the adaptive and evolutionary nature of adaptive cycles that are nested one within each other across space and time scales." Feedback both within and between the nested layers is critical to the long-term viability of the entire system. Thus, modern agriculture's narrow focus on maximum yield disrupts the adaptive cycle (and potentially the entire panarchy) by creating both excessive positive feedback (e.g., soil nitrate levels) and excessive negative feedback (e.g., the suppression of biodiversity). The result is, perhaps inevitably, the shift of the entire ecosystem to a degraded state, one of the many possible equilibria available to a complex system. Finally, the sole motive of profit must be seriously questioned as the best driver for the common good in large measure because it “necessitate[s]...the reduction of the human relation to nature to a set of market-based utilities” (Foster 2002).

Are there other, more sustainable ways to produce, process, transport, distribute, and store food?

A brief review of agroecology and the quest for sustainable agriculture.

The answer to the question above is a qualified “yes” --- but only if there are massive systemic changes (major paradigm shifts) in our social, economic and agricultural systems. Although only systemic changes to agricultural systems are considered in this paper, it must be clearly understood that the disaggregation of social, economic, agricultural, and environmental systems is a matter of scholastic convenience. These systems are, in fact, one planetary system; that they appear otherwise is a function of scale and cultural conditioning.

Agroecology offers the best hope for sustainable food production (Welch and Graham 1999; Ruttan 1999; Tilman 1999) . Altieri and Rosset (1996) outline the agroecology idea as one that will “go beyond the use of alternative practices ... to develop agroecosystems with minimal dependence on high agrochemical and energy inputs, emphasizing complex agricultural systems in which ecological interactions and synergisms between biological components provide the mechanisms for the systems to sponsor their own soil fertility, productivity and crop protection.” In this regard, agroecology is a term that describes an agricultural process that seeks to mimic nature. But others have noted that the term agroecology has been used to define a broader paradigm that includes social and economic dimensions

(Beus and Dunlap 1990). Table 1 summarizes the dimensions of the broader paradigm as contrasted with the agribusiness paradigm.

To some extent, agroecology is still in its nascent phase and is currently a collection of groups (including organic farming, permaculture, agroforestry, bio-dynamics, polyculture, low-input sustainable agriculture, holistic agriculture, and others) each with its its own unique knowledge base (created from a mixture of traditional, indigenous, New Age, and scientific sources), elements of practice, emphasis, and even ideology (Vandermeer, 1995). Yet the potential of agroecology (as a sustainable agricultural system that provides good yields, strong resilience, and high adaptability) is immense because a healthy agroecosystem should have the very same productive, resilient, and adaptable potential as any other healthy ecosystem. And initial results are promising (Badgley and Perfecto 2007; Rosset 2002; Wolfe 2000).

The need then, is to develop the potential of agroecology in order to deliver systems of truly sustainable agriculture. The term "truly sustainable" is taken to mean "...the transformation of our ways of living to maximize the chances that environmental and social conditions will indefinitely support human security, wellbeing, and health" (IPCC 2001). This task requires huge amounts of work and research from many different disciplines and perspectives, and at many different levels of scale. This paper offers a possible model for sustainable agriculture termed, *adaptive cycle cultivation*. The model is based on a "found" (or natural) experiment; namely, the agricultural practices of the Classical Period Maya who lived in the Yucatán Peninsula of Central America between roughly 300 to 900 AD.

Table 1. Key Elements of the Competing Agricultural Systems

(adapted from Beus and Dunlap, 1990)

Agribusiness	Agroecology
Centralization	*Decentralization*
• National/international production, processing, and marketing	• More local/regional production, processing, and marketing
• Concentrated populations; fewer farmers	• Dispersed populations; more farmers
• Concentrated control of land, resources, and capital	• Dispersed control of land, resources, and capital
Dependence	*Independence*
• Larger, high-capital production units and technology	• Smaller, low-capital production units and technology
• Heavy reliance on external sources of energy, inputs, and credit	• Reduced reliance on external sources of energy, inputs, and credit
• Consumerism and dependence on the market	• More personal and community self-sufficiency
• Primary emphasis on specialists and experts	• Primary emphasis on personal knowledge and local wisdom
Competition	*Community*
• Lack of cooperation; self-interest	• Increased cooperation; community interest
• Farm traditions and rural culture outdated	• Preservation of farm traditions and rural culture
• Small rural communities irrelevant to agriculture	• Small rural communities essential to agriculture
• Farm work a drudgery; labor an input to be minimized	• Farm work rewarding; labor an essential to to be made meaningful
• Farming is a business – primary emphasis on speed, quantity, and profit	• Farming is a way of life – primary emphasis permanence, quality, and beauty
Domination of Nature	*Harmony with Nature*
• Humans are separate from and superior to nature; nature consists of resources to be used	• Humans are part of and subject to nature; nature is valued for its own sake
• Incomplete life-cycle assessments; linear thinking; growth and decay imbalanced (wastes not recycled)	• Complete life-cycle assessments; systems thinking; growth and decay balanced (wastes recycled)
• Human-made systems are imposed on nature	• Human-made systems imitate nature
• Production maintained by agrochemicals; soil is a dead medium	• Production maintained by a healthy, soil food web; soil is a living medium
• Highly processed, nutrient-fortified food	• Minimally processed, naturally nutritious food
Specialization	*Diversity*
• Narrow genetic base; extensive use of hybrids; increasing use of GMOs	• Broad genetic base; extensive use of open-pollinated cultivars; no GMOs
• Most plants grown in monocultures; single-cropping in succession	• More plants grown in polycultures; multiple crops in complementary rotations
• Separation of crops and livestock	• Integration of crops and livestock
• Standardized production systems	• Locally adapted production systems

Why the state variables for adaptive cycle cultivation can be found in the Yucatán Peninsula.

> *A brief review of the important agricultural and cultural practices of the Classic Period Maya who offer an example of successful, long-term agricultural productivity in a region that rates as "fair" on the scale of agricultural quality.*

The Mayan people maintained an average population density of 100-200 persons/km^2 throughout the entire Yucatán peninsula for at least 600 years during the Classic Period (300 to 900 AD). At their peak, the Maya were feeding several million people (Gómez-Pompa 2003). Densities in ancient cities such as Chunchucmil (about 2500 persons/km^2) and Tikal (about 3800 persons/km^2) are even greater than densities in comparable cities in the region today (Dahlin et al. 2005, Faust 2001). After much debate and revision, the basic values for Mayan population data from the Classic period are now accepted in the literature. Scientists are left with an agricultural dilemma posed by these data; that is, how did the Classic period Maya successfully manage to feed themselves for centuries, sustainably (i.e., without severe ecosystem damage), in a tropical region that is poorly suited to agriculture? Toledo et al. (2008), echoing the thoughts of many, call it "*el misterio maya*" and Gomez-Pompa (2003) states that, "Although several research projects and symposia have explored this question, the answer is still unknown."

What is known is that the Maya began with an early type of swidden (*roza-tumba-quema*) agriculture that rapidly evolved into a comprehensive system of intensive agricultural practices in response to population pressures, ecosystem changes, and climactic uncertainty (Brenner et al. 2003; Dahlin et al. 2005; Allen and Rincón 2003). As a result of their intensive agricultural practices (actually a multiple-use strategy), Fedick (1996) and others recognized that the Maya had created a "managed mosaic" that ultimately extended across the entire Yucatán peninsula. More recently, Toledo et al. (2008) and Dahlin (2005) show that the Maya (both past and present) manage their mosaic landscape with (1) a fractal sense of the sacred (the human is sacred, the house is sacred, the garden is sacred, the forest is sacred, the world is sacred, the universe is sacred), and (2) a multiple-use strategy that promotes ecological and economic stability. Both components are absolutely necessary and mutually reinforcing. Taube (2003) notes that the sacredness of the forest includes elements of inspiration, reflection, and terror-- "...a place of fear and danger, the forest is an essential and necessary part of human existence...a fascinating nest of contradictions, the forest both threatens and reinforces social cohesion." Mayans treat their forests like they treat their beehives—with great respect. The multiple-use strategy (both past and present) includes a variety of local, agriculturally-intensive practices such as corn/squash/bean plantings (*milpas*) in the fields, *huertos* or *solares* (gardens/orchards) near the home, raised beds in karstic wetlands, modest terracing in the highlands, and the collection of periphyton for fertilizer. Other activities in the field and forest included apiculture, hunting, and the collection of firewood, medicinal plants and forest foods. Of special importance are the *milpa* and the *solares*.

Milpa is a deep cultural phenomena the outward manifestation of which is the planting of corn (and some other crops) on a small patch of cleared forest land. Ideally, a patch of "high forest" (mature forest) is cleared, planted in *milpa* for a few years, and then allowed to fallow for 10 – 15 years before the cycle begins anew (Alcorn and Toledo, 1998). *Solares* are intensively-planted home gardens that typically include some domestic (usually small-scale) animal husbandry. Like most indigenous gardening in tropical areas, *solares* are multi-strata (multi-storied) polyculture extravaganzas that are often best described as small-scale agroforestry sites (Benjamin et al. 2001; Scott, 1998; Jimenez-Osornio et al. 1999). In the Classic Period, s*olares* were part of every home dwelling and were everywhere. It is hypothesized that the Classic Period Maya, like the contemporary Maya, constantly experimented in their *solares* and thus maintained a large and constantly shifting floral biodiversity near their homes. Even today, contemporary Yucatán Maya folk maintain *solares* with substantial floral biodiversity. Jimenez-Osornio et al. (1999) note that the biodiversity in these modern *solares* ranges from a low of about 15 species to a high of over 387 species!

The Classic Period Maya constantly "tweaked" their forests, fields, and home gardens by engaging in a variety of agricultural and sacred activities in time and space. These "tweakings" can be considered perturbations on the ecosystem of the Yucatán peninsula. The net result of these practices (perturbations) was to create significant differences in land use, biodiversity, and human density over time and space across the entire peninsula.

A New Model for Sustainable Agriculture: Adaptive Cycle Cultivation

> *A brief explanation of the theoretical basis for, and the tenets of, adaptive cycle cultivation as a proposed agroecological model.*

Adaptive cycle cultivation postulates that the Maya achieved agricultural sustainability by the very nature of their spatio-temporal interactions with the biogeophysical components of the Yucatán peninsula; that is, Mayan activities in their gardens, in their fields, and in their forests imposed anthropogenic constraints that actually "flipped" (transitioned) the ecosystem of the Yucatán peninsula from one stable state (a naturally-evolved semi-tropical woodland) to another stable state (an anthropogenically-evolved sustainable agricultural mosaic). Once the new, agricultural mosaic was in place, it was likewise maintained by the very same anthropogenic constraints or essential perturbations that caused the transition in the first place; namely, a suite of Mayan agricultural practices and life-style choices applied continuously over century-long time scales. The net result of these essential perturbations was a dynamically stable state characterized by a constantly shifting mosaic or ecological pattern that included patches of home gardens, patches of freshly-cleared forest, patches of *milpa*, and patches of forest in various stages of succession. At some point, this "patchy" mosaic began to produce kaleidoscope-like patterns of land use through time across the entire peninsula. However, *adaptive cycle cultivation* hypothesizes that regardless of the spatial pattern at any given moment in time, there existed a constant land use ratio and its associated biodiversity ratio and human impact gradient that defined the stability of the agricultural mosaic state.

Stated more specifically, the non-equilibrium constraints imposed by the Classic Period Maya caused specific biogeophysical state variables (the land use ratio, the biodiversity ratio, and the human impact gradient) in the state functions of the Yucatán's ecosystem (evolved by natural selection over the millennia without human contact) to exceed specific critical (or threshold) points and enter into autocatalytic cycles that resulted, ultimately, in hysteresis. Similar anthropogenic perturbations in the historical times before the Classical Period Maya were dampened because the Yucatán ecosystem (as a dissipative structure) exhibited asymptotic stability; that is, the critical points in the ecosystem state functions were never exceeded and thus the ecosystem remained in its "natural state" as a semi-tropical woodland.

In the language of panarchy, *adaptive cycle cultivation* is an intentional, anthropogenic intervention in the K phase of a regional ecosystem's adaptive cycle. The early onset of the K phase in small patches throughout an entire ecosystem creates a unique pattern of "lumpiness." As a result, the α phase of the entire ecosystem is reorganized and a new, adaptive cycle (the agricultural mosaic) is born.

Adaptive cycle cultivation proposes the following biogeophysical state variables as core state variables for any model of sustainable agriculture:

1. *A Land Use Ratio* - A very specific ratio of the area of land maintained in mature forest, the area of land maintained in cultivated field, the area of land maintained in various stages of fallow or non-actively cultivated field (successional land), and the area of land maintained in home gardens.
2. *A Biodiversity Ratio* - A very specific ratio of the number of plant species found in mature forest, the number of plant species found in various stages of field-returning-to-forest succession, the number of plant species found in cultivated fields, and the number of plant species found in home gardens.
3. *A Human Impact Gradient* - The human density (people/km^2) in the forest, the human density in cultivated fields, and the human density around home gardens generates a human density gradient (pattern) moving from areas of forest (low human density) to areas of home gardens (high human density).

Adaptive cycle cultivation, as a model for sustainable agriculture, is a two-step process. First, anthropogenic constraints push an ecosystem up to, and then beyond, *critical points* of hysteresis causing the ecosystem to attain a new stable state. Second, essential perturbations maintain the new stable state by forcing the ecosystem to keep to a unique trajectory around an (as yet undefined) strange attractor.

In support of this hypothesis it is noted that the property of superposition (linearity of causation) is, at best, a special case when complex systems are involved. Complex systems have "tipping points" where a seemingly small change in a state variable produces a massive response. Because complex systems also have multiple states of equilibrium (or stability), tipping points are typically associated with a hysteresis cycle. A hysteresis cycle "bounces" a complex system back and forth between two stable, but distinct, equilibria. In this case, the complex system is said to exhibit the phenomena of bistability. Thus, the two, stable equilibria of the complex system (branches) are connected through a hysteresis cycle triggered by tipping points (Nicolis and Prigogine, 1989). It is well-established that ecosystems (naturally-occurring complex systems) exhibit bistability or regime shifts (Folke et al. 2004).

A Computer Simulation of Adaptive Cycle Cultivation

> *An agent-based, computer simulation has been developed as an "idea pump" to explore adaptive cycle cultivation.*

A simple, agent-based computer simulation called Mayan_Ag_6 was built using NetLogo 4.1.3, an agent-based, programmable modeling environment for simulating natural and social phenomena (Wilensky 1999). The Mayan_Ag_6 simulation is an attempt to show that the proposed mechanism of adaptive cycle cultivation is plausible and to explore the effects of variations as a method for gaining insight into the complex phenomenon of agricultural sustainability (Mitchell 2009).

In Mayan_Ag_6, the entire Yucatán peninsula becomes a very small bounded world, a square box filled with pixel-like, immobile patches and time-activated, mobile agents. The 3721 individual and distinct NetLogo patches define the physical geography of this world and the agents manipulate the world through interactions with the patches. In the center of this world is a (Mayan) "town" surrounded by "gardens." The "town" is a roughly circular group of (NetLogo) patches that are colored dark blue. The size of the "town" is not fixed but can be varied for different simulations. Surrounding the "town" is a roughly circular ring of (NetLogo) patches, colored light blue, that represent (Mayan) "gardens." Like the "town," the size of the "gardens" is not fixed but is a simulation variable. Outside of the "town" and "gardens," and filling the remaining space (NetLogo patches) of this world, is the "high forest" which is colored green. The passage of time in this world is marked by ticks -- the computer simulation advances one tick at a time, each tick being one iteration of the computer simulation. When a simulation begins, “farmers” (agents) leave their “town” and “gardens” and “plant” “milpa” if they (randomly) encounter “high forest.” The act of real-world planting of milpa in the Yucatán forest is simulated in Mayan_Ag_6 by changing the color of a small group of the “high forest” patches (i.e., NetLogo “high forest” patches) from green to white. “Planting” creates a “milpa” that is seen as a small group of white squares in the simulation. The 10-15 year cycle of fallow that occurs in real-world Mayan milpa cultivation is modeled in Mayan_Ag_6 as a successional change of “milpa” back to “high forest.” The real-world successional change of milpa returning to forest is seen in Mayan_Ag_6 as as a color change in the “milpa” (i.e., the NetLogo “milpa” patches) going from white → yellow → red → black → green. During a simulation run, two land use ratios are calculated after every 10 ticks. Ratio 1 is defined as the ratio of the number of existing “milpa” (NetLogo) patches at any given moment to the number of initial “high forest” (NetLogo) patches at time equals zero (ticks = 0): [*(Milpa / Forest_1*) * 100%]. Ratio 2 is defined as the ratio of the number of existing “milpa” (NetLogo) patches at any given moment to the number of existing “high forest” (NetLogo) patches at any given moment: [*(Milpa / Forest_2*) * 100%].

As the simulation evolves through time (at every tick), it creates a spatio-temporal kaleidoscope of (NetLogo) patches. The kaleidoscopic, constantly changing pattern produced by the Mayan_Ag_6 simulation is proposed as a (simulated) example of the real-world “managed mosaic” expected of adaptive cycle cultivation. Figure 1 is a snapshot (screenshot) of a simulation run at time equals zero (ticks = 0) before the “farmers” (agents) begin “planting” “milpa”. Figure 2 is a screenshot of the same simulation after about 50 ticks and Figure 3 is a screenshot of the same simulation after about 2000 ticks. Figure 4 is a screenshot of another, different simulation run after about 2000 ticks where the population variable has been set to 25, rather than to 5 as in Figures 1, 2, and 3.

Figure 1. Sample screenshot from the Mayan_Ag_6 simulation model before beginning a simulation run

"Farmers" (black) have not yet emerged from "town" (dark blue). The "town" is surrounded by "gardens" (light blue) and by "high forest" (green). The population of "farmers" (active agents) can be varied (here set at 5) as can the size of the "town" and its "gardens" (here set at 10). *ForestClock_One* and *ForestClock_Two* are test variables for future modeling efforts. The variable *Forest_1* counts the initial number of green squares (patches) of "high forest"before any interaction with the "farmers." *Forest_2* counts the number of green squares at any given moment after "farmers" have started "planting" "milpa." *Milpa* counts the number of white squares at any given moment. *Ratio 1* is the value, [*(Milpa / Forest_1)* * 100]. *Ratio 2* is the value, [(*Milpa / Forest_2*) * 100].

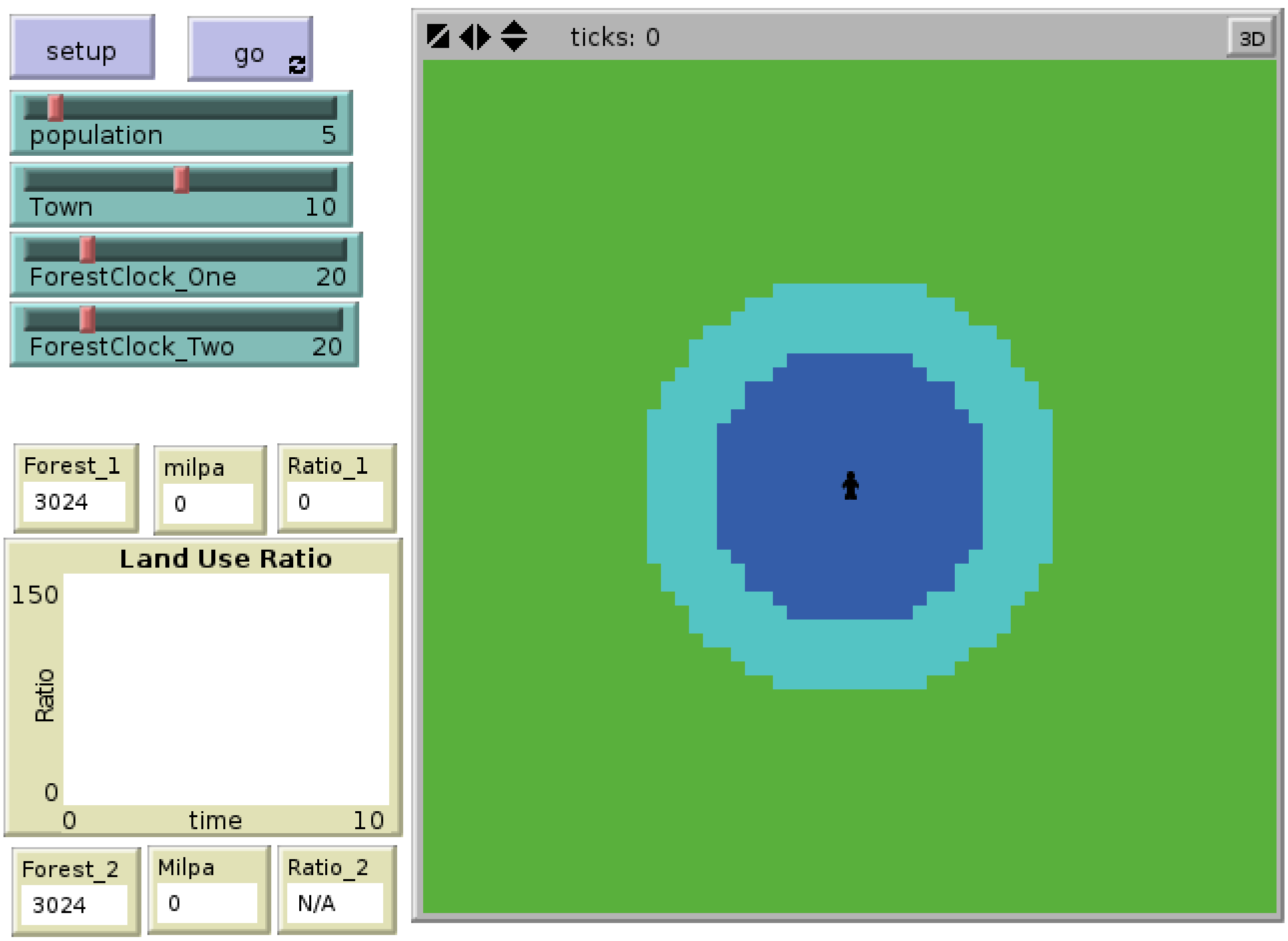


Figure 2. Sample screenshot from the Mayan_Ag_6 simulation after approximately 50 iterations of a simulation run (population = 5)

Five "farmers" (purple) have emerged from "town" (dark blue) and have begun "planting" "milpa." As the "farmers" go about "planting", patches of white ("milpa") begin to appear in the green ("high forest"). Once a "milpa" is "planted", the "farmers" move on to plant a new area of forest. "Farmers" will keep "planting" so long as they encounter "high forest" (a NetLogo patch of green beneath themselves), otherwise, "farmers" will keep moving without "planting." "Milpa" that have been planted (white) remain white for a time then begin succession back to "high forest" (white → yellow → red → black → green). Here, some "milpa" are in the first stage of succession (yellow).

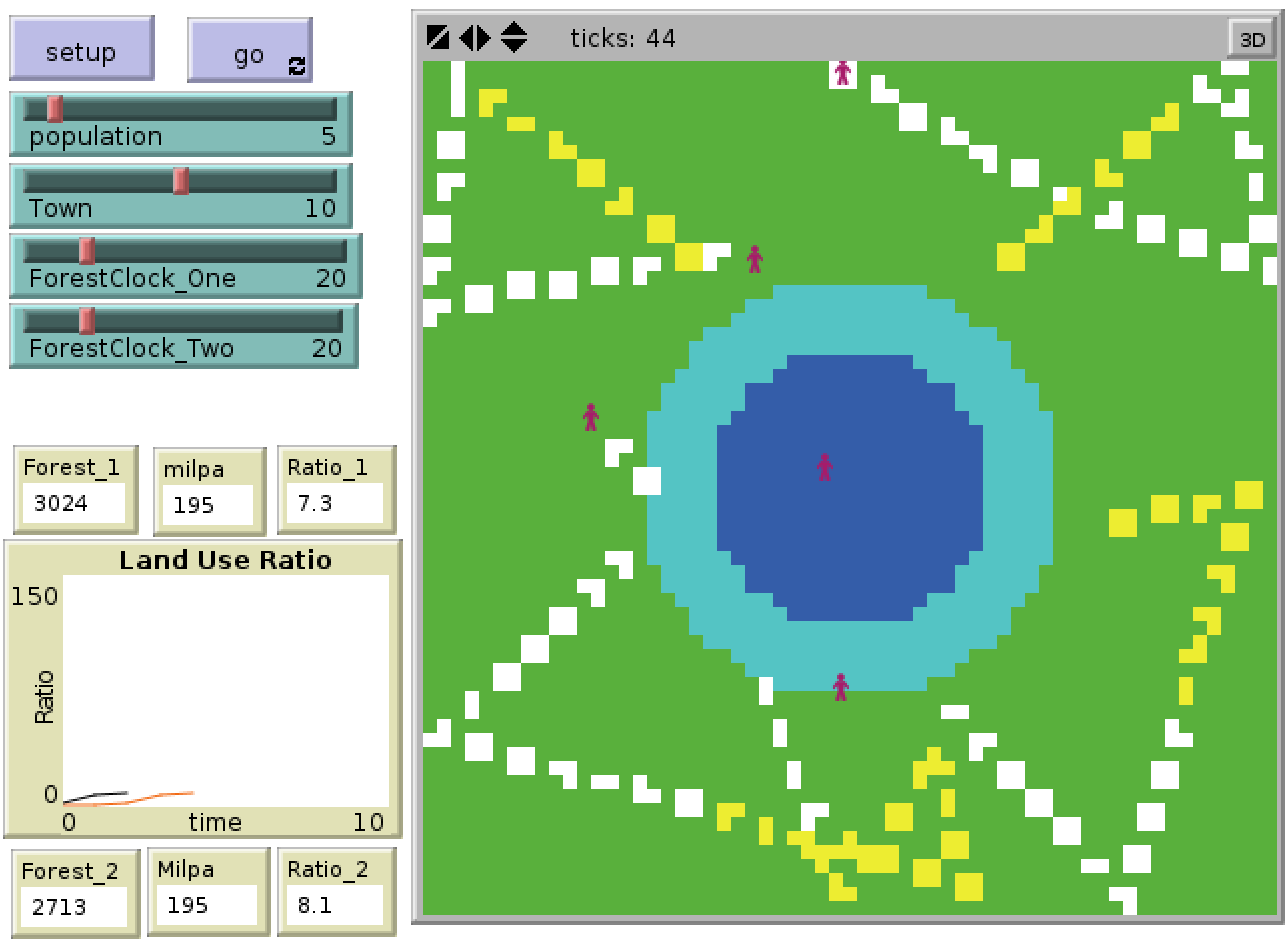


Figure 3. Sample screenshot from the Mayan_Ag_6 simulation after approximately 2000 iterations of a simulation run (population = 5)

A kaleidoscopic-pattern is now apparent as the "high forest" is continually being "planted" and renewed through succession. Ratio 1 and Ratio 2 appear to have stabilized with relatively similar values although the variability in Ratio 2 is higher.

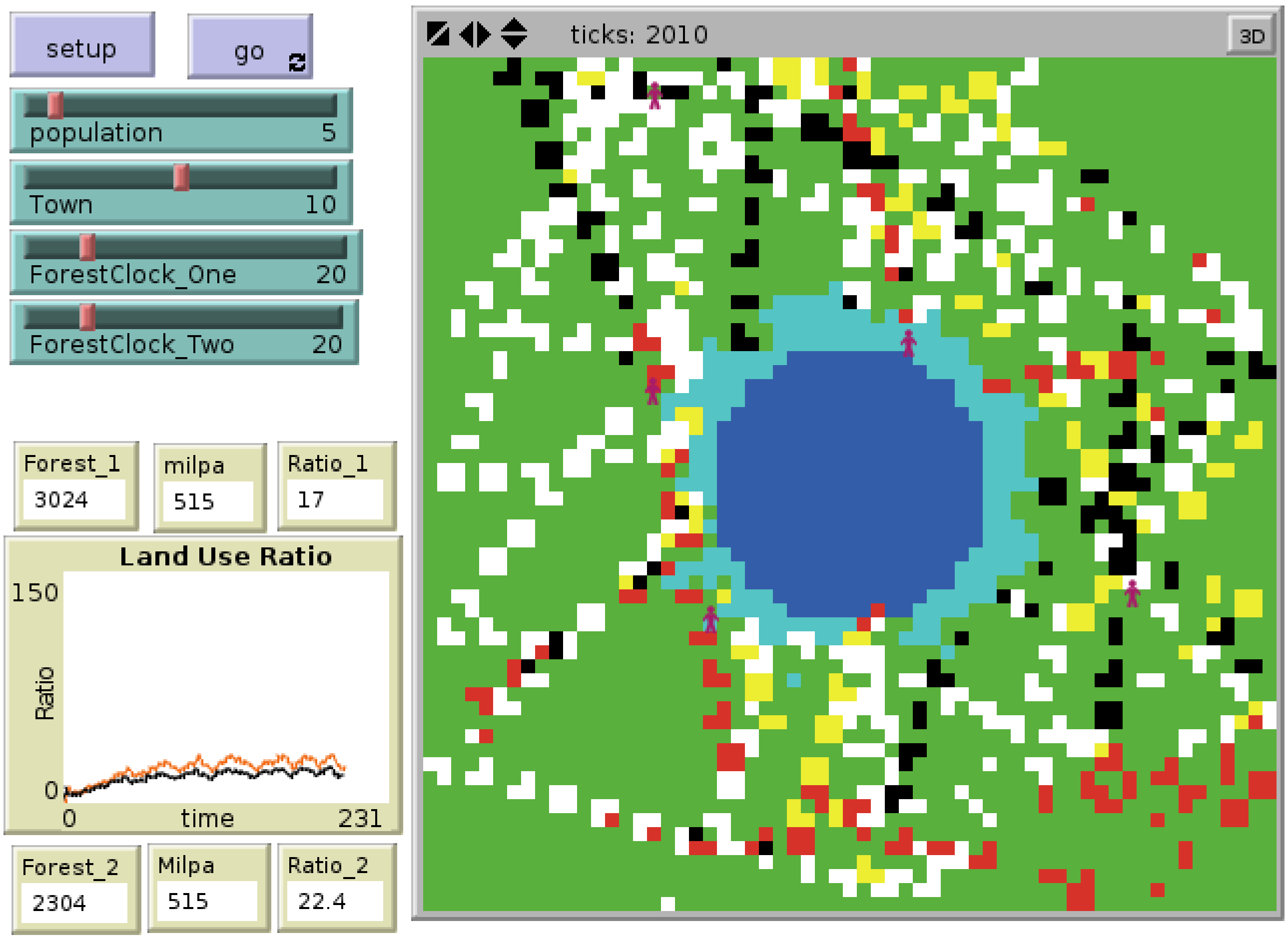
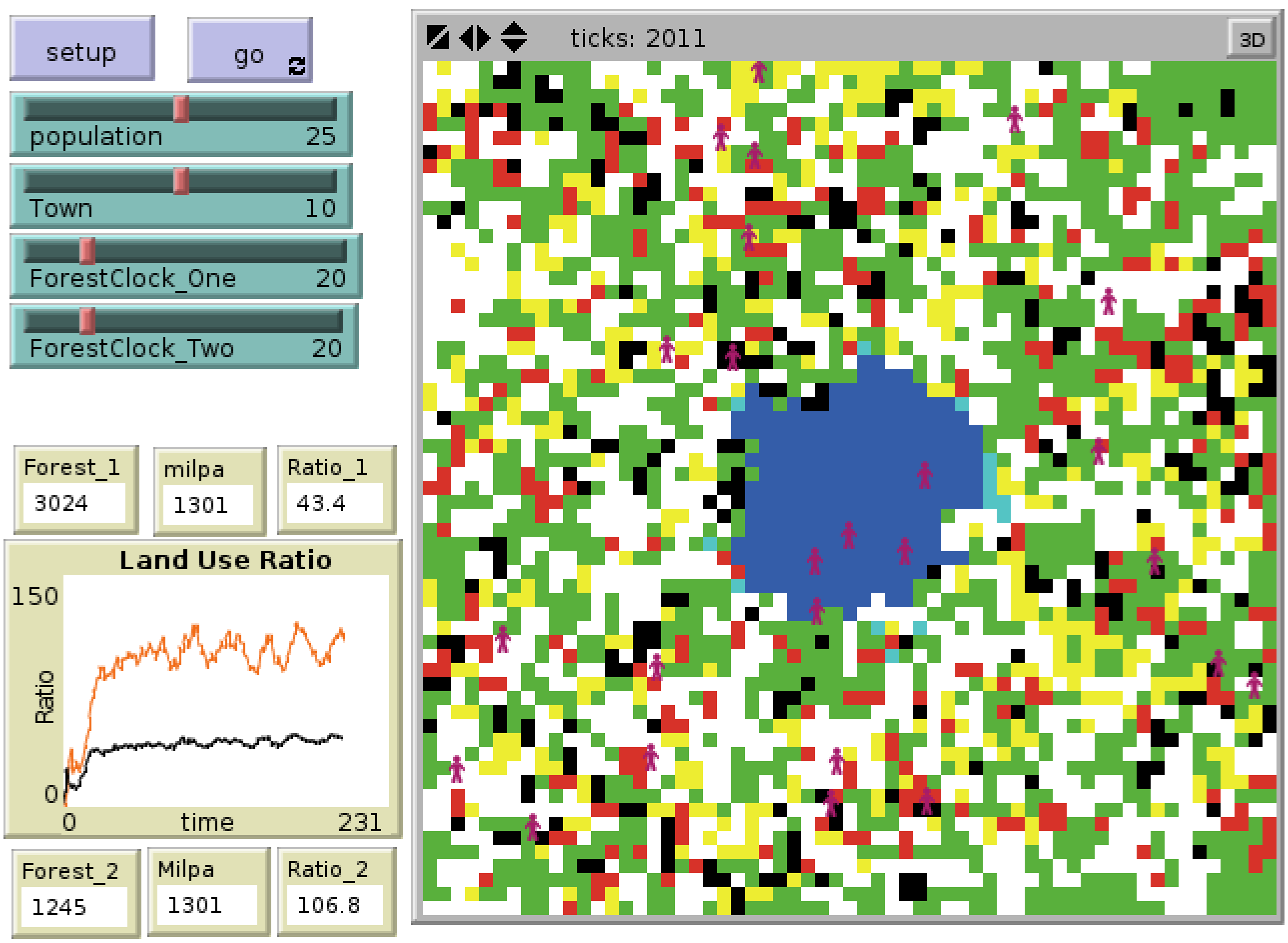


Figure 4. Sample screenshot from the Mayan_Ag_6 simulation after approximately 2000 iterations of a simulation run (population = 25)

Dramatic changes in the output of the simulation appear as the population of "farmers" increases. First, the density of the kaleidoscopic pattern has increased-- more of the "high forest" is involved in succession and the number of (NetLogo) patches in each color (except green) has increased. Second, there is now a substantial difference between *Ratio 1* and *Ratio 2* – *Ratio 2* is about double that of *Ratio 1* and exhibits very high variance (±30). *Ratio 1* has risen compared to Figure 3 but remains relatively stable with small fluctuations. The mosaic pattern appears much more complicated than in Figure 3.



Although the simulation is quite simple with many acknowledged assumptions and limitations (e.g., the successional stages are all equal in length, no protected areas [sacred groves] are incorporated, the simulation eventually consumes the "town" and the "gardens"), it has generated some surprising results. First, Mayan_Ag_6 seems to generate a dynamic picture of what a "managed mosaic" would actually look like. Second the simulation confirms the premise that there can be a relatively constant value for a land use ratio amid the flux of adaptive cycle cultivation (Ratio 1). Not surprisingly, this land ratio seems to be a function of population. But the drastic differences between Ratio 1 and Ratio 2 that occurs as a function of population is a surprise. It is suspected that the initial ecosystem hysteresis has to do with Ratio 2 and that there is an important relationship between Ratio 1 and Ratio 2 that may actually be the sought-after state variable of adaptive cycle cultivation.

A Final Word

We must begin now to rigorously investigate all possible historical, traditional, and current practices of agroecology not only to define the "best practices" for this potent agricultural strategy, but more importantly, to define the key elements (state variables) of sustainable agricultural systems. Once identified, these state variables can be incorporated into predictive models and field trials that can help shape the course of policy development leading to the design and implementation of truly sustainable agricultural systems. *Adaptive cycle cultivation* suggests that a land use ratio, a biodiversity ratio, and a human density gradient are such state variables.

Adaptive cycle cultivation certainly offers the hope of agroecology as a healthy, ecosystem-friendly, and sustainable agricultural strategy on a crowded planet. But adaptive cycle cultivation offers much more than just food for the belly. *Adaptive cycle cultivation* could well be the centerpiece of "self-reliant development." Max-Neef (1992) states that "self-reliant development allows for a more complete and harmonious satisfaction of the entire system of human needs" and a "regeneration or revitalization through one's own efforts, capabilities, and resources" that "changes the way in which people perceive their own potentials and capabilities." *Adaptive cycle cultivation* would place environmental sustainability center stage and provide a real ecological niche for the human being as an augmenter of biodiversity and a hands-on, (positive) participant in Earth's biogeochemical cycles. And because *adaptive cycle cultivation* would require collective, social action and would create collective, social interdependence, implementing *adaptive cycle cultivation* has the potential of creating emergent social structures and diversities that could be the basis for new and wholesome cultural satisfiers of the nine fundamental human needs (Max-Neef 1992). In large measure this prediction is supported by the fact that implementing *adaptive cycle cultivation* would require a <u>substantial</u> re-structuring of the economic and social (legal) status of land, land ownership and property rights.

We know that the quantitative development of increased throughputs of matter and energy that is offered by capitalistic consumerism is unsustainable. Continued on a global scale, quantitative development is environmentally unsustainable, economically unsustainable, socially unsustainable and is already creating planetary havoc. We need a major paradigm shift. By radically changing the way in which we provision ourselves, *adaptive cycle cultivation* could be the basis for the paradigm shift to self-reliant, global sustainable development.

References

Alcorn, Janis B. and Toledo, Victor M., 1998. "Resilient resource management in Mexico's forest ecosystem: the contribution of property rights" in *Linking social and ecological systems : management practices and social mechanisms,* Fikret Berkes and Carl Folke, ed.s, New York: Cambridge University Press.

Allen, Michael F and Rincoń, Emmanuel, 2003. " The Changing Global Environment and the Lowland Maya: Past Patterns and Current Dynamics". In *The Lowland Maya Area : Three Millennia at the Human-wildland Interface,* Gomez-Pompa, A.; Allen, M.F.; Fedick, S.L.; Jiménez-Osornio, J.J.; eds., Binghamton NY: Food Products Press.

Altieri, M. and Nicholls, C.I., 2001. Chapter 6. "Ecological impacts of modern agriculture in the United States and Latin America". In *Globalization and the Rural Environment*. Solbrig, O. and David Rockefeller Center for Latin American Studies, Cambridge, Mass. Harvard University Press.

Altieri, M.A., and P. Rosset. 1996. "Agroecology and the conversion of large-scale conventional systems to sustainable management." *International Journal of Environmental Studies* 50 (3-4): 165–185.

Badgley, C., and I. Perfecto. 2007. "Can organic agriculture feed the world?" *Renewable Agriculture and Food Systems* 22 (02): 80–86.

Beus, C.E. & Dunlap, R.E., 1990. Conventional versus Alternative Agriculture: The Paradigmatic Roots of the Debate. *Rural Sociology*, 55(4), 590–616.

Benjamin, P. et al. 2001. "Carbon, water and nutrient flux in Maya homegardens in the Yucatán peninsula of México." *Agroforestry Systems* 53 (2): 103-111.

Bomford, Michael. 2010. "Getting Fossil Fuels Off The Plate." In *Post Carbon Reader: Managing the 21st Century's Sustainability Crises,* Richard Heinberg and Daniel Lerch, (ed.s). Watershed Media Press.

Brenner, W., Hodell, D.A., Curtis, J.H., Rosenmeier, M.F., Anselmetti, F.S., Ariztegui, D., 2003. "Paleolimnological approaches for inferring past climate change in the Maya reion: recent advances and methodological limitations." In *The Lowland Maya Area : Three Millennia at the Human-wildland Interface*, Gomez-Pompa, A.; Allen, M.F.; Fedick, S.L.; Jiménez-Osornio, J.J.; eds. Binghamton NY: Food Products Press.

Brinkman, Henk-Jan, Saskia de Pee, Issa Sanogo, Ludovic Subran, and Martin W. Bloem. 2010. "High Food Prices and the Global Financial Crisis Have Reduced Access to Nutritious Food and Worsened Nutritional Status and Health." *The Journal of Nutrition* 140 (1): 153S -161S.

Carson, R. 1962. Silent spring. 40th ed. Boston: A Mariner Books.

Dahlin, B. H, T. Beach, S. Luzzadder-Beach, D. Hixson, S. Hutson, A. Magnoni, E. Mansell, and D. E Mazeau. 2005. "Reconstructing agricultural self-sufficiency at Chunchucmil, Yucatan, Mexico." *Ancient Mesoamerica* 16 (02): 229–247.

Deffeyes, K.S. 2008. *Hubbert's peak: the impending world oil shortage*, Princeton Univ. Press

Diamond, J, 2010. *Collapse How Societies Choose to Fail or Succeed: Revised Edition.*, Penguin Group USA.

Fedick, S., 1996. *The Managed Mosaic : Ancient Maya Agriculture and Resource Use.* Conference on Ancient Maya Agriculture and Biological Resource Management held at the University of California, Riverside (1991). University of Utah Press.

Faust, Betty Bernice. 2001. "Maya environmental successes and failures in the Yucatan Peninsula." *Environmental Science & Policy* 4 (4-5) (August): 153-169.

Finlayson, A. Christopher and Bonnie McCay, 1998. "Crossing the threshold of ecosystem resilience: the commercial extinction of northern cod" in *Linking social and ecological systems : management practices and social mechanisms,* Fikret Berkes and Carl Folke, ed.s, New York: Cambridge University Press.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and CS Holling. 2004. "Regime shifts, resilience, and biodiversity in ecosystem management." *Annual Review of Ecology, Evolution, and Systematics*: 557–581.

Foster, John. 2002. *Ecology against capitalism*. New York: Monthly Review Press.

Gillis, J., 2009. Norman Borlaug, Plant Scientist Who Fought Famine, Dies at 95. *The New York Times*.

Gómez-Pompa, Arturo. 2003. "Research challenges for the Lowland Maya area: An Introduction." In *The Lowland Maya area : three millennia at the human-wildland interface*. Gomez-Pompa, A.; Allen, M.F.; Fedick, S.L.; Jiménez-Osornio, J.J.; eds., Binghamton NY: Food Products Press.

Gunderson, Lance H., and C. S. Holling. 2001. "Resilience and Adaptive Cycles" in *Panarchy: Understanding Transformations in Human and Natural Systems*. 1st ed. Island Press.

Hoekstra, A, 2010. "The Water Footprint of Humanity." Lecture in the Peter Roberts Memorial Lecture Series sponsored by Compassion in World Farming delivered 20 September 2010, Savoy Place, London.

Horwith, B., 1985. A role for intercropping in modern agriculture. *BioScience*, 35(5), 286–291.

IPCC, 2007. *Climate Change 2007: Synthesis Report*, Pachauri, R.K. and Reisinger, A. (Eds.), Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Jimenez-Osornio, J.J., Rocío Rosales, y Patricia Escalante, 1999. "Agrodiversidad de los solares de la península de Yucatán." *Red, Gestión de Recursos Naturales.* 2 (14). Biodiversidad y biotecnología: pp. 30-40.

Kovel, Joel. 2007. *The enemy of nature : the end of capitalism or the end of the world?* Zed Books.

Lenton, T.M., H. Held, E. Kriegler, J.W. Hall, W. Lucht, S. Rahmstorf, and H.J. Schellnhuber. 2008. "Tipping elements in the Earth's climate system." *Proceedings of the National Academy of Sciences* 105 (6): 1786-1793.

Lovelock, James. 2010. *The vanishing face of gaia : a final warning*. Pbk. ed. New York: Basic Books.

Max-Neef,. 1992. "Human-scale economics" in *Real-life economics : understanding wealth creation*. Ekins, Paul (ed.), Routledge; London, New York.

McKibben, Bill. 2010. *Eaarth : making a life on a tough new planet*. 1st ed. New York: Time Books.

Mitchell, Melanie. 2009. *Complexity a guided tour*. Oxford University Press.

MEA, 2005. *Ecosystems and Human Well-Being: Synthesis Report*. Millennium Ecosystem Assessment, United Nations.

Murphy, T., 2011. Galactic-Scale Energy:Part 1. Accessed at http://www.theoildrum.com/node/8155 on 11 November 2011

Nicolis, G., and I. Prigogine. 1989. *Exploring complexity*. R.Piper GmbH and Co., Munich.

Olesen, J.E., and M. Bindi. 2002. "Consequences of climate change for European agricultural productivity, land use and policy." *European Journal of Agronomy* 16 (4): 239–262.

Olson, D. M, and E. Dinerstein. 1998. "The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions". *Conservation Biology* 12 (3): 502–515.

Pauly, D. 2007. "The Sea Around Us Project: Documenting and communicating global fisheries impacts on marine ecosystems." *AMBIO: A Journal of the Human Environment* 36 (4): 290–295.

Pretty, J., C. Brett, D. Gee, R. Hine, C. Mason, J. Morison, M. Rayment, G. Van Der Bijl, and T. Dobbs. 2001. "Policy challenges and priorities for internalizing the externalities of modern agriculture." *Journal of Environmental Planning and Management* 44 (2): 263–283.

Rosset, P. 2002. "Alternative agriculture and crisis in Cuba." *Technology and Society Magazine, IEEE* 16 (2): 19–25.

Ruttan, V.W., 1999. The transition to agricultural sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, 96(11), 5960 -5967.

Sala, O. E, F. S Chapin III, J. J Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, et al. 2000. "Global biodiversity scenarios for the year 2100." *Science* 287 (5459): 1770-1774.

Scott, James. 1998. *Seeing like a state : how certain schemes to improve the human condition have failed*. New Haven: Yale University Press. 262-306

Schj\onning, P., S. Elmholt, and B. T Christensen. 2004. Chapter One. Soil Quality Management – Concepts and Terms. In *Managing soil quality: challenges in modern agriculture*. P. Schjønning, S. Elmholt and B.T. Christensen, ed.s. CAB International

Shiva, V., 2004. The future of food: countering globalisation and recolonisation of Indian agriculture. *Futures*, 36(6-7), 715–732.

Taube, K., 2003. Ancient and Contemporary Maya Conceptions About Field and Forest. *In The Lowland Maya Area : Three Millennia at the Human-wildland Interface,* Gomez-Pompa, A.; Allen, M.F.; Fedick, S.L.; Jiménez-Osornio, J.J.; eds., Binghamton NY: Food Products Press.

Tilman, D., K. G Cassman, P. A Matson, R. Naylor, and S. Polasky. 2002. "Agricultural sustainability and intensive production practices." *Nature* 418 (6898): 671–677.

Tilman, D., 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences of the United States of America*, 96(11), 5995.

Toledo, Víctor, Narcisco Barrea-Bassols, Eduardo Garcia-Frapolli y Pablo Alacon-Chaires, 2008. "Uso múltiple y biodiversidad entre los mayas yucatecos (méxico)." *INCI* 33 (5) (May): 345-352.

Vandermeer, John. 1995. "The Ecological Basis of Alternative Agriculture." *Annual Review of Ecology and Systematics* 26: 201-224.

Welch, R. M, and R. D Graham. 1999. "A new paradigm for world agriculture: meeting human needs: Productive, sustainable, nutritious." *Field Crops Research* 60 (1-2): 1–10.

Wharton, C.R., 1968. The Green Revolution: Cornucopia or Pandora's Box?. *Foreign Aff.*, 47, 464.

Wilensky, U 1999. NetLogo; http://ccl.northwestern.edu/netlogo. Center for Connected Learning and Computer-Based Modeling. Northwestern University, Evanston, IL.

Wolfe, M. S. 2000. "Crop strength through diversity." *Nature* 406 (6797): 681–682.

WWF, 2010. *Living Planet Report 2010*. World Wildlife Fund.