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Determining desirable levels of ecosystem services *per capita*

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Abstract. Ecosystem services are the numerous, essential processes that natural ecosystems provide free to human societies. Examples include the maintenance of breathable air; the movement, storage, and purification of water; the breakdown of wastes; and the provision of food, building materials, and medicines. However, the exponential increases in human population and concomitant environmental destruction make it likely that the level of ecosystem services available *per capita* will decline. There are three possible scenarios. First, if present practices continue, ecosystem services *per capita* will surely decline. Second, if a no-net-loss policy is implemented for habitats and species, ecosystem services *per capita* will still decline due to increases in human population, but the declines will be less precipitous. Third, if habitat is restored (including concomitant ecosystem services) at a rate exceeding that of destruction, then, perhaps the current level of ecosystem services *per capita* can be maintained, or even expanded to provide increased levels of ecosystem services *per capita* to more of the world's people.

1. Introduction

In mid-1992, a joint statement by the officers of the Royal Society of London and the United States National Academy of Sciences entitled *Population Growth, Resource Consumption, and a Sustainable World* was released. Although this document restates the dangers of concomitant human population increase and environmental destruction, the stature of both the institutions and the signatories may renew attention to these important problems.

The report notes that a rapidly growing population and the pressure to establish economies, especially in developing countries, are leading to substantial and increasing damage to the local environment. This damage results from direct pollution from energy use and other industrial activities, as well as by activities such as forest clearing and inappropriate agricultural practices. In addition, the report notes that some of the environmental changes may provide irreversible damage to the earth's capacity to sustain life. Less developed countries (LDCs) face overwhelming challenges in coping with their environmental and resource problems by themselves. In some areas where resources are administered effectively, development and/or population growth does not inevitably imply deterioration in the quality of the environment (Janzen, 1988).

The UNFPA brief report also notes that international action is necessary to cope with all of these problems, although, of course, local action is extremely important as well. Major attention is also given to the contribution of science. Relevant scientific topics include: development of new generations of safe, easy to use, and effective contraceptive agents and devices; development of environmentally-benign, alternative energy sources; improvements in agricultural production and food processing; further research in plant and animal genetic varieties; further research in biotechnology relating to plants, animals, and preservation of the environment; and improvements in public health, especially through the development of effective drugs and vaccines against malaria, hepatitis, AIDS, and other infectious diseases causing immense human burdens. Also needed is research on topics such as: improved land-use practices to prevent ecological degradation, loss of topsoil, and desertification of grasslands; better institutional measures to protect watersheds and groundwater; new technologies for waste disposal, environmental remediation, and pollution control; new materials that reduce pollution and the use

of hazardous substances during their life cycle; and more effective regulatory tools that use market forces to protect the environment. The world's biodiversity is also given attention, and the concluding statement notes that global policies are urgently needed to promote more rapid economic development throughout the world, more environmentally benign patterns of human activity, and a more rapid stabilization of world population.

As I read this excellent report, it seemed to me that one of the major issues not explicitly stated was the *per capita* ecosystem services that would be available under the various scenarios. Ecosystem services (Ehrlich & Ehrlich, 1991) include a variety of natural processes such as nutrient cycling, food chain support, the production of biomass (food, fiber), stabilization of waterways, and numerous other functions from the life support system that we take for granted.

The continuing global reduction in biodiversity is well accepted by mainstream science (Wilson, 1988). There is, however, considerable uncertainty about the effects upon ecosystem services (Ehrlich & Ehrlich, 1991) of this reduction in biodiversity. The existence of apparent functional redundancy is well established. For example, in aquatic ecosystems, a number of species perform similar functions such as grazers and filter feeders. Therefore, the loss of one species in one of these categories might be viewed as inconsequential if there are species remaining and available to carry out the same function (Walker, 1992). For example, Schindler (1987) and colleagues have found that the species residing in acid stressed lakes change well before any change in the functions can be detected as one species replaces the other. On the other hand, there is evidence to indicate that this view is somewhat simplistic. For example, in lakes and ponds, daphnids and copepods both filter planktonic algae, but the latter are more selective than the former. There is persuasive evidence (Douglass Distinguished Lecture by Nelson G. Hairston, Jr. at Rocky Mountain Biological Laboratory, June, 1992) that, under certain circumstances, they produce quite different ecological results. Additionally, my own research with protozoan colonization has shown that, although there may be representatives in major functional groups (Pratt & Cairns, 1985), ecological conditions at a particular site may only be appropriate for a relatively few species at any one point in time. In other words, species guilds are actually smaller than functional groups. Thus, maintaining a large species pool in any functional group increases the likelihood that an ecological service (function) will be stable and continuing despite natural or even anthropogenic environmental change (Pratt & Cairns, 1992).

2. Options for change

Humans have three basic options with regard to their interactions with natural ecological systems:

1. Continue present practices that are causing both loss of species and loss of habitat with the hope that ecological services will not be disrupted because there will be enough species in each major functional category to ensure that ecosystem services continue.
2. Attempt to implement a no-net-loss strategy for ecosystems and species. Since species cannot exist without appropriate habitat, one might assume that restoration of damaged habitat at a rate equal to the loss of this habitat would substantially arrest the biotic impoverishment or at least reduce the rate of loss, thus allowing more time to gather evidence on the relationship between biodiversity and ecosystem services.
3. Restore ecological capital and, thus, provide a larger safety margin for ecosystem services by restoring damaged ecosystems at a rate greater than the rate of destruction.

2.1. *Option 1: Continue present practices*

Even if the level of ecosystem services remained stable despite the present loss of biodiversity and destruction (which seems highly unlikely although evidence is not robust), the ecosystem services *per capita* would diminish substantially because of growth in human population. Since *per capita* energy use and *per capita* income, to mention a few examples, are considered important, it seems quite reasonable to consider ecosystem services *per capita* as one of the important criteria in establishing an appropriate relationship between humans and natural ecosystems. Regrettably, there

are only the most rudimentary quantitative estimates of ecosystem services, and I have yet to see even the most preliminary estimates of ecosystem services *per capita.*

However, the level of ecosystem services does not appear to be stable. There is robust evidence of the global decline in freshwater quality (Okun, 1991) resulting from such factors as the enormous loss of wetlands in the United States (National Research Council, 1992) and other modifications of the hydrologic cycle. Also relevant are (1) reported declines in song birds in North America due to loss of winter habitats in the South, which causes a reduction in insect control (Hagan & Johnston, 1992) and (2) threats to bat populations in many tropical and temperate areas with consequent loss of pollination, seed dispersal, and insect control (Sheffield *et al.*, 1992). There is also little question that some of the genetic diversity essential for adjusting to global changes of various kinds is being diminished (Wilson, 1988). Readers interested in a more detailed description of ecosystem services should read *Healing the Planet* (Ehrlich & Ehrlich, 1991) and the references provided in that volume. In view of the uncertainty about the relationship between the global loss of biodiversity and ecosystem services, it seems imprudent to continue on our present course of destruction of species and habitat until this crucial issue is better resolved. Even if the probability of a strong correlation between loss of biodiversity and loss of ecosystem services is small, continuing our present rate of destruction of species and habitat seems imprudent. The reason for this is that the consequences are likely to be severe or catastrophic if there is a close relationship.

2.2. *Option 2: Attempt to implement a no-net-loss of habitat and species by restoring natural systems at a rate comparable to the rate of destruction*

I spend summers at Rocky Mountain Biological Laboratory near Crested Butte, Colorado. At nearby Gunnison, Colorado, an airport taxiway was built several years ago, partly on an existing natural wetland. In mitigation of this, a constructed wetland was to be established west of Gunnison between Route 50 and the Gunnison River. Unfortunately, the first attempt at creating a replacement wetland failed. Efforts are being made to rectify the mistakes and create a wetland area similar in size to that lost to the airport runway and somewhat similar to adjacent natural wetlands. The main point of this, however, is that the original wetlands were destroyed before the replacement wetlands were functional. Thus, these ecosystem services have been lost for at least 2 years and very likely for several years more, even if the current wetland creation efforts are totally successful. The replacement wetlands should be in hand and certified as acceptable *before* the original wetlands are made available for conversion. Attempts to replace damaged or lost habitats should begin before the damage or loss occurs, and the damage or loss should not be permitted until fully functional replacements are in place. This would ensure stability in ecosystem services. Our present legislation does not take this into account. Just west of Gunnison is Blue Mesa Reservoir, which decades ago flooded an elk wintering ground. A replacement elk wintering ground was contemplated when the Blue Mesa Dam was built but not implemented until nearly 2 decades later. Even now, conversion of the Beaver Creek area from cattle grazing to an elk wintering ground is far from complete. Thus, the ecosystem service provided by an elk wintering ground has been lost for at least 2 decades and partially lost for at least a few additional years. We would not accept this if other services society demands (e.g., power, roads, garbage collection, police protection) were interrupted for comparable periods of time, and ecosystem services should be given at least the same priority.

Even if a no-net-loss of habitat, species, and ecosystem services is fully successful, we still face continually diminishing *per capita* ecosystem services as long as the population continues to grow because the level of services will be constant and the population will be expanding.

2.3. *Option 3: Increase global ecosystem services through ecological restoration*

In order for global ecological services to increase, effective ecological restoration must exceed, by a substantial margin, global ecological destruction. In order to accomplish this, explicit goals should be established in association with specific time

intervals. The National Research Council (1992) book uses, as an illustration of establishing goals, restoration of 10 million acres of wetlands in the United States by the year 2010. Although this sounds as if it is an enormous undertaking, an estimated 117 million acres have been lost in the United States in the past 200 years. Less than 10 percent of the wetlands lost would be restored over a 20-year period. However, as one might expect, the percentage loss of wetlands is by no means uniformly distributed among the various states. California is the leader with a loss of approximately 91 percent of its wetlands, while Alaska has lost less than 1 percent of its wetlands. Thus, the *per capita* loss of wetland ecosystem services in California is far greater than the national average, not only because of the high percentage lost, but also because California's population growth has exceeded that of many other states. On this basis, one might make a case for a disproportionate emphasis on restoration in California than in those states with a less significant *per capita* loss.

3. Limitations and future needs

If one accepts the assumptions and the analysis in this discussion, serious limitations are clearly evident. For example, what ecosystem functions should be expressed on a *per capita* basis? Clearly, some ecological functions are more crucial to the survival of human society in its present form than others. Presumably, society would be more willing to fund these studies than studies of functions for which the value to human society is difficult to document. For example, the yew tree, from which taxol is extracted and which appears to be beneficial in the cure/control of ovarian and possibly some other cancers, now appears valuable but would not have been before. Additionally, some functions are global, such as ultraviolet light filtration or blocking in the atmosphere or global climate change. Other functions are local, such as water quality maintenance and food and fiber production. Still others are regional, such as the influence of rivers on coastal productivity in marine systems. In short, the range of scales is far greater than these few illustrative examples. Since we have developed the capability of studying biology at different levels of organization from subcellular to landscape, we should be able to do the same for these different scales of services.

There is also the question of determining who is to keep trace or determine the level of ecosystem services *per capita*. For those at the global scale, the United Nations appears to be the appropriate organization. It appears highly improbable that all political systems would view the benefits of the various global services identically. However, an informed debate on this subject will require a level of environmental literacy not yet achieved in even the most developed countries and, therefore, it seems likely that the initial measurements and determinations of global level ecosystem services *per capita* will necessarily be focused on survival levels. For regional and local services, the outlook is more promising not only because the political systems are smaller and the level of environmental literacy might, in at least some cases, be exemplary, but because science is more accustomed to making measurements at these levels. Problems are associated with determining who is to decide acceptable levels of ecosystems services and, perhaps even more intractable, because successful enforcement requires that there be substantive consequences for failure to comply and also substantive funding to ensure that there are sufficient personnel of adequate professional capabilities to carry out the various activities necessary for compliance and the maintenance of predetermined quality control conditions.

4. Concluding statement

The spotted owl controversy in the Pacific Northwest (Thomas *et al.*, 1990) indicates a wide range of public opinion about both biotic impoverishment and loss of habitat. The short-term economic benefits of continued destruction are readily apparent, especially to those direct beneficiaries. The loss of ecosystem services, which may very well have much greater but less visible long-term economic consequences, are not at all clear to the general public. Nevertheless, numerous case histories indicate that lack of awareness of ecological services does not protect

society from the consequences of poor environmental management. For example, when the Aswan High Dam was built in Egypt, the short-term gains were obvious: flood protection and irrigation for expanded croplands. The long-term economic and ecological consequences were not fully considered, and, even discounting the spread of bilharzia (schistosomiasis), the project has been an economic and ecological nightmare (Goldsmith & Hildyard, 1984). Because the flood plain was not annually renewed by flooding, chemical fertilizer dependence increased. The loss of nutrients (not accumulating behind the dam) to the eastern Mediterranean Sea resulted in a failure of the anchovy fishery. In short, the ecosystem services provided by the Nile River were removed, and the societal and ecological costs associated with these losses are much greater than the monetary costs and benefits of the dam. Dams in other parts of the world have produced similar consequences (failures of fisheries, control of geomorphic processes sculpturing ecosystems) that were not completely considered when the short-term gains of irrigation were a high priority (Fearnside, 1989). In North America, to replace lost ecosystem services, we now have an elaborate network of hatcheries to stock salmon into streams that can no longer produce their own, and sedimented channels must continually be dredged. The cost of these foregone services is enormous.

While dams are obvious contributors to economic gain and ecosystem damage, they are only one of a number of human controls on ecological services that require costly subsidies. For example, much of wildlife management and public land management is dedicated to controlling what herbivores and predators once did. The point here is not that human alteration of the environment should cease, but simply that the full *per capita* loss of services should be considered when ecosystem manipulation is contemplated.

The relationship between biodiversity and ecosystem services remains unclear. If some species are unnecessary to the functioning of ecosystems because they are transient, trivial, or poor competitors, then nature should have eliminated them. They still exist, and so we have yet to answer the question 'why are there so many kinds of animals?' (Hutchinson, 1959). We should not destroy what we cannot replace! Since there is compelling evidence that we have not even come close to naming all of the species on earth, it is a *sine qua non* that their functions and ecological relationships are unknown to us. Neither of these attributes are well documented for many of the species that have been classified or named. By accepting that species loss is inevitable, we accept that ecological services will be compromised, perhaps at levels we cannot now measure. We are absorbed in understanding the details of some ecological processes to several decimal places and others to within only an order of magnitude. We need to understand when species loss is significant and when (or if) it is not.

Ecologists must develop more persuasive evidence concerning the relationship between biodiversity and ecosystem services, and other disciplines should assist in incorporating this information into the total mix used in societal decision making in the information age. Such information will not be generated swiftly, and interim measures designed to arrest the loss of ecosystem services *per capita* globally through ecological restoration and protection of existing habitat seems quite prudent. There is persuasive evidence from a variety of case histories that the benefits of ecological restoration (National Research Council, 1992) do not depend on a robust determination of ecosystem services.

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