ELSEVIER

Ecological Engineering 15 (2000) 171–180

ECOLOGICAL ENGINEERING

www.elsevier.com/locate/ecoleng

Guest editorial

Setting ecological restoration goals for technical feasibility and scientific validity

John Cairns Jr

Department of Biology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

Abstract

Major ecological restoration will not be undertaken unless human society approves the goals and objectives of restoration. In addition, restoration will not persist unless human society has sufficient esteem for the restored ecosystem to protect its integrity. Linking ecological restoration to sustainable use of the planet seems a promising way to foster society's interest in and acknowledgment of human dependence on natural systems. An increase in environmental and ecological literacy is essential to achieving this end, as is an awareness of the goals and conditions of sustainability. If the science and technology underlying ecological restoration are not understood by the general public, implementation will fail for lack of public support. Ecosystem services, those functions of natural systems perceived as beneficial to human society, are likely to be understood and accepted if their value in the life support system of human society is explained. Emphasis in ecological restoration must shift from reestablishing a naturalistic community of plants and animals in the damaged ecosystems to restoring ecological functions, particularly those perceived as ecosystem services. Most restoration projects thus far have emphasized structure rather than function, although both are doubtless important to sustainable use of the planet. Nevertheless, support for ecological restoration may be enhanced by emphasizing the restoration of ecological services. An essential third consideration beyond technically feasible and scientifically valid goals is whether the goals are socially feasible. This manuscript will explore aspects of social feasibility because neither technically feasible goals nor scientifically valid goals will be possible in the absence of societal acceptance.

Keywords: Ecological restoration; Ecosystem services; Sustainability; Social feasibility; Eco-societal restoration

1. Introduction

The success of restoration efforts is determined, in part, by the ability to set technically feasible and scientifically valid goals. Technically feasible goals require adequate knowledge about basic processes and reliable methods to effect repairs. Scientifically valid goals are those appropriate to the spatial and temporal scale of the restoration project. An essential third consideration is whether the goals are socially feasible. Is society willing to commit sufficient resources to support

E-mail address: cairnsb@mail.vt.edu (J. Cairns, Jr).

PII: S0925-8574(00)00068-9

the restoration activities through ecologically relevant time frames: years, decades, or even centuries?

Society lacks many of the prerequisites for goals that are technically, scientifically, and socially feasible. Because both adequate background knowledge and reliable methods are lacking for many restoration problems, large-scale projects will continue to be technically challenging. But these shortcomings are unlikely to be addressed without first addressing the gap in social feasibility. The most successful restoration projects (e.g. the Kissimmee River in FL, the Hackensack River Meadowlands in NJ, and the Guanacaste dry forest in Costa Rica) have had adequate social support and have shared an approach that integrates people into the restoration. The impetus for many of these projects was the sense of loss felt by people living and working in or near the damaged ecosystems. The people most affected must hold the system in considerable esteem to be willing to effect repairs and protect the system from further damage.

In order to facilitate the social commitments necessary to restoration, the linkages between restoration and quality of life must be made increasingly obvious at every scale, from local to global. One approach is to rephrase some restoration goals in terms of ecosystem services — those functions of natural systems perceived as useful to human society, such as capture of sunlight and production of food and materials by plants; flood control, storm protection, and water purification by wetlands; nutrient recycling in soils; maintenance of breathable air; and recreation and aesthetic values (Cairns Jr and Niederlehner, 1994). All ecosystem functions are beneficial, but it is not yet possible to persuade everyone of this. Costanza et al. (1997) furnish a preliminary estimate of the value of ecosystem services at US$33 trillion per year. Avise (1994) provides a fascinating illustrative example using Biosphere II, which cost US$9 million per person per year to provide through human engineering the services provided free by the ecosystem. Daily (1997) makes a persuasive case for human society's dependence upon these services. Alarmingly, the amount of ecosystem services per capita is declining precipitously as the natural systems providing these services are destroyed, while the human population is simultaneously increasing. Both prevention of ecological damage and ecological restoration are needed to counteract this trend. Sustainable use of the planet requires, as a minimum, a balance between ecological destruction and repair. Since prevention is more effective than the cure, human society must use all possible means to avoid or dramatically slow down on-going ecological destruction — to preserve those remaining ecosystems that are still in reasonably good shape. Simply repairing ecological damage more rapidly is neither a desirable nor effective way to achieve balance. This necessity is particularly true while ecological restoration is still a developing field. Doing so has all sorts of different social, legal, and institutional ramifications, but the probable consequences of further degrading the ecological life support system pose problems that are more daunting.

Preventing ecological damage is preferable to ecological restoration for another reason as well. Species are almost always lost from stressed ecosystems, and there may be no comparable sources elsewhere. Even when there are other sources, the individuals may not be as well suited for specific local conditions as the original inhabitants were.

Many environmental professionals object to an emphasis on ecosystem services, believing it devalues natural structures and functions that do not have immediate importance to human society. While I wholeheartedly agree that natural systems have intrinsic value independent of human consideration, I think the best way to engage the larger society in efforts to conserve and restore natural systems may be an appeal to self-interest. Contrasting the value of ecosystem services received from self-maintaining natural systems to the enormous engineering and maintenance costs of providing some of the same services from industrial systems may result in a broader appreciation for those natural systems. In addition, many ecosystem services simply cannot be engineered.

Finally, successful restoration goals must balance the societal commitment to maintenance over ecologically relevant time frames with the number and amount of ecosystem services desired in return. The stated goal of many restoration projects is a return to predisturbance condition — a self-regulating system that is integrated with the ecological landscape in which it occurs. However, restoration to predisturbance condition is often impossible. Too often, disturbances continue and landscapes are irrevocably changed. What remains possible is a gradient of restoration goals, from the large-scale, self-sustaining systems providing many ecosystem services to smaller, intensively managed systems providing fewer ecosystem services. Obviously, restoration to a close approximation of predisturbance condition is desirable if possible. These more complete restorations provide myriad ecosystem services, both those that have been identified as valuable to human society and those that have not, with minimal maintenance costs. Clearly, restorations following planned disturbances should be required to restore as many ecological structures and functions as scientifically feasible. However, if spatial or temporal constraints make return to a self-maintaining predisturbance condition scientifically invalid, more modest goals are possible for systems that are too small or too disturbed to ever again resemble a self-maintaining forest or prairie. These smaller systems can provide a narrower range of ecosystem services with higher maintenance costs and counter the alarming cumulative loss of ecosystem services per capita. If the prognostications of Tibbs (1992) are correct, then hybrid systems that are neither wholly ecological nor wholly industrial, similar to the reservoirs and treatment wetlands present now, may proliferate. The more ecosystem services that can be obtained from these systems, the better. Increasingly, straightforward economic reasons for restoring ecological systems will multiply as the engineering costs of replacing lost ecosystem services with industrial systems becomes more burdensome.

The close link between ecological restoration and sustainability will become more obvious as the consequences of ecological destruction become more of a hardship. Human society at large, rather than just a few scientists and engineers, may become intimately involved in restoration. It is by acknowledging the partnership between human society, its technology, and the natural components of the world with which society functions, that future ecological restorations can succeed.

2. Faith in human ingenuity and the social feasibility of restoration

Does human ingenuity and technology free the human species from subjugation to dependence on the natural world? Wilson (1993) identifies the opposing views of environmentalism and exceptionalism.

Environmentalism sees humanity as a biological species tightly dependent on the natural world. Without denigrating human intellect and technology, this belief maintains that these factors are not always sufficient to free humankind from the constraints of the natural environment in which human ancestors evolved. A key assumption is that, despite solutions to comparatively smaller environmental limitations of the past, successful solutions may not continue. This caution is rather like the standard warning on a stock or mutual fund prospectus that past performance is no guarantee of future returns. Future solutions must be derived for a world where materials may be unavailable, where the atmospheric chemistry maintained for millions of years by natural systems has substantially changed, and where the abundance of natural systems providing essential services is substantially reduced.

> '... exceptionalism... holds that since humankind is transcendent in intelligence and spirit, our species must have been released from the iron laws of ecology that bind all other species. However serious the problem, civilized human beings, by ingenuity, force of will, and — who knows — divine dispensation, will find a solution.'

In this view, the human species has pulled free of nature and has begun a different order of life. In addition, evolution should now be allowed to proceed along this new trajectory. The planet would have more than enough resources to last indefinitely if human ingenuity were allowed to address each new problem in turn, without alarmist and unreasonable restrictions imposed on economic development.

The key to the future of ecological restoration depends upon which of these views dominates policy debates! Predictably, my position in this debate is that humankind is bound by biophysical laws that affect all other species and is dependent on natural systems to provide essential human needs. In addition, I believe humans, even at their most destructive, cannot cause the entire Earth's biota to become extinct. Even massive extinction could be followed by a biotic enrichment or increase in diversity equaling or exceeding those of previous extinctions; however, the time scales required are beyond human relevance since humans might not be one of the species surviving any mass extinction. Concerns about quality of human life, given any changes in ecological systems, are justified. Therefore, ecological restoration, protection of natural systems and the services they provide, and development of a coevolutionary relationship with natural systems in which each partner flourishes are in the long-term, enlightened self-interest of human society and are essential to sustainability.

Sustainability is neither anti-technology nor anti-business and, if successful, is likely to enable more humans to inhabit the planet over a longer period of time. In contrast, relying on new technologies to repair problems that are knowingly propagated seems overly demanding. One simplistic analogy is to take off voluntarily in an airplane without a landing gear, but to have aboard some engineers and whatever materials and tools were left after a yard sale. The problem would then have to be solved before fuel runs out.

The vast respect implicitly accorded science and technology by this willingness to trust lives to future developments is gratifying to me as a scientist. But Horgan (1996) asks the question: 'Have we reached the end of science?' One might dismiss this question if Horgan were not a senior writer for Scientific American and two-time winner of the American Association for the Advancement of Science Journalism Award as well as recipient of the National Association of Science Writers Science-in-Society Award. For his book, Horgan interviewed an impressive array of scientists, all on the cutting edge in their area of specialization, and concludes that major breakthroughs will be rarer in the century to come. Horgan believes that applied science will continue for quite some time, but one wonders whether applied science, however defined, will be adequate to address the problems created by indiscriminate use of technology. When one adds to this the deemphasis on research in favor of classroom teaching in public-supported colleges and universities, which must necessarily displace time allocated to fundamental research, the ability of science and technology to bail humankind out of awkward, possibly life-threatening, situations caused by science and technology seems a risky proposition.

A book by the National Academy of Engineering (1997) asks two fundamental questions: (a) Is the direction of innovation lowering pressure on the environment? and (b) If this is the case, are the rates of innovation likely to be rapid enough to raise the quality of life for a large majority of people? The contributors to the volume use the basic assumption that scientific and technological innovations, analogous to those that have occurred during this century, will continue and that they will generate further innovations of a type that cannot be foreseen. Another key assumption is that environmental problems as presently defined — with respect to energy and food, but in most other instances as well — derive from specific scientific and engineering accomplishments of recent decades. The pivotal assumption is that just as human intelligence has created these problems, it offers the only possible solutions for them. Most of the volume consists of documentation of signs of hope. Some of the contributors do express concern over what they deem to be a too rapid growth in population, especially in the developing countries, but note that public debate about this issue and numerous other related matters has diminished in intensity. The contributors do not raise the issue of whether this diminished concern is justified, based on new information, or is due instead to denial of unpleasant or impolitic truths (e.g. Orr and Ehrenfeld, 1995; Maher, 1997). Neither do the authors comment on whether diminished concern is due to the popularization of deliberate distortions of scientific evidence in an anti-environmental backlash (Ehrlich and Ehrlich, 1996).

An overriding faith in human ingenuity undermines social commitment to ecological restoration. Restoration will only occur at a significant level if human society acknowledges its dependence on the planet's ecological life support system and if esteem develops for natural systems and the species that inhabit them. Effective ecological restoration at the landscape level (as recommended by the National Research Council, 1992) will only be possible if human society is willing to endorse and support long-term restoration efforts and the species necessary to recolonize these systems have not been permanently lost. If neither of these attributes is present, ecological restorations have neither the scientific underpinning nor the necessary methods and procedures.

3. Homeorhesis and ecological restoration

Odum (1997) makes an important distinction between homeostasis and homeorhesis. Homeostasis is a familiar term since humans and other individual organisms have fairly tightly regulated temperatures, chemical composition of body fluids, blood pressure, heart rate, and the like. Variations exist, of course, but these variations remain within a narrow range due to feedback loops. The goal is clearly defined in homeostasis. In contrast, ecosystems have homeorhesis — wider variability and more than one stable condition. Ecosystems still have limits of tolerance that mark the transition between one stable state and another, but the 'best' state is a matter for conjecture. However, humans clearly would prefer that ecosystems maintain a state favorable to human life.

The eighteenth century Scottish geologist James Hutton, originally trained as a physician, gave a lecture to the Royal Society of Edinburgh in 1785 suggesting that Earth should be regarded as a superorganism and should be studied by the science of physiology. More recently, Lovelock (1979) developed the Gaia hypothesis, which views Earth as a kind of living superorganism, where each animal and plant serves a specific function that helps maintain a stable, living environment. While this hypothesis has its critics (e.g. Williams, 1992), Lovelock makes an essential observation that Earth is more hospitable to human life because of its biota than it otherwise would be. By extension, many ecosystem services described by Allaby (1989) and earlier by Lovelock (1979) deserve serious attention. Among them are the relationship between the gases in the atmosphere and Earth's temperature, and some notable cycles, such as nitrogen, carbon, and salt. Should the biota be placed in serious disequilibrium, Earth would be less hospitable for humans and many other species. Is there a reasonable probability that severe disequilibrium of Earth's biota could so disrupt ecological services that Earth would become inhospitable to life as it is known? This issue can be divided into two components: (a) Is there a point for most ecosystems where the disequilibrium is so severe that unassisted recovery is either highly improbable or of such a temporal span that it appears not relevant to the human condition? and (b) Is there some point at which ecological disequilibrium is so severe that even assisted recovery or ecological restoration is extremely unlikely or requires such a temporal span as to be irrelevant in terms of the human condition? The distinction between these two situations is important. Epicenters serving as sources for recolonizing species might be so distant or the intervening areas so ecologically hostile that recolonizing species are unlikely to arrive on their own. Eventually the necessary species may not exist anywhere on the planet. To date, most successful ecological restoration efforts have had the advantage of a nearby naturalistic assemblage of plants and animals that could recolonize the formerly damaged area. If appropriate colonists are not available, then new ecosystems and habitats, in a sense, will be created. Neither the stability, the capability of self-maintenance, nor the functional attributes of the new systems will be known beforehand.

Biotic impoverishment, or loss of biodiversity, is occurring, perhaps at an unprecedented rate (e.g. Wilson, 1988). Equally evident is the fact that the planet has previously undergone notable and severe biotic extinctions. However, both the long time frame required for recovery and the uncertain final product of the recovery are incompatible with most views of sustainable use of the planet. For sustainability, as it is now viewed, effective ecological restoration that requires relatively short time spans and has a reasonably predictable outcome is the desired goal. The more severely Earth's biota is placed in disequilibrium, the more difficult and uncertain scientific and technological ecological restoration will be because the conditions under which restoration has been studied thus far will have been dramatically altered. As the environment changes, effective techniques for ecological restoration will also change. Techniques developed for ecological conditions that no longer exist are unlikely to be effective.

4. Bioregional planning

Ecological restoration is facilitated by the establishment of antecedent or predisturbance conditions and the existence of nearby epicenters acting as a source of recolonizing species. Establishing antecedent conditions, of course, implies that the physical, chemical, and biological conditions prior to the disturbance are known. Although this information can be gathered by scientists from anywhere in the world, it may be most valuable if collected by local scientists on a continuing basis, making it possible to characterize normal variability in the ecosystems sufficiently well to distinguish it from a new trend and also to estimate critical thresholds. In addition, it is important that a reservoir of indigenous species be available for recolonization, ideally close enough to the damaged area so that some or all recolonization can occur naturally. For example, in aquatic systems such a reservoir of species could be from protected tributaries that are not too ecologically dissimilar in biota from the main river. In terrestrial systems, patches of forest can be protected for this purpose. Species from afar, not indigenous to the area, have been known to cause unanticipated problems, either by exuberantly expanding their range or by initially appearing successful only to fail as a result of being unable to tolerate seasonal variations in the new habitat, as has happened in the case of the Asian clam and the zebra mussel in the United States (Cairns Jr and Bidwell, 1996a). Establishment of antecedent conditions might require shade if an exotic grass has taken over a previously forested area and grows so rapidly that the indigenous flora cannot survive, as has happened in Panama. In this instance, trees growing faster than the exotic grass kept the grass under control and simultaneously permitted the establishment of shade-requiring trees.

One other aspect of bioregional planning is extremely important in ecological restoration — establishing a bond between humans and a particular type of ecosystem. Close association with natural systems, characteristic of many earlier tribal societies, has been greatly diminished by the urbanization occurring globally. The dissociation of humans and nature has seriously weakened the bond that once existed. In an era of high human mobility, humans moving to a new area will need to be acculturated to the local ecosystems by persons better established there. In some cases, even in developing countries, reacquainting the local people with their local ecosystems is essential, as Janzen (1988) has shown for the restoration of the Guanacaste dry forest in Costa Rica. Janzen refers to this process as *biocultural restoration*, and I have called it *eco-societal restoration* (Cairns Jr, 1994, 1995a). The basic premise in both cases is that restoration cannot be accomplished over the large spatial or temporal scales necessary to self-maintaining ecosystems without the support of the human society associated with the ecosystem.

5. The link between sustainability and ecological restoration

So close is the relationship between the behavior and practices of human society and the condition of natural systems that I have suggested that it may be easier to measure ecological integrity by examining the behavior and practices of human society than by examining natural systems (Cairns

Jr, 1995b) and that human society and natural systems are coevolving (Cairns Jr, 1994, 1996). The most recent of a series of articles on these ideas is Cairns Jr (1997a). It is not difficult to persuade most humans that their societies are having a major effect upon natural systems, but the fact that natural systems can also alter human societies is much less widely accepted. Cairns Jr and Bidwell (1996a,b) attempt to demonstrate this phenomenon, as have other publications showing that natural systems can affect human society (e.g. Garrett, 1994).

The major turning point in my view on the coevolving relationship between human society and natural systems was my preparation for the Abel Wolman Distinguished Lecture for the National Academy of Sciences (Cairns Jr, 1994) and a book chapter for the National Academy of Engineering (Cairns Jr, 1996). The Abel Wolman Distinguished Lecture was reprinted in its original form (Cairns Jr, 1995a) and in a modified form (Cairns Jr, 1995c) in two quite different publications, yet the readers of each were interested in ecosystem services. The coevolving relationship is not a new subject, as Westman (1978) and other such publications illustrate, but increasing numbers of publications on the subject show an attempt to make more disciplines and more people aware of the overriding importance of preserving these aspects of natural systems.

The National Research Council (1992), noting that the rate of destruction of aquatic ecosystems in the United States had far exceeded the rate of repair, made modest recommendations toward reversing this imbalance by the year 2010. If ecological destruction continues to exceed ecological repair, a day will come when ecosystems can no longer provide adequate services. Of course, ecological restoration generally requires longer time spans than ecological destruction. Since thresholds for unacceptable damage are difficult to estimate precisely and since the number of trained personnel for major ecological restoration is not now adequate, it would be good to begin major efforts in restoration before a major unmistakable crisis occurs.

6. Restoration ecology and goals and conditions for sustainability

Cairns Jr (1997b) lists ten goals for achieving sustainable use of the planet from an ecological perspective. Under each of these goals is a set of conditions that must be met if these goals are to be achieved. These goals (as outlined in Table 1) are intended to provoke discussion and are therefore tentative. Goals 5, 7, 9, and 10 are only indirectly related to restoration. However, goals 1, 2, 3, 4, 6 and 8, if properly implemented, should dramatically reduce the need for ecological restoration in the future.

Implementation of these goals will require substantive changes in human society's practices and behavior. Even if these goals and conditions were implemented immediately and worked effectively, society would still have to determine at what point the per capita global affluence and population levels should stabilize and how rapidly new 'green' technologies are put into place before determining how much of Earth's already damaged ecosystems should be restored. A concomitant problem is the virtual certainty of ecological accidents, such as the recent fires in Indonesia or the introduction of diseases, deliberately or inadvertently, into natural systems. In addition, the question of exotic species will be ever present, given the global transportation and marketing system now in place. Depending on assessments of current conditions compared to the desired level of ecosystem services per capita and the success of sustainability initiatives, a period of intensive and ambitious ecological restoration may be necessary, followed by a period where continual restoration is necessary but at a much lower level because ecosystems are being better protected and because ecological damage and accidents have been reduced.

7. Concluding statement

Although not intended at the outset, preparing the first draft of this manuscript led to a concern that however robust the science and technology of ecological restoration becomes, most data will not

Table 1
Goals and conditions for sustainability (reprinted from Cairns Jr, 1997b, with permission)

Goal 1	To see that the machinery of nature has sufficient energy to deliver necessary ecosystem services
Condition	Human society shall not co-opt so much of Earth's energy that ecosystems can neither furnish services nor endure for substantial periods of time
Goal 2	To avoid poisoning or impairing the machinery of nature by altering both the structure and function of natural systems by means of toxicants
Condition	Substances extracted from Earth's crust or synthesized from raw materials must not be concentrated or dispersed in ways harmful to the biosphere (e.g., metals, oil, or pesticides)
Goal 3	To ensure that ecosystem services, such as the maintenance of atmospheric gas balance, favorable to human and other life forms continue at their present or, preferably, better levels
Condition 1	The physical and biological basis for the services provided by nature shall not be systematically diminished (e.g. overharvesting whales or fishery breeding stocks)
Condition 2	Artifacts created by human society may not systematically increase on the planet
Condition 3	A balance must exist between ecological destruction and repair
Condition 4	Management strategies for sustainability must allow natural processes such as succession, evolution, predator/prey relationships, and the like to continue
Goal 4	To devise a better balance in meeting short-term and long-term needs of human society
Condition	Short-term human needs may not be met if doing so endangers the planet's ecological life support system
Goal 5	To ensure that most of Earth's population has the opportunity for a high quality life
Condition	Human population over the long term must be stabilized at a point where adequate per capita resources are demonstrably available
Goal 6	To avoid a human-induced episodic environmental catastrophe that would cause much human suffering
Condition	When employing environmental management strategies about which the precise consequences are still somewhat uncertain, large protective safety margins (i.e., either slowing development or carrying it out extremely cautiously) are essential until the outcome has been better defined and the consequences have been determined to be acceptable and not of long-term sustainability significance
Goal 7	To diminish the conflict between generations caused by US Social Security and Medicare and elsewhere caused by the perception that future generations will lead impoverished lives because of present greed
Condition	Older people must become deeply involved in sustainable use of the planet to demonstrate by deed, not words, the older generation's concern for generations to follow
Goal 8	To reincorporate all waste from human society into natural systems without damaging their integrity
Condition 1	Materials that cannot be safely reintroduced into natural systems should not be produced
Condition 2	Assimilative capacity of natural systems shall not be exceeded
Condition 3	To develop robust predictive models regarding assimilative capacity, validate these models, and continually monitor them to ensure that previously established quality control conditions based on these two prior activities are being met at all times
Goal 9	To develop equity and fairness in resource distribution within human society and with other species with which it shares the planet
Condition 1	A sufficient majority of humans must acknowledge the reality of equity and fairness so that there is an incentive to preserve the ecological life support system for sustainability
Condition 2	Ethnic and racial strife, holy wars, wars over resources, and other extremely diverse political issues must be eliminated or restrained so that destructive energy can be rechanneled into constructive activities
Goal 10	To develop a holistic sustainability initiative
Condition	Each specific or targeted sustainability initiative (e.g. agriculture, transportation, energy, cities, fisheries, etc.) must not act as if it is the only 'flower facing the sun'

be collected at the scale necessary unless there is societal acceptance of dependence upon ecosystem services as part of society's life support system. If there is such an acceptance, the science and technology of ecological restoration must necessarily be developed within a sustainability framework. Such an acceptance will, in turn, focus on ecosystem services since these are the ecological attributes most likely to be appreciated by the general public because natural systems will then be regarded as essential to human society's well-being and survival, rather than peripheral.

The debate over whether humans have escaped the domination of natural laws or are subject to them as are other species will probably continue into the future. Just as a prudent investor will maintain a mixture of bonds, stocks, and other securities, influenced by the degree of tolerable risk and the like, it seems imprudent to depend entirely upon human ingenuity and technology to free society from the restrictions of natural law. Additionally, there is the question of ethical responsibility in humankind's relationship with natural systems and the species that inhabit them. Even if it develops that the human species is no longer dependent upon other species, is it morally neutral to destroy them? If they are destroyed, should just fragments be retained as a reminder of the days when human ingenuity and technology were not so triumphant, or should humans continue to share the planet with them?

The future of ecological restoration will depend on expanding the science and technology of this newly developing field. More important, the present and near-future generations of humans will either deliberately embrace restoration or inadvertently reject it in favor of blind exercises of individual rights, economic development, and the like.

Acknowledgements

I am indebted to B.R. Niederlehner for detailed and useful comments on drafts of this manuscript, to Eva Call for typing the drafts, and to Darla Donald for editorial assistance in preparing the manuscript for publication.

References

Allaby, M., 1989. A Guide to Gaia. E.R. Dutton, New York.

Avise, J.C., 1994. The real message from Biosphere 2. Conserv. Biol. 8 (2), 327–329.

Cairns, J. Jr, 1994. Ecological restoration: re-examining human society's relationship with natural systems. In: The Abel Wolman Distinguished Lecture. Water Science and Technology Board, National Research Council, Washington DC.

Cairns, J. Jr, 1995a. Eco-societal restoration: Re-examining human society's relationship with natural systems. Ann. Earth. 13 (1), 18–21.

Cairns, J. Jr, 1995b. Ecological integrity of aquatic systems. Reg. Rivers: Res. Manage. 11, 313–323.

Cairns, J. Jr, 1995c. Re-examining human society's relationship with natural systems: maintaining ecosystem services and sustainable use. Corp. Environ. Strat. 3 (1), 69–74.

Cairns, J. Jr, 1996. Determining the balance between technological and ecosystem services. In: Schulze, P.C Jr (Ed.), Engineering Within Ecological Constraints. National Academy Press, Washington DC, pp. 13–30.

Cairns, J. Jr, 1997a. Commentary: defining the goals and conditions for a sustainable world. Environ. Health Perspect. 105, 2–8.

Cairns, J. Jr, 1997b Global co-evolution of natural systems and human society. Revista de la Sociedad Mexicana de Historia Natural 1 (1), 1–3.

Cairns, J. Jr, Bidwell, J.R., 1996a. Discontinuities in technological and natural systems caused by exotic species. Biodiv. Conserv. 5, 1085–1094.

Cairns, J. Jr, Bidwell, J.R., 1996b. The modification of human society by natural systems: Discontinuities caused by the exploitation of endemic species and the introduction of exotics. Environ. Health Perspect. 104 (11), 1142–1145.

Cairns, J. Jr, Niederlehner, B.R., 1994. Estimating the effects of toxicants on ecosystem services. Environ. Health Perspect. 102 (11), 936–939.

Costanza, R., d'Arge, R., de Groot, R., et al., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Daily, G., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington DC.

Ehrlich, P.R., Ehrlich, A.H., 1996. Betrayal of Science and Reason. Shearwater Books, Island Press, Washington DC.

Garrett, L., 1994. The Coming Plague. Farrar, Straus, and Giroux, New York.

Horgan, J., 1996. The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age. Helix Books, Addison–Wesley Publishing, Menlo Park, CA.

Janzen, D.H., 1988. Guanacaste national park: tropical ecological and biocultural restoration. In: Cairns, J. (Ed.), Rehabilitating Damaged Ecosystems, vol. 2. CRC Press, Boca Raton, FL, pp. 143–192.

Lovelock, J.E., 1979. Gaia: A New Look at Life on Earth. Oxford University Press, Oxford, UK.

Maher, T.M., 1997. How and why journalists avoid the population-environment connection. Popul. Environ. 19 (4), 339–346.

National Academy of Engineering, 1997. Technological Trajectories and the Human Environment. National Academy Press, Washington DC.

National Research Council, 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington DC.

Odum, E.P., 1997. Ecology: A Bridge between Science and Society. Sinauer Associates, Sunderland MA.

Orr, D.W., Ehrenfeld, D., 1995. None so blind: the problem of ecological denial. Conserv. Biol. 9 (5), 985–987.

Tibbs, H.B.C., 1992. Industrial ecology: an environmental agenda for industry. Whole Earth Rev. 77, 4–19.

Westman, W.E., 1978. How much are nature's services worth? BioScience 197, 960–964.

Williams, G.C., 1992. Gaia, nature worship, and biocentric fallacies. Quart. Rev. Biol. 67, 479–486.

Wilson, E.O., 1988. Biodiversity. National Academy Press, Washington DC.

Wilson, E.O., 1993. Is humanity suicidal? NY Times Mag. 30, 24–29.