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Commentary

One world, one experiment: addressing the biodiversity–economics conflict

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Abstract

The self-organizing principles of markets that have emerged in human cultures over the past 10000 years are inherently in conflict with the self-organizing principles of ecosystems that have evolved over the past 3.5 billion years. The rules governing the dynamics of ecosystems, within which all human activity takes place, are ultimately a function of biological laws, not a function of human-created economic systems. The conflict between these systems is illustrated by the fact that economic indicators have shown vigorous growth during the last century while a variety of environmental indicators have exhibited negative trends. Ultimately, however, the growth of human economies faces the constraints that limit all biological systems. In this article we outline the bases for the conflict between biological and economic activity and suggest policy approaches that will enhance the chances for creating cultures that are economically and environmentally sustainable.

Keywords: Biodiversity–economics conflict; Biological limits; Discounting; Market economy

1. Introduction

Without exception, life on Earth has evolved within the constraints of chemistry and physics. In addition to these physical laws, the evolution of life forms and biological processes gave rise to a number of biological laws. Some of these biological laws are well understood while others are only beginning to be comprehended. For example, it is well established that organisms are precise arrangements of molecules that maintain and generate order by utilizing energy flow (Schroedinger, 1944). On the other hand, we are only beginning to understand how the stability of an ecosystem, and the population sizes within an ecosystem, are a function of complex interactions among abiotic and biotic relationships (Wilson, 1992; Naeem et al., 1994; Pimm, 1994; Tilman and Downing, 1994).

Of all the environmental crises threatening the long-run prospects for the human species, the loss of biodiversity is the most irreversible. For example, the ozone layer should eventually recover, greenhouse warming should eventually reverse, and the human population will eventually decline. The species richness, genetic diversity, and biological integrity we are now losing, however, will not recover within the time *Homo sapiens* exists since the recovery from past major cataclysmic extinctions

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took from 20 to 100 million years (Wilson, 1992). Biodiversity encompasses all of the species that currently exist on Earth, the variations that exist within each species, and all of the interactions that exist among all of these organisms and their biotic and abiotic environments as well as the integrity of these interactions. *Homo sapiens* evolved within, and as a part of, the thick mantel of biodiversity that now exists, and has thrived. As Wilson (1992) and many others have convincingly argued, human activities are currently causing the sixth major biodiversity extinction of the past 500 million years.

It is our belief that economic policies should be adopted that are consistent with sustaining biodiversity and the services it provides. We argue that there is an irreconcilable conflict between environmental sustainability and the material growth and the functioning of the market economy. [1] As we discuss below, the overall economic value of biodiversity is extremely high though unmeasurable. Even the most efficient economic use of biological resources, as judged solely by market criteria, will continue to degrade these resources if not checked by enlightened cultural behaviors and appropriate government policies.

2. Humans pushing biological limits

Population dynamics are a consequence of biological potential and environmental resistance (Pimm, 1994). Biological potential is theoretically unlimited. For example, under ideal conditions one bacterium could increase to 2.2×10^{43} bacteria in 48 hours with a mass of over 100 times that of the Earth. Evolved behavioral patterns in association with environmental resistance, including climate, abiotic resources such as water and nutrients, and biotic factors such as parasites, predators, and competition for resources, prevent an organism from realizing its biological potential. In a dynamic fashion environmental resistance creates at any given time a limit for the population size of a given organism. In general, under a particular set of conditions, an ecosystem often supports some finite number of a given species on a sustained basis because there is a balance between population size and available resources. When this number is exceeded, some component of the environmental resistance will lead to a reduction. Although the kinetics of this reduction vary, large-animal examples are informative. In 1944, 29 reindeer were introduced onto St. Matthew Island off the coast of Alaska. With no predators and abundant food sources, the population grew in the next two decades to over 6000 and then, as a result of starvation, the population crashed to a size of fewer than 50 (Klein, 1968). The same phenomenon occurred in the deer population of the Kaibab National Forest in Arizona. The original deer population of 4,000 swelled to over 100000 in only 18 years after almost all predators were exterminated, then fell abruptly to less than 10000 due to starvation and disease (Worster, 1977).

Our species, *Homo sapiens*, has been around for something less than a million years. For at least 95% of this time we lived as hunter-gatherers more or less in equilibrium with the biological world. Although early humans undoubtedly were a major force in local ecosystems, as any large species is, various lines of evidence indicate that humans started having a substantial detrimental effect on local ecosystems only after the adoption of agriculture as a way of manipulating species and ecosystems for their use (Ponting, 1991). So long as a population size was small in relationship to the resources available, biological laws allowed for the existence and growth of the human population and its material culture. In the past, however, a number of regional human cultures exceeded the capacity of their ecosystems to provide for their needs as a consequence of both human activities and natural cycles (e.g., the Akkadian, Easter Island, Mayan, and Sumerian cultures) (Ponting, 1991). As a result, the complexity of these cultures as well as their populations declined. The adoption of fossil fuels as our major source of energy moved us further along the path of relying on stocks of natural resources rather than renewable flows and ushered in a new era of environmental exploitation and degradation (Georgescu-Roegen,

[1] We use the word "market" in the broadest sense of the term. We recognize that planned as well as free economies have impacted negatively on the environment. We also appreciate the distinction between "growth" versus "development" made by numerous people. See, for example, Daly (1977) and Orr (1992).

1971; Gowdy, 1994). As we now move from regional economies to a global economy, there are many indications that our economic systems are pushing the capacity of the biosphere to sustain the current level of human activity.

2.1. Humans pushing limits of available energy flow

Essentially all life on Earth, including human life, is a direct or indirect function of solar energy. Several types of calculations have been made to estimate the maximum human population the Earth can support. [2] Vitousek et al. (1986) calculated that humans are directly or indirectly using almost 40% of the potential terrestrial products of photosynthesis. Based upon solar energy flow, efficiencies of conversion, and a number of other factors, Kraushaar and Ristinen (1993) estimate that the world has enough arable land to support a population of 10.6 billion people. Even without the complex assumptions and energy conversions they employed, this estimate seems reasonable based upon the potential availability of about 8 billion acres of arable land and our current use of about 3.5 billion acres of the best quality arable land to support 5.5 billion people. Using the numbers in Kraushaar and Ristinen (1993) and calculating from a total energy capture in the world by photosynthesis of 40×10^{12} watts, we estimate that the maximum human population would be about 16 billion persons if all photosynthetic products were directed toward human food alone. [3]

All of these unique calculations give essentially the same numerical answer. Such coincidence indicates that the Earth might be able to accommodate, albeit unsustainably and briefly, an upper limit of between 10 to 15 billion *Homo sapiens*. Using a variety of methods, many others have arrived at the same general conclusion: regardless of the exact number, we are near or past the sustainable population limit (Ehrlich and Ehrlich, 1990; Daily and Ehrlich, 1992; Meadows et al., 1992; Kendall and Pimentel, 1994). Although some have proposed that future technologies and different resource use patterns might increase the upper theoretical limit of energy use and therefore population size (Simon and Kahn, 1984), our position is that policies should be based upon current knowledge, feasible technologies, recognized patterns of human behavior, and environmental sustainability.

2.2. Human displacement of other species significant and accelerating on a global scale

The growth in the number of humans on the planet has been accompanied by a decline in the numbers of other organisms. Human-caused, worldwide environmental disruption, especially habitat destruction via deforestation, is now placing a large fraction of the earth's biodiversity in danger of extinction (Myers, 1979; Wilson, 1992; Ehrlich and Wilson, 1991). Crude calculations indicate that the extinction rate has increased from an historic base level of about one species per year to thousands per year. In the past two millennia humans have been the primary cause of the extinction of about 2000 species of birds worldwide or about 20% of the extant species, and another 1000 are endangered (Wilson, 1992). If current trends in tropical habitat destruction continue, by about 2020, 10–20% of all tropical species will be extinct. The consequences of this ongoing mass extinction for the planet are unknowable, but are likely to be very negative for human cultures.

2.3. World-wide human impact on natural atmospheric cycles and natural resources accelerating

Over the past several hundred years, especially during the last hundred, our economies have dramatically altered the surface of the planet and are now

[2] Each calculation is based upon a different set of living standards ranging from our current mix of living standards to only the provision of food calories sufficient for minimal activity. It is clear that high rates of consumption and high birthrates are both environmentally detrimental.

[3] 40×10^{12} watts equals 3.0×10^{20} cal/year [(40×10^{12} J/s)(1 cal/4.2 J)(3.5×10^{7} s/yr)]. Assume a food yield of 5% from total photosynthate or equal to the yield of an Iowa corn field [(3.0×10^{17} kcal/yr)(0.05) = 1.5×10^{16} kcal/yr]. Assume average human caloric needs to be 2580 kcal/day or 9.4×10^{5} kcal/yr or that required for working in an office 12 h/day and sleeping 12 h/day. Maximum number of people would be about 16×10^{9} or 16 billion [(1.5×10^{16} kcal/yr) divided by (9.4×10^{5} kcal/yr)]. Other estimates of the total world photosynthesis are as high as 100×10^{12} watts which would increase the maximum number of humans to 40 billion.

influencing global biological, chemical, geochemical, and physical processes (Turner et al., 1990). We have been a major factor in the rise of atmospheric CO_2 concentration from 0.029% to over 0.035% in less than 100 years, and we will most likely push the CO_2 level much higher (Walker and Kasting, 1992). Many predict that this, and increases in other greenhouse gases, will lead to global climate change. Human-synthesized chlorofluorocarbons now in the upper atmosphere are providing breakdown products that are catalyzing the destruction of stratospheric ozone with the consequent increase in life-threatening UV-B radiation at the Earth's surface (Kerr and McElroy, 1993). This increase in UV-B may explain, at least in part, the worldwide decreases in the populations of many amphibians (Blaustein et al., 1994). Current data indicate that on a global scale fisheries are in decline and that soil erosion, desertification, salinization, and water-logging are decreasing soil fertility in many places throughout the world. Accompanying these global changes are our alteration and simplification, on a world scale, of ecosystems. The consequent destruction of a large percentage of the earth's natural habitat drives species to extinction. It is the relative stability of natural cycles and processes (e.g., carbon cycle, water cycle, UV-B filtering, soil fertility) that, in the long run, enable humans to feed, clothe, and shelter themselves.

The overriding reasons for these and other negative environmental trends is the growth of both the human population and the per capita economic output. The world's population has doubled since 1950, and mathematical calculations indicate it should double again by the year 2037 (World Data Sheet, 1994). In recent decades population growth has been accompanied by an even faster growth of the world's economic output; it has more than doubled since 1970 (World Development Report, 1994). The divergence of environmental and economic indicators is a consequence of the fundamental conflict between biological laws and the rules that govern market decisions.

3. Markets and the environment

Decisions concerning resource use are now driven by world markets. The advantages of competitive markets in allocating resources based on decentralized decision-making are well-known (Friedman, 1962; Samuelson and Nordhaus, 1992). When it comes to insuring that the human economy is sustainable, however, market systems have serious, potentially fatal, shortcomings. Ecosystems change through time, and evolve quasi-stability over time periods measured in hundreds to thousands of years, a time scale well outside the decision framework of individual humans or even of human cultures. Market exchange and economic activity, however, are driven by individual decisions made at a given point in time.

The standard economic view of biodiversity loss is that it is simply a result of a market that does not function properly because biodiversity has not been appropriately priced. Thus, most economists contend that if the proper prices were assigned to environmental goods such as species, the market would allocate them in an optimal way. Many critiques of this position have been written by economists, ecologists, and environmental philosophers (Sagoff, 1988; Daly and Cobb, 1989; Wilson, 1992; Gowdy and Olsen, 1994). Some criticize the assumption that the only criterion for the use of the environment is how it affects human interests. Others focus on the unrealistic conditions for optimal use by competitive markets. In our view the central problem is the impossibility of assigning one "correct" price to an environmental good such as a species or a service provided by an ecosystem (Georgescu-Roegen, 1971; Gowdy, 1994).

Ecosystems are complex organizations with myriad checks and balances and with many hierarchical levels of interacting influences. Though market systems are also hierarchical and complex, the use of resources by markets is dictated by a single criterion, namely relative price. The price of a good or a productive input is a single-dimensional function which is assumed by most economists to be capable of containing all the relevant information necessary to make correct choices about resource use. The environmental policy recommendations of most economists focus on ways to force relative prices to reflect the "true" value of environmental goods. Economists may recognize use values, option values, or existence values, but most still assume that there is a single price capable of reflecting the true social value of an environmental good. [4] We recognize that adjusting prices to reflect environmental costs and assigning property rights where none exist would move us toward a more rational use of biological resources, but it would not move us to an environmentally sustainable society for the following reasons.

3.1. Market efficiency independent of scale

The market is a mechanism by which individuals in the economy use relative prices as a guide for allocating scarce resources. A properly functioning market will allocate a given amount of economic goods or productive inputs to their most efficient use. Nothing in the information contained in relative prices, however, indicates the scale of economic activity vis-a-vis the capacity of the environment to support that level of activity. [5] To describe market allocation, Herman Daly (1992) uses the analogy of loading a boat. A properly operating market will insure that the economic "boat" is loaded evenly so that it is level as it sinks lower and lower into the water. In the economy nothing is analogous to the Plimsoll line on a boat that indicates how much weight the boat can take without sinking. Many environmental indicators, however, show that the Earth's biological systems are in distress. This distress is most clearly reflected in the accelerating rate of the biodiversity loss mentioned earlier (Myers, 1979; Ehrlich and Wilson, 1991; Wilson, 1992).

Market outcomes are driven by the uncounted millions of decisions made by individual producers and consumers. The environmental impact of each decision taken by itself is, in almost all cases, negligible. An individual decision to eat, or not to eat, a hamburger made from beef grown on land that was formerly rain forest has no measurable impact on the destruction of rain forests for cattle ranches. The collective impact of such decisions, however, is huge. To make matters worse, there is no short-term, negative feedback to the individuals from the economic system that could bring about corrective behavior (Hardin, 1968). In the long run incremental environmental damage does create negative feedback. For example, there is no longer a significant Hudson River fishery, nor do we plough or graze cattle to the same extent we did in the past on the marginal lands of the southwestern United States because these ecosystems could not tolerate the imposed level, and kind, of human activity while maintaining the biological processes that made them economically productive (Leopold, 1991; Glantz, 1994).

3.2. Process of discounting incompatible with environmental stability

Market decisions are made by individuals at a specific point in time. For individuals with a finite life span, impatience and uncertainty about the future are powerful motives to use resources now rather than at some later date. [6] This is reflected in market prices because an individual will be willing to pay a certain price to have an item now, and a lower price for that same item delivered sometime in the future. Goods and services to be delivered in the future are traded in today's market using prices based on their discounted present value. For example, if you were to pay \$100 for an item today and \$90 (today) for that same item if delivered in one year, the implicit annual discount rate would be 10%. The existence of discounting means that markets are extremely my-

[4] Many economists take this view even further by claiming that these prices will automatically be called forth if property rights are assigned to all environmental goods (Coase, 1960). This argument clearly exposes the basic assumption that human preferences, as reflected in market transactions, should be the only criteria for making choices about resource use. By this view, the validity of these preferences, or how they are formed, is not a subject for discussion (Stigler and Becker, 1977).

[5] Market exchange as described by neoclassical microeconomic theory is driven by relative prices. Consumers maximize utility by equating the price ratios of market goods to the ratios of their marginal utilities. Producers maximize output [or minimize costs] by equating the price ratios of productive inputs to their marginal products. The total available amounts of goods and inputs, and their distribution, are the starting points of economic analysis, not a derived outcome.

[6] In the past 50 years, western industrialized cultures have emphasized consumption which has exacerbated this tendency to use resources now (Durning, 1992). Thus, the strength of the motivation to use resources is culture dependent.

opic with respect to the welfare of future generations. [7]

If policy-makers intervene in a market to override market discount rates, perhaps in calculating a "social discount rate" for a development project such as a dam, a discounting dilemma still exists. If a discount rate of zero is used to evaluate the project, a near-infinite value will be given to any resource with a positive benefit, and this value means that none of it should be used. [8] Alternatively, with any positive discount rate the welfare of future generations is ignored.

The discounting dilemma shows that the problem of the use of irreplaceable biological resources has no purely economic solution. Under the logic of discounting it can be economically rational to hunt a species, such as the blue whale, to extinction. Economically rational decisions involving resource use made at a particular point in time by individuals with finite life spans may be totally irrational for the human species. Although the ethical problems associated with discounting the future have been long recognized and much discussed (Daly and Cobb, 1989; Gowdy, 1994), the complexity of the issue has not been sufficiently appreciated by policy-makers. Furthermore, appreciation of the ethical dimension of this issue does not guarantee ethical behavior.

3.3. Few substitutes exist for biological species, ecosystems and their services

In the case of unique biological resources, markets work in perverse ways. Since there are only limited economic substitutes for species like tigers, whales, or bluefin tuna, their prices increase exponentially as they become more and more scarce. This increases the incentive to hunt them, driving up the price even more as they are killed, until the animal is driven to the brink of extinction or, in fact, to extinction. The case of the bluefin tuna shows the striking difference between biological health, as measured in number of fish, and economic health, as measured in monetary value. The stock of western bluefin tuna has declined to less than 20% of its 1970 level while the real price has increased about 20-fold; a single fish recently sold for $83 500 (Seabrook, 1994). [9] A constant dollar measure of the western bluefin tuna stock indicates that its real value has actually increased in the past 22 years. What has been a biological loss shows up as an economic increase using conventional market criteria.

The same logic, though more complex, drives the destruction of ecosystems that contain economic value in the form of minerals, wildlife, wood, and land. In addition to these types of items, ecosystems also provide difficult or impossible-to-replace ser-

[7] The notion of discounting is one of the most thorny problems in economic theory. Economists distinguish between time discounting, which reflects the pure rate of time preference, and goods discounting, which is measured by the real interest rate. Pure time preference is only one of many reasons for a positive rate of interest (Pearce and Turner, 1990; Tisdell, 1991; Hanley and Spash, 1993). Many well-known economists including Pigou, Harrod, Myrdal, and Ramsey have argued on moral grounds against discounting the future. According to neoclassical economic theory, if the growth rate of capital stock is equal to the rate of discount, this justifies discounting the future. The stock of irreplaceable resources may be reduced, but future generations are compensated by the increase in productive potential that comes with the increase in capital. This is referred to as the "weak sustainability" criterion. This view may be justified in the case of exhaustible resources such as minerals for which technology may be able to provide substitutes, but in the case of biodiversity substitution possibilities are problematic. We serve future generations best by preserving their options for sustainability. Future generations will undoubtedly have value systems different from our own and we should leave them the greatest leeway to reject our choices (Johnson, 1994).

[8] Dasgupta (1982) has shown that even if we have zero pure time preference, future costs and benefits are still discounted if consumption is increasing through time. See the discussion in Hanley and Spash (1993).

[9] The estimated spawning biomasses of the western Atlantic bluefin tuna under three different assumptions about population mixing between eastern and western stocks are given in Holden (1994). The price of western bluefin tuna in 1970 was about $.20 a pound. By 1992, the price had skyrocketed to $14.00 per pound (NMFS, 1992). The real price increase, based on the Consumer Price Index, was about 19 times. As a result, the monetary value of the stock increased between 3.2 times with 0 mixing ($0.17 \times 19 = 3.23$), 3.8 times with 1–2% mixing ($0.20 \times 19 = 3.80$), and 7.2 times with 3% mixing ($0.38 \times 19 = 7.22$). So, with the most conservative estimate of the remaining stock, showing a decline of 83% in a little over 20 years, the economic value has increased over three-fold.

vices. For example, forests capture, and slowly release, huge amounts of water, thereby permitting long-term availability of water and preventing erosion (Durning, 1994). In addition, forests provide a local cooling effect primarily via transpiration, which in turn recycles enormous quantities of water. Taken all together these activities influence the microclimate. Similarly, the shell fish and other organisms in a healthy, rich estuary can filter a volume of water equal to that of the estuary in periods approaching a day, thereby maintaining clear and clean water (Kennedy, 1984). The cost of replacing such services, even if technically possible, are so high as to make them essentially irreplaceable. More to the point, however, is the fact that we do not know how to quantify these services comprehensively, in part, because many ecosystem services have not been explicitly identified.

It is also clear that species unknown to us now will provide unique products for human use in the future. Taxol from the Pacific yew tree for treating cancer, enzymes from leech saliva employed to dissolve blood clots during surgery, and a plant terpene, artemisinin, that shows promise for the treatment of malaria are several examples (Wilson, 1992). When species go extinct, their potential use will forever remain unknown and unavailable.

3.4. *Price information about environmental features always deficient*

A necessary condition for an efficiently operating market is that all producers and consumers be fully informed of the relevant characteristics of all goods and productive inputs (Friedman, 1962; Samuelson and Nordhaus, 1992). Reliable information about both the productivity of inputs and the utility derived from products consumed is critical if economic agents are to place correct relative prices on market goods. These relative prices dictate the allocation of resources in production and consumption. In the case of biological resources, as discussed above, a lack of information exists as to their complete value. Thus, the market cannot place reliable prices on these resources. In addition, the wastes from production and consumption are returned to the environment without considering the consequences for future production and consumption. Attempts to "internalize" environmental "externalities" will fail if it is impossible to assign correct market prices to these "externalities."

4. Policies for the preservation of biodiversity [10]

In spite of the fact that a conflict exists between the preservation of biodiversity and the scale of the human economy, it may be possible to continue our present course for years before the degradation of the environment shows up in traditional market measures of economic activity. Sooner or later, however, the expansion of human-created economic systems will be constrained by biological laws because the human economic enterprise cannot exceed the limits that all biological systems obey. Why can't science predict when the downturn is going to occur so that corrective actions can be taken? Unfortunately the biosphere is too complex and interactive—perhaps even chaotic—for precise predictions (Gleick, 1987; Pimm, 1994). Even for issues such as global warming, ozone depletion, or the loss of biodiversity, the timing and consequences are controversial. When controversy is strong, the politics and social structure of the scientific community first decide which position is supported, and only later does the science establish what appears to be an "enduring" truth (Collins and Pinch, 1993). Thus, by the time we know what is going to happen in these complex environmental situations, it will most likely be too late to take meaningful corrective action.

Why should we preserve biodiversity? The more biodiversity we destroy and the more irrevocably we change the biosphere, the more we limit our choices for the future. Consider a deck of 52 playing cards as representing the Earth's current biodiversity, and let the human uses of, and the services provided by, biodiversity be represented by all of the card games

[10] We do not attempt to consider how these policy recommendations will be implemented or the cultural changes that may be required. It is apparent that changes in beliefs and values of the dominant cultures will be necessary for these policies to be implemented and successful. It is also clear that changes in social structure and organization will be required.

that could be made up.[11] During *Homo sapiens'* existence until recently, the number of cards has been virtually constant since the creation and loss of biodiversity normally occur at very slow rates. We are now randomly tossing out cards at an increasing rate, but essentially no new cards are being made. As we play our card games (i.e., use biodiversity, benefit by its services) with fewer and fewer cards, the games will become harder and more unpredictable to play (because we don't know which cards are missing) until it will be impossible to play some games because important cards, or too many cards, are missing. In the beginning, a few missing cards are not noticed. Each additional loss, however, leads to an exponentially greater impoverishment of the possibilities.

At the lower end of complexity (i.e., one to about 20 species not including micro-organisms), scientific evidence now indicates that ecosystem stability and productivity are a function of species diversity. Small ecosystems with more species are not only more able to tolerate stress, but also more able to recover after stress, and ecosystem productivity increases as a function of increasing biodiversity (Naeem et al., 1994; Tilman and Downing, 1994).[12] Scientists have been unable to study higher levels of complexity; however, evolution appears to have favored constellations of organisms that interact over time to produce relatively stable ecosystems (Wilson, 1992; Pimm, 1994). Thus, as ecosystems become simpler, their stability, and in some instances their productivity, decreases. The recent human tendency has been to simplify ecosystems primarily through agriculture and resource management. Predictably, this tendency, coupled with the massive species extinction currently underway, will lead to greater and greater ecosystem instability. Extrapolation of current trends indicates that at some point the Earth will experience the loss or collapse of numerous ecosystems on a global scale, perhaps similar to the numerous, human-mediated, local ecosystem collapses that have occurred in the past (Ponting, 1991).

We have a serious dilemma. The scale and nature of our current economic system are rapidly eliminating biodiversity, and we need some unknown fraction of it to maintain the Earth as a place that will support our cultures. To be certain that we preserve enough, the solution is quite obvious—save everything.[13] With growing development pressure and the almost exclusive policy emphasis on economic growth, this will be impossible in the near future. Thus, the best we can do now is to have biodiversity preservation policies that have two related, long-term objectives: first, setting aside certain areas and environmental resources that are off-limits to economic exploitation, and second, requiring those areas and environmental resources that will be economically exploited to be used according to policies that will insure their sustainability. In essence, we must decide both to use some smaller fraction of the world than we currently use, and to use it more efficiently, and also to keep a larger portion free of unrestricted market forces.

4.1. Protect and expand existing wild areas

It is important that large tracts of land be taken out of the market so as to remain in, or be returned to, a status that is essentially free of human economic exploitation, thereby permitting the existence of complex ecosystems and reserves of biodiversity. There are precedents for this position. Costa Rica has set aside about a quarter of its land as wildlife preserves and seeks to do more while Paraguay proposes to do much the same thing. The recent treaty placing Antarctica off-limits to exploitation establishes the commitment of the international community to exclusion as the only way to guaranty

[11] The germ of this analogy came from a conversation CNM had with his son as they walked on the day before Stuart left for his Peace Corps assignment in Paraguay.

[12] Human-created agricultural systems that consist of one to several plant species can be highly productive; however, these contrived ecosystems rapidly collapse without substantial labor and other inputs.

[13] Few would care if the remaining vials of small pox virus were destroyed. This is, however, a rather simple case since small pox virus only lives in human cells. For other organisms, like wolves, spiders, rattlesnakes, dandelions, and fruit flies, the situation is less clear because these organisms serve functions in highly evolved and interactive ecosystems. Although their removal will lead to some predictable changes, other changes will be unknown and unpredictable.

preservation. For 70 years in North American wildlife management, we have deliberately removed wildlife from the private market and strictly regulated its use. The end result has been the preservation of wildlife and the development of a $70 billion dollar industry (Geist, 1994). It is clear that the 3.2% of the Earth's land area currently set aside in national parks (Reid and Miller, 1989) is insufficient for the survival of biodiversity. The Wildlands Project for North America offers a long-term vision of the kind of approach we might take for the preservation of biodiversity (Mann and Plummer, 1993). An analysis of northern river systems has led to similar recommendations being made for biodiversity preservation (Dynesius and Nilsson, 1994).

The cultural decision to restore the Everglades is providing us with many insights on how to remove human intrusion and expand natural habitat (Davis and Ogden, 1994; Walker and Solecki, 1994). For example, the data clearly establish that the only way to prevent land-use changes that ultimately result in habitat destruction is to prevent any use changes not only in core areas, but also in buffer and transition zones. The several-decade-long controversy over the old-growth forest in the Northwestern United States has provided us with many policy lessons for how to go about the preservation of biodiversity (Booth, 1994; Yaffee, 1994).

4.2. Sustainable use of the resources we choose to exploit

In those disturbed ecosystems where we will exploit biodiversity, the policies dictating its use must be compatible with the best scientific and economic procedures for sustainable use. An enormous amount of biodiversity is found in our agricultural and forestry systems. If these systems are to remain highly productive, they must be managed in ways that are compatible with the preservation of this biodiversity (Pimentel et al., 1992). Historically our attempts to exploit forests, fisheries, range land, and farm land in a sustainable way have fallen short of success (Ponting, 1991). The collapse of numerous fisheries is testimony to our inappropriate and ineffective policies. Many of our failures have been a consequence of the assumption that biological resources were unlimited. The past has, however, provided us with a wealth of scientific information that can be used to achieve sustainable resource use. Economists will have to imperfectly employ use values, option values, and existence values to price environmental goods sufficiently high so that degradation rates do not exceed rates of restoration. In formulating policies, as the economist Joan Robinson remarked, the market may be a poor master, but it can be a useful servant. Incentive-based regulation such as marketable pollution permits, ending subsidies for environmentally destructive activities, adoption of the polluter-pays principle, and the bubble concept should be used, whenever possible, to achieve environmentally sustainable use. With the full knowledge that resource bases will collapse if overexploited, we should be able to employ the best knowledge, including the best science, to develop sustainable use policies (Booth, 1994; Yaffee, 1994). History makes clear that it is imperative that these use policies also take into account uncertainty and human behavior if we hope to be successful (Ludwig et al., 1993; Schnaiberg and Gould, 1993).

Policies must be adopted that will greatly reduce those human activities that are affecting global changes, such as stratospheric ozone depletion, increases in greenhouse gases in the atmosphere, and development that destroys natural habitat. These activities, in the long run, have a high probability of causing a substantial reduction in the Earth's biodiversity even in areas outside of the zones of economic activity. As choices are made between extinction of biodiversity and human consumption, we must favor biodiversity. To do otherwise at this point in the sixth major extinction is to further reduce our chances of achieving sustainability. As the industrial world is re-developed and other parts of the world develop, there will be hard choices to make. The appropriate guiding principle in making these choices is the Safe Minimum Standard Approach or the Precautionary Principle (Ciriacy-Wantrup, 1952; O'Riordan and Cameron, 1994).

4.3. Reduce the size and impact of the human population

The number of people on the planet is directly correlated with the impact human economies have on biological resources and the functioning of ecosystems. As Bongaarts (1994) demonstrated mathematically, the population momentum is so large that even if we immediately achieved a replacement fertility rate of two children per woman (an impossible goal), the world's population would still increase to about 10 billion by 2100. As has been pointed out by many others, however, if we do not reduce the growth rate to at least zero in the very near future, then there is little hope that any of our other actions will lead to sustainable cultures. Thus, the most important and imperative policy changes we must seek are those that reduce human fertility.

A large and growing literature on human demographics contains numerous examples of programs and policies that have been successfully and unsuccessfully employed to reduce fertility (Fornos, 1987; Keyfitz, 1989; Ehrlich and Ehrlich, 1990; Daily and Ehrlich, 1992; Grant, 1992; Robey et al., 1993). It is clear that our failure to curtail the growth of the human population resides, to a large extent, in our unwillingness to accept it as the major problem it is. As we discussed earlier, our numbers are most likely beyond the number that the Earth can sustain for any period of time. Almost 200 nation-states and many more cultures and subcultures exist in the world. Reducing the human world fertility rate is a matter of influencing millions of individual decisions made by couples every day. No policy or set of policies will be effective in all cultures and for all couples. Clearly each nation-state, and its cultures, must evolve their own effective policies.

It is also well recognized that it is not the person *per se* who impacts on the environment, but rather the economic system in which the person acts. As Ehrlich and Ehrlich (1990) and others have often stated, the environmental impact of a person is a function of affluence and the technologies employed to achieve that affluence. Thus, for developing countries, policies must focus on dramatically reducing fertility while developing technologies and patterns of consumption that have minimal environmental impact. Developed countries, on the other hand, must focus on dramatically reducing the environmental impact of their affluence and technologies while achieving negative population growth as quickly as possible. Above all we should recognize that the rational goal is not to maximize the number of humans on the planet, but rather to maximize the quality of life and the chances for survival of our species for a reasonable amount of time.

5. Acceptance of the ecological perspective

A fundamental conflict does exist between the healthy functioning of the biosphere and the continual expansion of human-created economic systems. Biological laws will not change. It is clear that our currently expanding economic systems will change. We can be pro-active in effecting this change by revising our conceptual understanding of the world and adopting policies that reflect an ecological view, thereby assisting the evolution of our current dominant cultures into sustainable cultures.

It is important to understand that ideal policies for an ideal world are inappropriate; ours is not an ideal world. Additionally, we must adopt policies taking into account the fact that our future policies will be flawed as our past policies have been. Policies should anticipate the occurrence of unexpected outcomes and have built-in corrective possibilities. We also need to understand that it is not going to be easy to adopt policies that will put our economics on a path that does not conflict with ecological reality; however, the alternatives are certainly more unpleasant and clearly less desirable (Ponting, 1991; Homer-Dixon et al., 1993). History clearly indicates that biological laws will correct imbalances in rather unpleasant ways.

When all is said and done, we suspect that the greatest challenge before us is to recognize that we are subject to biological laws and that we have exceeded or soon will exceed the limits of sustainable resource exploitation and abuse. If and when we, as a world of numerous communities, do accept these understandings, we might very well create sustainable cultures. It is humbling to understand that we are merely just one component of the giant experiment being conducted on planet Earth. As others have noted—one planet, one experiment: there are no controls and the experiment will be run once.

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