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The Role of Constructed Ecosystems in An Era of Rapid Climate Change

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Abstract : Rapid climate change is causing ecological disequilibrium in many parts of the planet, which makes restoration of natural ecosystems to predisturbance conditions less probable. An alternative to restored ecosystems may be constructed ecosystems that are designed to address this problem. These circumstances offer only two choices: (1) do nothing and see if natural systems can adjust and (2) design constructed ecosystems that can tolerate and adjust to rapid climate change. Constructed ecosystems are not restored to ecological predisturbance condition because the probability of restoration to predisturbance condition is minimal. The ecological procedures and goals for constructed ecosystems are similar to the emergency room at a hospital – the goal is to keep the patient alive. The goal is a naturalistic biotic community with a structure and function similar to natural communities, which should consist of natural capital that provides ecosystem services similar to those provided by natural systems. An important feature of constructed ecosystems is a certain degree of standardization that permits large-scale development of colonizing species at a reasonable cost. These species should be tolerant of the rapid climate change the planet is now experiencing, which will probably continue for some time. Constructed systems might even require low maintenance.

Key words : Constructed ecosystems, Climate change, Naturalistic biotic communities, Colonizing species, Low maintenance.

We've got 30 years of climate change ahead of us even if we stop right now (greenhouse gas emissions). We're persuading countries they have to adapt to the changes that are ahead of them.

David King (as quoted in Bremer, 2006)

The world's top polluting nations were told in Monterrey, Mexico, to prepare for decades of weather turmoil, even if they act now to curb emissions and pursue green energy sources. The British government's Chief Scientific Advisor David King noted: "Yet even if countries froze emission levels tomorrow, the world still faces 30 years of floods, heatwaves, hurricanes and coastal erosion" (Bremer, 2006).

The approximately 1°C temperature rise over the past century has caused farmers in Spain to battle arid conditions, while Greenland has been able to start growing barley and potatoes. If the warming trend continues as predicted, farmers globally will have to cope with weather conditions that change rapidly and unpredictably. The end of the era of cheap, readily available petroleum sources adds to the problem, as does the stunning loss of agricultural biodiversity. Diamond (2005) provides examples of societies that experienced rapid climate change and environmental damage. In some cases, food production methods were able to surmount the challenge; in other cases, food production suffered and the societies collapsed. Species other than humankind must also be considered – what about the 30+ million other species with which humans share the planet? Wilson (2006) is deeply concerned about them. Collectively, they constitute the biospheric life support system that maintains favorable conditions for *Homo sapiens*.

William E. Rees (2002-03) states: "…the sustainability dilemma is not merely an ecological or technical or economic crisis as is usually assumed, but rather it is a crisis rooted in fundamental human nature. More specifically, it is a crisis of human evolutionary success – indeed, we have reached the point where our success is killing us!" Constructed ecosystems are an emergency, interim measure until humankind accepts responsible membership in the interdependent web of life which is the planet's biocentric life support system.

Terminology :

Constructed ecosystems are standardized and use a wide range of species. Created ecosystems (*e.g.*, Atkinson *et al.*, 2005) differ from constructed ecosystems since they are not standardized and use indigenous species whenever possible. However, many of the colonizing species often did not exist previously in the area in which they are used as colonists (*e.g.*, Atkinson *et al.*, 1995). The created ecosystems may be colonized by non-indigenous species, but their structure and function is more unique than those of constructed ecosystems. An analogy that may describe the difference between these two kinds of ecosystems is that created ecosystems are similar to a local, small business and constructed ecosystems are like a global franchise.

The need for constructed ecosystems has not been apparent until recently, when rapid global climate change became evident. Created ecosystems will probably not be adequate for the new era of rapid climate change. Constructed ecosystems may better meet the need for flexible, adaptable systems that can provide the natural capital needed because of the increased loss of species and compromised natural ecosystems.

The terms *reclamation* and *ecological repair* have often been used interchangeably with the terms *creation*, *construction*, *reclamation*, *repair*, and *restoration*, but, in an era of ecological disequilibrium (*e.g.*, Cairns, 2006), goals, methods, and procedures should be explicitly stated in each discussion. The reason for this additional terminology is the concomitant acceleration of climate change loss of species, which has already impaired the integrity of the biospheric life support system. If the life support system fails, humankind will be severely threatened.

Obstacles to Development of Constructed Ecosystems :

1. Not nearly enough ecologists are available with substantial "hands-on" experience in ecological restoration and ecosystem construction.

2. Sources of recolonizing species are inadequate, both in number of species and number of individuals per species.

3. Governmental agencies are unprepared for this type of emergency ecological restoration.

4. Many academic institutions have no major programs that afford students experience in the rapidly developing field of restoration ecology, including constructed ecosystems.

5. Many countries regard the United States as a threat to global security (*e.g.*, Weir, 2006), a situation that is not conducive to the exchange of the scientific information essential to success in this undertaking.

6. Global warming and other types of climate change will make survival of all species, even those in "pristine" ecosystems, more difficult.

7. A majority of citizens in the United States, and elsewhere in the world, has failed to grasp the seriousness of global warming and other environmental dangers or is in denial about them.

8. Restoration goals are usually not explicitly stated, especially regarding time, thus making judgment of progress difficult. Even with all the uncertainties involved, detailed statements of goals are essential to make sound, mid-course corrections.

Difficult Choices :

The number of ecosystems restored previously, even when finances were better, energy was cheap, and an almost adequate number of restoration ecologists were available, was far less than the number destroyed. At present, with a huge and rapidly growing human population, the petroleum age ending, and global warming and other types of climate change making an already bad environmental situation even worse, where will the resources to repair damaged ecosystems come from? Also, the loss of cheap petroleum energy could distract policy makers and citizens even further from any interest in ecological restoration and other environmental problems.

Gaia : The Biospheric Life Support System :

Ancient Greeks viewed Earth as a living goddess named Gaia. More recently, Lovelock (1979) has espoused the theory that both species and the physical/chemical environment of Earth have evolved into a single, self-regulating process that has been favorable to *Homo sapiens*. In short, Gaia is a biospheric life support system that is seriously threatened by human activities. Before humans evolved, Gaia had taken many forms, not all of which would have been as suitable for humans as the present system. Some systems would even have been hostile to humans had they been present. In enlightened self interest, humankind must preserve this age of Gaia that is so favorable to humans, so that they can function well for as long as possible. Otherwise, sustained use of the planet by humans is a fantasy. As Lovelock (1988, Preface, p. xvii)) notes: "Gaia theory forces a planetary perspective. It is the health of the planet that matters, not that of some individual species of organisms . . . The health of Earth is most threatened by major changes in natural ecosystems." As a consequence, sound policy dictates both eliminating the stress to natural systems so as to improve their health and using constructed ecosystems when rapid climate change makes more traditional types of ecological restoration extremely difficult or impossible. How can humankind's policy makers decide what to do?

Difficult Decisions :

An ecological triage system is necessary so that limited resources can be used to maintain the biospheric life support system in its present state (*i.e.*, favorable to humans). Humankind must act on the unprecedented ecological damage now occurring. However, since not much is being done at present, humankind is unlikely to be able to cope with an increased load. Military medical triage could serve as an example : (1) do not treat cases where treatment is not likely to be successful, (2) do not treat cases that will recover without treatment, and (3) use all treatment resources where the treatment will make a major difference.

Situation 1. Natural processes will restore some damaged ecosystems once the stresses have been removed. Perhaps minor management may be helpful, such as restocking lost species that might not easily return on their own. Socolow and colleagues (1994) have many useful suggestions on the steps that industry can take in this era of global change.

Situation 2. With assistance, ecosystems can sometimes recover to an approximation of their predisturbance condition. In some cases, they will become self regulating, but, in others, some subsidies will be necessary (*e.g.*, restocking some species of fish for recreational purposes). One National Research Council (1992) book discusses science, technology, and public policy for restoring damaged aquatic ecosystems and gives a variety of useful case histories.

Situation 3. Natural processes are not likely to restore a damaged ecosystem to an approximation of its predisturbance condition, and neither, in many cases, would managed ecological restoration. Constructed ecosystems should be given serious consideration under these increasingly common circumstances (*e.g.*, Media Alerts Archive, 2006). A primary reason for doing so is to prevent the damaged area from being colonized by invasive species that are difficult or impossible for humans to control effectively. Lovelock (1988, p. 19) notes that the Gaia hypothesis supposes that the atmosphere, the oceans, the climate, and the crust of Earth are all regulated at a state comfortable for life because of the behavior of living organisms. However, this regulation does not necessarily mean that *Homo sapiens* will always be favored as it is now. Constructed ecosystems are supposed to help maintain the present favorable conditions. The dynamics of nature are not predetermined, and human survival is not assured. However, the health of the biospheric life support system and human society are closely coupled, so restoring the former should aid the latter.

Habitat Mosaics :

Ecosystems usually consist of a mosaic of habitats. A particular habitat can be a source of colonizing species at times and a sink, which loses members of a species rather than exporting them, at other times. Availability of colonizing species is a major factor in the succession processes that are so important to ecosystem structure and function. Constructed ecosystems should duplicate this feature of natural systems to the maximum extent possible. Inevitably, this increased complexity will initially be more costly than a simple system. However, a complex system is more likely to be self sustaining, which, if achieved, would markedly reduce long-term costs. Complexity should reduce the disruptive impact of invasive species, but this reduced disruption will depend upon the ecological landscape in which the constructed ecosystem is placed. If sources of invasive species are nearby, the ecological benefit of construction might well be minimal since invasive species are quite disruptive.

All too often, a species is introduced for a specific purpose, but the introduction has major, unanticipated, adverse effects. For example, a plant (*Prosopis juliflora* or the "mathenge" plant) introduced into Kenya 20 years ago was supposed to stop desertification (Mawathe, 2006), but it has become a nightmare for inhabitants of Kenya's dry lands because it has both overgrown the local landscape and continues to spread at an alarming rate. Local people state that the mathenge seeds stick in the gums of their animals, eventually causing teeth to fall out. Thorns of the plant are said to be poisonous. Once an animal is pricked, the solution is to cut off the affected area. The mathenge plant also reduces the water retaining quality of the soil according to the local people. The government has formed a ministerial task force to assess the problem, but has taken no action to reduce the plant distribution or harmful effects. All this manipulation seems like an unnecessarily large amount of work for a system (the biospheric life support system) that has functioned well throughout human history. Like personal health, functioning well is taken for granted until it fails. Humankind does not want to witness anything even close to the failure of the biospheric life support system, but, in the 21st century, this catastrophe has moved from a possibility to a probability.

Landscape-level ecosystem restoration and management are new activities; however, with a 24% ecological overshoot (using resources faster than ecosystems can regenerate them), management skills must be acquired rapidly. Aquatic habitat mosaics are being both altered and destroyed by water overuse and abuse. For example, desert rivers in Arizona are being drained by overuse (McKinnon, 2006). A desert river depends on mountain snow runoff (now reduced by global warming), springs, and groundwater. If only one water source is removed or reduced, the system can usually adapt. The riparian vegetation both reaches deeper for water and remains dormant for a longer period. In Arizona, some stretches of rivers have been sucked dry by over pumping from wells that are mostly unregulated. Damage to the riverine portion of the ecological mosaic affects the entire landscape in arid regions because birds and other creatures come there for water and shade. Wells draw water from aquifers and cut off the streams and springs that supply and sustain rivers (McKinnon, 2006). Until the normal hydrologic cycle has been restored, restoration ecologists cannot do much. Desertification probably will follow. Some attempts to resuscitate short lengths of damaged waterways have succeeded (*e.g.*, National Research Council, 1992).

Hurricane Katrina devastated the US Gulf Coast city of New Orleans, but the disaster did not end when the hurricane departed. Louisiana's Department of Environmental Quality estimates the city will ultimately truck off and dispose of 20 million cubic yards of waste (Curtis, 2006). To speed the disposal process, the city converted a deep pit located amid the wetlands of New Orleans in April 2006 to a landfill. Anyone acquainted with the hydrologic cycle knows that hazardous substances will not remain in the landfill. Even though the landfill is intended only for non-toxic demolition debris, sorting wastes leaves much to be desired in emergencies. A partial solution would be to establish a disposal site that is not near the wetlands and construct an ecosystem over the site when it is closed in order to reduce water penetration and leaching of buried hazardous substances.

Marine Ecosystems :

The latest news about oceans and other marine ecosystems is frightening at the very least. Visualizing ecological restoration on such a vast scale and complexity is difficult. Equally difficult is visualizing what types of constructed ecosystems would be advantageous. However, possibilities generate a modest amount of optimism. In addition, much can be done on terrestrial ecosystems to benefit marine ecosystems. For example, carbon dioxide is increasing the acidity of marine ecosystems and causing a variety of serious problems (ENS, 2006). Reducing anthropogenic discharge of carbon dioxide would reduce the dangers of both global warming and ocean acidification. However, methane, a powerful greenhouse gas, is bubbling up naturally from some of the huge natural undersea reservoirs of the gas, which is mostly locked into the frozen mud under the sea floor (Blakemore, 2006). If much methane reaches the atmosphere instead of being absorbed into the water, the result would probably be a significant positive global warming feedback loop.

Restoring the vast marine ecosystem would be a truly daunting task. However, much can be done to reduce the toxic runoff from terrestrial ecosystems. This runoff is feeding an explosion of primitive organisms that have killed larger species and sickened people (Weiss, 2006). When fishermen touched fireweed, their skin broke out in searing welts and their eyes burned and swelled shut. Obviously, new conditions made possible by toxic runoff favor fireweed, so robust evidence is needed on how to make conditions less favorable for this troublesome species.

Regrettably, some "buffer systems," such as the Chesapeake Bay, are themselves in danger. Worse yet, the threat to the Bay ecosystem appears to be worsening (Williamson, 2006a). For example, the city of Cambridge plans a new residential golf course development overlooking the Blackwater River that will bring in additional tax revenue. However, the Chesapeake Bay Foundation across the Bay views this large development with concern. The development would be built upriver of a nationally important wildlife refuge and would add more sewage and polluted runoff to an already unhealthy bay. Of course, the buffer value of the Bay for the ocean would be diminished or lost. Much of the pollution entering the Chesapeake Bay could be reduced by use of constructed wetlands to assimilate and transform both nutrients and toxic substances. Many such wetlands would need to be constructed, and their role in mitigating pollution should be studied in micro- or mesocosms before they are actually constructed. The Bay is polluted from many sources, and cost-effective pollution reduction is best carried out before the wastes are both diluted and mixed with other wastes.

Information about the Chesapeake Bay's dirty water and contaminated fish does not reach the public, according to health experts, because of worries from the tourism industries (Williamson, 2006b). However, some promising examples of projects could benefit marine ecosystems. For example, environmentalist Chuck Cook and fisher Gordon Fox have developed a plan to preserve both the fish and the fishing off the central coast of California. The trawlers in Morro Bay have joined the Nature Conservancy and Environmental Defense in proposing three "no trawler zones" that would cover nearly 6,000 square miles of this marine ecosystem. If implemented, years would be needed to confirm the efficacy of the plan, but it seems well worth a try. Of course, if global oceanic acidification continues, it could negate regional and local plans, however well conceived.

Humanized Landscapes :

Humanized landscapes are markedly different from natural ecosystems, but they often have both ecological and esthetic value. Lovelock (1988, p. 233) states their value beautifully: "The England I knew as child and a young man was breathtakingly beautiful, hedgerows and small copses were abundant, and small steams teemed with fish and fed the others . . . Yet that landscape of England was no natural ecosystem; it was a nation-sized garden, wonderfully and carefully tended."

Now that the petroleum era is ending, a return to hedgerow agriculture would be energy efficient, less ecologically harmful (*e.g.*, less pesticides needed because insectivorous birds live in hedgerows), and more esthetically pleasing than enormous monocultures that require huge machines, pesticides, etc. Consequently, humanized landscapes and constructed ecosystems should reduce humankind's deleterious impact upon natural systems. Both should reduce and, together with other measures, eventually eliminate ecological overshoot. If they do not, no useful long-term purpose is being served since ecological overshoot is, by definition, not sustainable. Ideally, since natural systems are dynamic and highly variable, a substantial safety factor should be a major goal.

A combination of local and regional action has been recommended throughout this article. However, Sagoff (2004) comments in detail on the rift between national environmental organizations and their local chapters. For example, after the US House of Representatives passed the Quincy Library Bill (to protect and preserve national forests) nearly unanimously, the President announced his support and the Senate placed it on its agenda for quick passage. The National Audubon Society sent a letter to the senators that defended the normal processes of the Forest Service because "Forest Service employees are more likely on the whole to act in the public's best interest than local management conditions, which don't have the national scientific backing of an agency" (Sagoff, 2004). The Audubon Society acknowledged that one of its chapters was participating in and actively supporting the legislative strategy of the Quincy Library Bill but advised the Senate to ignore the position of the local chapter.

Home Vegetable Gardens :

In suburban United States, huge areas around homes are devoted to monocultures of grass, which are usually maintained by fertilizers, pesticides, and power mowers, all of which are energy intensive. Conversions of a significant portion of these lawns to edible produce gardens would increase food resources and have the added benefit of food being produced where it is consumed. In the United States, food may be transported hundreds, even thousands, of miles to reach consumers.

Pollan (2006) describes how inhabitants of the United States and much of the rest of the developed world evolved to its present diet. Climate change and the end of the era of cheap, readily available energy will alter that substantially – perhaps entirely. Home vegetable gardens, however small, could make the transition more bearable. The rate of climate change and the rate of decline of the cheap energy era may not permit a "soft landing," but doing nothing will produce a much less satisfactory outcome. The drought in much of the US "breadbasket" (Davey, 2006) is an ominous sign, and acid rain affected a third of China's land mass last year, posing a threat to food safety (Reuters, 2006). If vegetable gardens are out of the question, reduction in water use for lawns could at least be accomplished (Sanford, 2006).

Unfortunately, the forecasting group Henley Centre Headlight Vision tested public attitudes and discovered that, in three of four likely scenarios for 2005, selfishness appears to outweigh caring about others (Grice, 2006). This finding does not bode well for communal projects such as constructed ecosystems or for communal vegetable gardens.

In addition, one major problem for all constructed ecosystems is adequate supplies of freshwater. Kishan and Pearson (2006) note that the shortage of usable water worldwide has made water more valuable than oil. Even though vast amounts of water exist on the planet, over 98% is saltwater, which is not suitable for agricultural or human use. The remainder has been locked up in polar ice caps, which are melting into the seas. Except for those areas with a surplus of freshwater, constructed ecosystems should consist of species with minimal freshwater requirements.

Rooftops and Other Impervious Surfaces :

Cities consist almost entirely of impervious surfaces – roofs and paved roads. Impervious surfaces create serious runoff problems if the water is discharged directly into nearby rivers and streams. However, attractive alternatives are increasing. In Chicago, the rooftop of the city hall is a green oasis of native plants, and monarch butterflies and bees gather nectar from prairie clover and purple coneflower (Paulson, 2006). Chicago Mayor Richard Daly credits the idea to Germany, which has an estimated 20% greenery on flat rooftops. Green roofs can be twice as expensive as conventional roofs, but last twice as long. Buildings with green roofs are cooler than those with conventional roofs. Surplus rainfall can be stored in cisterns to reduce or eliminate the drain on municipal water supplies. Even though runoff from roads and parking lots can contain a variety of substances from dog feces to oil and grease, it can still be useful for watering median strips on parkways after some time in holding basins.

Just any plants for a green roof will not do. Rooftops are special environments where plants requiring shade will probably not thrive. In large metropolitan areas, at least one source of suitable plants should be available. Visits to other rooftop habitats in the area would be worthwhile. Low maintenance requirements will probably be a high priority item for most rooftop vegetation. Frequency of watering and amount of water will be increasingly important factors as water shortages worsen (Weiser, 2006). Perhaps rooftops should be planted with drought resistant species that are tolerant of other harsh conditions, such as severe winds and strong sunlight. Technology will not solve the problem just described (Yeston *et al.*, 2006), but local knowledge and careful choices can.

Rapidly Changing Conditions :

Numerous scientific publications provide evidence that Earth is in an era of rapid climate change. The general public in the United States has an opportunity to view Al Gore's film "An Inconvenient Truth" and Tom Brokaw's television documentary "Global Warming: What You Need to Know." Both focus on rapid climate change. Biota (including humans) accustomed to relatively benign, stable climate conditions will not fare well with rapid climate change, although some species should survive and others may thrive. How long the transition period will last is unknown, as are the new, dynamic equilibrium conditions that will emerge. Doing nothing about the causes (*e.g.*, greenhouse gases) of rapid climate change will further exacerbate an already perilous situation. Some systems may reach a point of no return, and uncertainty remains about reaching a permanent tipping point (*e.g.*, Loder, 2006). The more complex systems probably have a number of tipping points, but this fact does not greatly improve human prospects since reaching any major tipping point will have catastrophic consequences.

Humankind usually does not take action until a dangerous situation develops. The degree of ecological damage awareness already varies markedly from region to region. As a consequence, constructed ecosystems will be more accepted in some areas than others. Constructed ecosystems will differ from one ecoregion to another, but this difference is not a major obstacle since much ecological information must be communicated in each situation. However, even less affected regions will probably be "magnets" for environmental refugees from affected areas, so this migration should expedite development of awareness. Furthermore, humans are basically a small-group species and, despite present demographics, should function better in a "tribal" context.

Fortunately, science is transitioning from a fragmented aggregation of specialists (who will always be needed) into a complementary, transdisciplinary, interactive group with a global perspective (*e.g.*, Wilson, 1998). Equally important, cultural evolution, which has led many past civilizations to extinction, can also modify human behavior in order to reach a harmonious relationship with natural systems (Ehrlich, 2000). Since there are both major ecological (*e.g.*, climate change) and social (*e.g.*, end of cheap, readily available energy) problems, the rate of cultural evolution must be rapid and must include a redefinition of progress. For example, the current 24% ecological overshoot is the result of consuming the planet's resources much more rapidly than they are regenerated. Humans have made a huge contribution to the present global crisis. Humans can be a major part of the healing process.

The time frame for reaching a mutualistic relationship with natural systems is difficult to predict. How long will it take to stabilize the human population? How many years will it take to repair the damage to the biospheric life support system? How long will it take to withdraw from a high energy/high consumption lifestyle? Most important, how long do humans have before natural limiting factors (*e.g.*, disease and starvation) override their plans? How will the "contest" between environmental ethics and global market forces end?

Concluding Statement :

Since global warming and other types of climate change in some regions will preclude the restoration of damaged ecosystems to their predisturbance condition, constructed ecosystems could replace many lost ecosystem services. However, the science for constructing ecosystems is not robust, so all constructed ecosystems should be regarded as experimental. They must also be compatible with the ecoregion in which they are placed. Much of the work can and should be done by local people with guidance of a credentialed restoration ecologist. Even the successful constructed ecosystems will probably require some, or even much, management in an era of rapid climate change.

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