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# Global Coevolution of Natural Systems and Human Society*

***Coevolución global de los sistemas naturales y la sociedad humana***

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## ABSTRACT

Human society has been accustomed to thinking of natural systems as entities requiring protection or exploitation. There has been much hyberbole in the presentation of both views. Although people have spoken of the death of nature, it is unlikely that humanity could entirely eliminate all non-domesticated species. Each time human society does something, natural systems adjust, not always in ways intended. And, this, in turn, requires human society to adjust. This mutual modification is analagous to coevolution seen in pairs of species.

Coevolution between one species and another is often accomplished through harsh penalties for a component that does not respond rapidly to changes in the other component. A coevolution of human society and natural systems will be less unpleasant to humans if rapid information systems are developed to alert society to needed changes, coupled with a sufficiently high environmental literacy to make the changes before the selective pressures of natural systems are too harsh.

Instead of polarizing views of human society's relationship with natural systems, to the degree possible, this relationship should be viewed as one system coevolving with another. Wild systems must always be valued and maintained, but the point at which human society and complex ecological systems modified by humans co-exist is where society must spend more time working on a mutually beneficial relationship.

**Keywords:** coevolution, population growth, environmental literacy, environmental ethos.

## RESUMEN

La sociedad humana se ha acostrumbrado a pensar en los sistemas naturales como entidades que requieren protección y explotación. De ahí se deriva mucho de lo hipérbolo en la presentación de ambas observaciones. Aunque la gente habla de la muerte de la naturaleza esto es improbable ya que la humanidad debería eliminar por completo todas las especies silvestres. Cada vez la sociedad se ajusta un poco al sistema natural, no siempre de manera predeterminada. Esta mutua modificación es análoga a la coevolución vista en un par de especies.

*** It is a great pleasure to be among those privileged to honor Dr. Eucario López-Ochoterena in this special issue of *Revista de la Sociedad Mexicana de Historia Natural*! I have warm memories of my association with Dr. López-Ochoterena, his colleagues, and his students. Intellectual stimulation was skillfully combined with gracious hospitality! This dedicatory manuscript was prepared as if I were giving another seminar at the invitation of Dr. López-Ochoterena.**

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La coevolución entre una especie y otra es a menudo competitiva por haber dificultades en un componente que no responde rápido a los cambios en los demás componentes. Una coevolución de la sociedad humana y el sistema natural puede ser menos desagradable para el hombre, si la información del sistema se desarrolla tan rápido para alertar a la sociedad de la necesidad de cambio, al par de contar con una educación ambiental lo suficientemente fuerte para hacer los cambios necesarios ante la presión selectiva del sistema natural.

En cambio desde el punto de vista de las sociedades humanas las relaciones de polarización con el sistema natural, en el grado que sea posible, estas relaciones podran ser vistas como un sistema que coevoluciona con otros. Los sistemas silvestres simpre deberan se valorados y sostenidos, pero hasta el nivel en que la sociedad humana y la complejidad ecológica en la modificación del sistema por el hombre coexista hasta el grado que la sociedad pueda devolver mayor tiempo de trabajo para llegar a una relación de mutuo beneficio.

**Palabras Clave:** Coevolución, desarrollo poblacional, educación ambiental, ética ambiental.

**The World Community may no be sufficiently motivated to undertake those steps necessary to protect the global environment until it fully appreciates that a failure to do so will endanger the health of its childern, and that of generations to come.**

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## Selecting an Analogy

The particular analogies chosen to frame the discussion of global change seem to be a key part in communicating the scientific view of these issues to the wider public. Without access to the applicable science from many fields, the general public cannot fully participate in the debate. Of course, most ecologists feel that even the most basic ecological concepts are instrumental in enlightening the debate on global change. However, this can be true only if these concepts are communicated in a relevant context. In addition, ecological concepts must be integrated with key concepts from other disciplines: economics, demography, political science, cultural anthropology, public policy, etc.

One such ecological concept that may help shape the debate on global change is coevolution. A basic definition of **coevolution** is given by Raven and Johnson (1986): "The simultaneous development of adaptations in two or more populations, species, or other categories that interact so closely that each is a strong selective force on the other." In ecology, coevolution has been used to describe paired changes in butterflies and the flowers they feed on (Ehrlich and Raven, 1964), hosts and parasites (Pimentel *et al.*, 1978), and predator and prey (Thompson, 1986). The concept has been extended to describe changes in more than species pairs, e.g., the reciprocal changes in agricultural practices and weeds (Ghersa *et al.*, 1994). Further, in cultural anthropology, the concept of coevolution has been appropriated to describe paired changes in the human culture and human genetics (Durham, 1991). Others (e.g., Odum, 1992) use it to describe the relationship between human society and natural systems.

The key parts of the coevolution definition are that the interacting entities must serve as selective forces on each other and that changes enhance the survival of each partner; otherwise, these change would not be adaptive. The idea I wish to explore here is that human societies and the global environment interact and shape each other, that these mutual changes can enhance the survival of both, and that understanding the mechanisms underlying coevolution may enhance the debate on global environmental issues.

This use of the term **coevolution** to describe the relationship between human society and natural systems has some similarities to the Gaia hypothesis (Lovelock, 1988). Living things, including humans, not only adapt to physical conditions but also modify them in ways sometimes beneficial to life. However, there are significant differences between the proposed coevolution analogy and Gaia's hypothesis (Van Valen, 1982). Gaia maintains that the earth is a superorganism in which nonliving and living components self-regulate to maintain a constant state (Kerr, 1988). In the superorganism analogy, the key concept is the physiological one of homeostasis. For example, a steady state in global climate would be maintained through feedback mechanisms in the same way mammals regulate body temperature. However, as Odum (1992) and others (Kerr, 1988) have pointed out, feedback in ecosystems is different from physiology because it has no fixed goals.

By selecting an analogy from farther up in the hierarchy of biological organization (e.g., cells, organs, individuals, populations, communities, ecosystems, landscapes, biosphere, etc.), the language of the physiologist is exchanged for that of the ecologist. Instead of the term **homeostasis**, the term **mutual change** is used. And, instead of any change of state being bad for the emergent whole, coevolution allows for the possibility of mutually beneficial changes. Coevolution occurs through the mechanism of selection. In the case of coevolution between human society and natural systems, the selection would be among alternate cultural practices (structures and functions of families, schools, communities of religious belief, governments at many levels, economies, and industries) and alternate landscapes. This shift in analogy accommodates current thought in the area of sustainable development because mutually beneficial change is possible if selective pressures elicit responses in both partners. Another description of the interaction between human society and natural systems invokes the chaos theory (Kauffman, 1993). In this view, the mechanism of selection is augmented by that of self-organization.

Do the basic requirements for coevolution exist in the relationship between human society and natural systems, i.e., do they shape each other? Certainly, humans have shown a remarkable ability to adapt to environments from one pole to the other. Human adaptations to these widely varying environments have been largely behavioral rather than physiological. This sort of behavioral change falls within some definitions of an adaptation (e.g., Raven and Johnson, 1986) but outside others (Ricklefs, 1990). Clothing, shelter, fire, and agriculture have allowed people to change their physical environments to suit themselves. This physical restructuring of the environment that is a central part of human response to adverse environmental conditions has progressed and intensified, making changes increasingly pervasive, long-lasting, and removed from the intended modification. Human society has altered natural systems in significant ways. Now, in turn, is human society likely to be shaped by environmental changes that it has brought about? Of the many selective forces at play, some may be more effective than others in shaping their partner in coevolution.

## Human Society as a Selective Force

Ways in which human society has presented a strong selective force to the global environment have been listed by many authors (e.g., Ehrlich and Holdren, 1971; Myers, 1979; Wilson, 1988; Ehrlich and Ehrlich, 1991; National Research Council [NRC], 1992a; Brown *et al.*, 1992). A few authors challenge the cause-effect link in some of these changes in the environment and human actions or dispute their importance (e.g., Ray, 1992; Bailey, 1993). Certainly, gross changes on a local level are easier to experience directly and to assess scientifically than are changes at the global level. Even Ray (1992) does not dispute the importance of local environmental problems such as pollution. However, some observed global trends are occurring at rates unprecedented in historical record, are correlated to simultaneous activities of human societies, and cause adverse effects in small scale, controlled experiments. Without replicate planets to manipulate, science will never get closer to a determination of causation at the global level than this. It is the projection of observed changes to larger scales, longer periods, interactions with other mitigating or potentiating factors, and future social consequences that is a much greater source of uncertainty. Even with room for responsible scientific debate about causation, magnitude, and importance, there are a number of areas in which human society demonstrates a strong selective force on the environment.

**Habitat Fragmentation and Loss**

Human society has been altering the physical structure of natural systems dramatically for thousands of years. Since the beginning of the agricultural revolution, agricultural systems created by human society have displaced natural ecological systems over much of the arable area of the planet. Even today, the loss of forests in certain countries, such as Brazil, is more likely to be due to clearing for agricultural purposes than from harvesting of timber (NRC, 1992a). Rates of deforestation in the most diverse systems, wet tropical forests, are estimated at 0.4 to 2.7% annually and are not readily reversible (Brown *et al.*, 1992).

Another example of precipitate losses in an entire category of habitat is wetland loss. More than half of the wetlands that existed in the coterminous United States has been lost since colonial times (NRC, 1992b). These wetlands once provided a means for containing floodwaters, cleaning water, and providing one of the most productive of habitats for fish and wildlife.

**Loss of Species**

With loss of habitat comes loss of species. Only a rough estimate can be made of how many species exist on the planet. Erwin (1988) suggests at least 30 million insect species and possibly 50 million in the canopy of tropical forests. Simberloff (1986) estimates that, if deforestation continues at present rates until the year 2000 and then halts completely, an eventual loss of about 15% of the plant species in Amazonia is likely. If the forest cover were further reduced to those areas now set aside as parks and biological reserves, 66% of plant species would eventually disappear as well as almost 69% of bird species and similar proportions of other types of animal species. The National Biological Inventory in the United States is now underway to improve knowledge of the species that inhabit this country and also improve the accuracy of the estimates of where they are and how many now exist (NRC, 1993). Carried out over a multi-year period, the inventory will facilitate more robust estimates of rates of species extinction.

There is no precedent within the period of human history to use in judging the potential effects of the elevated rates of biotic impoverishment currently estimated. However, some experimental evidence shows that losses in species richness can affect key ecosystem services, especially the ability to capture sunlight and turn it into biomass, the ability to store carbon, and the ability to recover from unfavorable conditions. Naeem *et al.* (1994) manipulated trophically complex terrestrial mesocosms and found that more species-rich assemblages produced more biomass and stored more carbon dioxide than species-poor assemblages. Further, the relationship between richness and productivity appeared linear, yet there was no similar relationship between species richness and other important ecosystem services such as nutrient retention, decomposition, or water retention. In addition, a summary of work presented at the SCOPE Global Biodiversity Assessment Synthesis Conference in February 1994 reports the work of David Tilman and John Downing on prairie grasslands -- more species rich plots were better able to recover from drought (Baskins, 1994).

At this point, the database is too sparse to identify any crucial threshold in species richness or any general pattern between species loss and ecosystem functioning. Perhaps each species contributes incrementally to the functioning of the system or perhaps some species are redundant, i.e., duplications whose loss would not be critical. However, without knowing which of these relationships apply or how many species are being lost, a threshold in species loss could be passed without the scientific community even being aware of the event. This possibility concerns a number of people in species-rich Amazonia itself, as well as elsewhere in the world. Nevertheless, it would be misleading to characterize this situation as a matter of deep general concern. It is difficult for the average person to see how loss of species in a distant part of the world will affect his/her own future in any direct or important way. Much of human society thinks of the many individual contributors to biodiversity as pests, weeds, disease carriers, or things that bite, scratch, or are in other ways annoying. Most of human society either does not appreciate the functional roles of various species as part of a complex operating system and must be persuaded that many species are necessary to work efficiently.

**New Habitats**

Human societies have created new habitats quite different from those in surrounding areas and often different from anything that has existed before. For example, masses of heat-holding concrete and asphalt, a dearth of plants, and the lack of open waters in cities have been found to result in 10-20 F differences in temperature between cities and surrounding rural areas in summer (e.g., Akbari *et al.*, 1992). Some studies have linked local climate change from urban heat islands to local extinction of animals (Baur and Baur, 1993). Urban heat islands have also been blamed for skewing temperature measurements, thus leading to unwarranted conclusions about global temperature trends. Because urban environments present so many formidable obstacles to the survival of most species (e.g., little water, wide temperature swings, little plant life, concentrated pollution, etc.), the species that survive will be those opportunistic and communal species simultaneously tolerant of all these anthropogenic alterations. Obviously, the more individual stresses to be dealt with, the fewer species will be tolerant to all. Erwin (1991) has suggested that little more than weeds, flies, cockroaches, and starlings may be left in these extremely modified habitats.

**Modifying Biogeochemical Cycles**

While the inevitability, magnitude, and consequences of global warming are debated, there is much consensus over anthropogenic increases in atmospheric carbon dioxide and methane levels and the presence of novel chemicals in the atmosphere. Both natural and anthropogenic activities contribute to the movement of carbon dioxide, methane, and nitrous oxides back and forth from fuel and air and soil and water and plant and animal. Obviously, a great change in one rate can affect the others, with poorly anticipated secondary effects.

Hydrologic cycles have been modified extensively by human intervention, not only in rivers (i.e., dams, levees, storage basins, canals, etc.) but by deforestation, wetland destruction, and creation of impervious surfaces such as roads, parking lots, and roofs on houses. These structures and activities result in pulses of water in rivers following rainfall that are quite dissimilar from broader natural pulses both in amplitude and duration. Even with human intervention, floods occur. Smith (1994) notes that forecasting and water management problems demand an interdisciplinary approach. However, he also notes in the same article that one of the causes of the flooding of the Mississippi River in 1993 was global anomalies in atmospheric circulation. This observation is important in a number of ways, but, for the purposes of this discussion, there are two: (1) global changes can affect human society's relationship with an ecosystem, such as the Mississippi River, in a major way, and (2) however robust the models developed, there will always be some uncertainties that could produce misery for those taking the risk of putting dwellings, etc. on the floodplain itself.

## Environment as a Selective Force

In what ways has the environment presented a strong selective force to human society? In the most basic sense, life on the planet has evolved to function at certain gravity, pressure, atmospheric gas compositions, etc. Gross and immediate changes in these factors certainly have adverse effects on organisms, as shown from experimentation in space. On the local level, the environment still presents strong selective forces and pressures in the form of famine, disease, or habitat destruction from natural causes such as flood, fire, tornado, earthquake, and volcanic activity. Human society uses all the technology it can muster to mitigate these factors.

**Limits to Population Growth?**

The human population continues to grow at an unprecedented rate. Most growth is in developing countries south of or near the equator, and the rate of population increase in developed countries is, by present day standards, relatively slight. However, Myers (1994) notes that there is now a much broader consensus in science that population is a problem.

The relevant term from basic ecology in the discussion of local population growth is **carrying capacity**: "The size at which a population stabilizes in a particular place is defined as the carrying capacity of that place for that species" (Raven and Johnson, 1986). Carrying capacity depends both on the number of users and the intensity of per capita use (Odum, 1992). While there is no evidence that the basic concept does not apply globally to humans, its relevance locally is obvious and unpleasant. Density-dependent limits on growth, such as the availability of food and potable water and disease transmission, provide strong selective pressures, but these limits have been extensively modified by human engineering. There are also density-independent limits to carrying capacity, such as earthquakes, tidal waves, and volcanic eruptions. While climate change has historically been a density-independent limit, per capita contributions to global warming may change it to a density-dependent limit. Contrarians have challenged the applicability of the carrying capacity concept for global human populations by pointing out its changeable nature locally through trade and other technology (Bailey, 1993). However, carrying capacity is never a static line in the sand; it changes as limits change. The green revolution, basic sanitation, and modern medicine all changed carrying capacity by modifying density-dependent limits. Global warming, salinization, soil loss, and pollution may modify both kinds of limits.

Still, instances in which carrying capacity is locally exceeded are an unpleasant and too common occurrence; one response is to flee. Myers (1993a,b), Trolldalen *et al.* (1992), and Westing (1992) have described the problem of environmental refugees. Myers estimates that there were at least 10 million environmental refugees compared with 17 million other refugees caused by political, religious, and ethnic conflict. It is worth noting that the United Nations and individual countries have been notably unsuccessful in stabilizing any of these situations, although, in Somalia, starvation was temporarily alleviated at enormous economic and military costs. This loss of stability in human society and the brutality so commonly associated with it has, in Africa, caused deterioration of already scarce habitat for gorillas and other species that resulted from mass movements of people into areas ill equipped to accommodate them. In areas of Africa that are comparatively stable politically, poachers have caused serious reductions in populations of large animals already in serious decline. Myers (1993a) mentions that the gravest effects of climate change may well be those on human migration as millions of persons are displaced by shoreline erosion, coastal flooding, and agricultural disruption.

The United States and many other developed countries have another type of environmental refugee -- those affluent individuals choosing to live in areas comparatively unaltered by human society. These affluent environmental refugees may be doing considerable cumulative damage to the integrity of natural systems by picking relatively wild areas and altering them by building roads, power lines, sewer lines, and water lines.

When the carrying capacity question is asked in a global rather than a local context, it is transformed into a new question about limits to human ingenuity given a fixed ultimate energy source: solar input. Many people believe that technological progress can ameliorate limits for an extended time, and, indeed, there are foreseeable technological fixes that could conceivably expand the carrying capacity of the earth. For example, the next agricultural revolution might be facilitated by genetic engineering of more efficient food crops. However, the raw material for genetic engineering is biodiversity. Scientists can move genes, but they cannot make them. If current rates of species loss are unabated, most of the raw material for genetically improved foods, fuels, and pharmaceuticals are lost with them. Thus, disparate parts of the global change picture interact in unpredictable ways.

The ultimate existence of limits seems hard to dispute given the fixity of solar inputs, but the timing for reaching those limits can be predicted only with uncertainty.

**Ecosystem Services**

Natural systems provide many services to human society either free of charge or with minimum management effort. These have been touched upon throughout this discussion but deserve more explicit attention. Examples of such ecosystem services (e.g., Westman, 1978; Wilson, 1988) are:

1. the capture of solar energy and conversion into biomass which is used for food, building materials, and fuel.

2. the decomposition of wastes such as sewage.

3. the regeneration of nutrients in forms essential to plant growth (e.g., nitrogen fixation).

4. the storage, purification, and distribution of water (e.g., flood control, drinking water purification, transportation, etc).

5. the generation and maintenance of soils.

6. the control of pests by insectivorous birds, bats, insects, etc.

7. the provision of a genetic library for development of new foods and drugs through both Mendelian genetics and bioengineering.

8. the maintenance of breathable air.

9. the control of both microclimate and macroclimate.

10. the provision of buffering capacity to adapt to changes and recover from natural stresses such as flood, fire, pestilence.

11. the pollination of plants, including agricultural crops, by insects, bats, etc.

12. aesthetic enrichment from vistas, recreation, inspiration.

These ecosystem services are essential to the human quality of life. If natural systems are no longer able to provide these services, they will have to be replaced through human engineering. Currently, society is unprepared to do so. In Biosphere 2, the cost of providing these ecosystem services through human engineering was a staggering $9 million per person per year (Avise, 1994).

These ecosystem services have been characterized as environmental interest — they are the payoff for maintaining environmental capital (i.e., the structures of natural systems). The economic analogy continues — if one dips into capital by destroying wild habitats, a loss of interest can be anticipated. Present knowledge of the ecosystems delivering these services is not sufficiently robust to enable a reasonably reliable prediction of what the consequences will be in delivery of services if 10%, 15%, 35%, or 50% of the earth's present habitats or species are lost. Neither does society know the degree to which managed systems supply ecosystem services comparable to natural systems. In addition, at the same time that environmental capital is being replaced with very different structures, human population is growing. The consequence is that the amount of ecosystem services per capita is plummeting.

The term **sustainable use** is common these days, and the conditions for attaining this state have been defined in broad strategic terms (Huntley *et al.*, 1991; Lubchenco *et al.*, 1991; Risser *et al.*, 1991). For example, Huntley *et al.* (1991) include, under sustainability, equity and coexistence with other species and components of mankind's heritage in a biologically and culturally diverse world. The ecological research agenda to support this has been summarized in Lubchenco *et al.* (1991) and Risser *et al.* (1991) and prioritizes research to understand changes in climate and its effects on ecological processes, patterns and interactions with biological diversity, and breaking points at which ecological systems are no longer sustainable. An example of the various degrees of sustainable use is provided by Stickney (1994), who discusses the varying degrees of dependence upon hatcheries for replenishing natural stocks of fishes. He notes that this can vary from near total dependence to elimination of hatchery programs.

Of course, equating sustainable use to a set of steady-state, ecological conditions is naive. Holling (1986), Odum (1989), and many others have pointed out the dynamic nature of ecosystems and the low probability of long-term, steady state conditions. Constant adjustments must be made by human society to accommodate episodic stresses on natural systems. For example, during extremely low flow conditions, withdrawal of water cannot simply be set at the same levels as during normal and high flow periods. Sustainable use almost certainly means paying close attention to the condition and health of the system being used and not over-stressing it even if this means ceasing or reducing use for substantial periods of time. Sustainable use will also mean adjusting the $I = P \times A \times T$ equation (environmental impact = population X affluence X technology) so that the multiplicative impact of these three attributes of human society remain at a level that will not harm the integrity of ecological systems.

## Coevolution in the Absence of Strong Selective Forces

Coevolution in natural systems between one species and another is often the result of harsh penalties exacted in those individuals or components that do not respond adequately or with sufficient rapidity to alteration in the other components. In the absence of strong selective forces like famine and disease, what forces are likely to change human behavior? The coevolution of human society and natural systems will be less stressful if rapid information systems are developed to alert society to needed changes that are coupled with a sufficiently high environmental literacy to accept the necessity to make the changes before the price of not doing so has gotten too high.

People are most affected by failures in ecosystem services that are intense, local, and immediate. However, as an environmental problem increases in intensity, spatial extent, and temporal extent, it is more difficult to experience directly or personally. In addition, cause-and-effect relationships become less obvious, more uncertain, and, therefore, less likely to motivate action. These are typical features of global environmental issues. Skinner (1983) suggests that people are unlikely to change their behavior on the basis of information or advice alone. Behavioral change is even more unlikely if the information is about a distant, future, or remote event; change is more likely if information from the particular source has lead to beneficial consequences in the past. As such, operant learning is unlikely to change behavior relevant to global issues (e.g., Ornstein and Ehrlich, 1989), and it may be quite difficult to change behaviors without some strong, unpleasant, concurrent pressures. Tools to change behavior using only weak selective forces include economic incentives, environmental education, and systems of ethical or religious belief.

**Environmental Economics**

Economic forces are a proven system for providing rapid feedback necessary to change collective human behavior in absence of strong, selective pressures on human biology directly. However, in order to promote the coevolution of human society with the natural world, the true environmental costs of human activities have to be expressly included in all economic analyses. This has not been the case to date. Instead, environmental costs have been relegated to the category of externalities; futures are discounted, natural resources (i.e., ecological capital) are not depreciated, and the economic costs of waste products are not assessed. Recent work has greatly improved the ability to include legitimate environmental considerations in economic analyses (e.g., Costanza, 1989).

Even so, economic selective pressures cannot function if they are circumvented by governmental policies or other "social traps" (Costanza, 1987). One of the most dramatic illustrations of a failure in human cultural adaptation to a biogeochemical cycle is the continued insistence on floodplain construction in societies where alternative options are open. Without enormous government subsidies, people would not be so eager to live on floodplains. Similarly, irrigation water in some of the western states would not be so cheap if government did not subsidize both the building of dams to collect the water and the construction of pipelines and canals to transport it to places where it would not normally occur. Government has also encouraged deforestation and mining of government lands, which might not have occurred in the way it did had these lands been in private ownership. The C38 Canal dug along the Kissimmee River probably would not have been built had private funds been necessary in its construction.

On the other hand, there is some evidence that current economic systems recognize the value of some ecosystem services. Cost considerations have promoted the use of tools from natural systems rather than relying on entirely technological solutions to modify environmental selective pressures. More intensively managed ecosystem services provide an alternative, and often cheaper, method of providing for human needs. Examples include the replacement of chemical technologies by artificial wetlands to treat many kinds of wastes, such as sewage, acid mine drainage, urban runoff, etc. (Hammer, 1989). Strategic planting of trees may save 200 billion kilowatt hours annually in the United States through modifying microclimate (Akbari *et al.*, 1992). There is also some movement toward the restoration of damaged ecosystems to provide for ecosystem services lost and missed by human society. The restoration of the Kissimmee River in Florida is perhaps the best known example (NRC, 1992b). This Restoration Demonstration Project, begun in the late 1980s, looked at techniques and the feasibility of restoring some of the ecosystem services lost when the Kissimmee was channelized, such as restoring hydroperiod, water quality, and habitat for fish and birds in the Kissimmee and the Everglades. The NRC report (1992b) that summarizes this and a number of other illustrations of restoration of aquatic ecosystems provides both guidance and inspiration for such efforts. I had the privilege to serve on the NRC committee that prepared this report and was struck by the enthusiasm and justifiable pride of all those involved with the restoration projects that the committee visited. This trend toward returning to managed, natural systems as the technological fix of choice can be seen as a form of benign coevolution between the environment and human society. Both are modified to increase chances of survival.

**Environmental Literacy**

Increasing environmental literacy may also affect human behavior in the absence of strong selective forces. Some questions inherent in the debates on global change are scientific: Is there a global temperature increase? Is this increase outside the normal operating range? How will this affect biotic interactions? Other questions are quintessentially political: How sure should society be before it expends scarce resources to mitigate a problem? Should society work or pay to protect other peoples, other species, future times? Who benefits? Who pays? Some of these questions are discussed in more detail below. However, clearly, in order to be able to participate in the public debate about the proper course of action, the general public needs access to relevant scientific data as well as political points of view. The shareholders in the system especially need to understand the scientific process and how it differs from other human endeavors. Yet, the environmental literacy of even the college student population seems woefully inadequate (Wallace *et al.*, 1993).

Science does not prove things, but instead fails to disprove them at some predetermined low level of uncertainty. This is in contrast to legal concepts of reasonable doubt. The quality of scientific studies is variable, and some are poor; however, when many studies from different researchers provide independent lines of evidence leading to the same conclusion, this constitutes strong evidence. When the weight of scientific evidence supports a hypothesis, every alternative does not deserve equal time or media attention. This contrasts with the equal time provision for political parties on television. When scientific information must be applied to an environmental problem that occurs at a larger temporal or spatial scale than humans can practically investigate, models to extrapolate across scales must be constructed. These models will always involve uncertainty. For every chosen course of action, there are trade-offs: if managers are intolerant of modeling uncertainty and postpone mitigation, it implies a tolerance of risk that may be exaggerated. The appropriate levels of tolerance for both uncertainty and risk are properly part of the public debate. In addition, the uncertainties of the scientific extrapolations are often presented explicitly, while the uncertainties of economic extrapolations are hidden.

**Environmental Ethos**

Clearly, moral or ethical components must be included in the debate on global change, but I suspect the number of issues in this category will decrease as clear scientific data demonstrate human dependence on natural systems and the simple self-interest at play in preserving them. Ethical questions fall into several categories: Do wild systems have intrinsic value? Does society owe anything to future generations? How much should individual freedoms or properties rights be sacrificed for preservation of the common good? How much geographic and temporal equity should there be in the distribution of environmental costs and benefits? VanDeVeer and Pierce (1994) provide a discussion of some of these issues. Certainly, it is difficult to deny humans, who are living on less than $1 per day, the opportunity to clear tropical rain forests for agricultural purposes or to deny housing for the homeless in order to prevent the loss of a single wetland.

There is evidence that communities of religious beliefs have served as the cultural transmittor of important local ecological information and have protected and distributed ecological services. Stevens (1994) provides examples of this concept. In Bali, rice temples had for centuries scheduled irrigation water rotations and planting cycles for competing farmers. These schedules were abandoned during the early introduction of green revolution techniques. However, in the presence of intervening problems with pests and insufficient water supplies, the original schedules have been found to be optimal, even with new high yielding varieties of rice. In Benin, West Africa, seasonal religious restrictions on fishing techniques preserved the health of aquatic systems. Enlisting both the intimate knowledge of the local ecosystem and the influence of local religious institutions has proven to be an essential tool.

## What Next?

Where does the coevolution analogy for the relationship between human society and natural systems lead society? In one possible pattern of coevolution, human society continues to present strong selective forces to natural systems and natural systems may eventually respond with strong selective forces. This may lead to a sharing of the planet only with domesticated species and a few other extremely tolerant and persistent species (i.e., pests) that have defied human management efforts. Because there will be little redundancy in species function left, any new pest or disease could cause severe fluctuations in food crop yields or pest control. This pattern is analogous to the recognized pattern of coevolution in host and parasite referred to as the arms race (Thompson, 1986) — the host develops some defense against infection and the parasite counters it and becomes more virulent, etc. Odum (1992) has also suggested the parasite-host model for the interaction between man and the biosphere. However, he points out that the most successful parasites reduce their virulence and establish some rewarding feedback that benefits their host to survive over the long term. Otherwise, the demise of the host means the demise of the parasite as well. In addition, as resources become strained (and humans already appropriated nearly 40% of the products of photsynthesis a decade ago; Vitousek *et al.*, 1986), mutualism, in which both partners benefit, becomes a more effective strategy for survival. Mutualism would require tempering the strength of the selective pressures and responding rapidly to changes. Human society could temper their virulence and respond quickly to changes in natural systems by establishing feedback loops. The current attention to a biomonitoring system for ecosystem health in one approach to developing this feedback loop (Costanza *et al.*, 1992).

While human culture will continue to respond to strong selective forces such as famine and disease, the pattern of coevolution cannot be shaped by weaker selective forces if they are obscured by imperfect cultural devices. Many of the changes currently proposed in the environmental economics and green engineering address these shortcomings. John Cairns, Jr. and R. M. Harrison summed up some of the changes that will foster mutualism between natural systems and human society in their revised foreword to the Chapman and Hall Environmental Management Series, for which they are co-series editors (statement reproduced with permission of Chapman and Hall):

*Focus is now shifting from the toxicological aspects of waste disposal to the larger issue espousing a transition to new resource use policies that: conserve natural resources and energy for long-term sustainable use; minimize ecological damage during the extraction of raw materials; minimize wastes during production and recycle as much as possible of the wastes produced; facilitate the reincorporation of the product into natural systems at the end of its life cycle; use wastes from one production process as inputs (i.e., raw materials) in some other production process (e.g., municipal sludge to agricultural production). There is a concomitant shift from merely preventing observable deleterious effects from potentially toxic materials to enhancing ecosystem health and condition.*

While wild systems must always be valued and maintained, it is where human society and complex ecological systems modified by humans co-exist that we need to spend more time working on a mutually beneficial relationship.

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