Utah State University

DigitalCommons@USU

Economic Research Institute Study Papers

Economics and Finance

2000

Contemporary Research in Ecological Economics: Five Outstanding Issues

Amitrajeet A. Batabyal
Utah State University

Follow this and additional works at: <https://digitalcommons.usu.edu/eri>

Recommended Citation

Batabyal, Amitrajeet A., "Contemporary Research in Ecological Economics: Five Outstanding Issues" (2000). *Economic Research Institute Study Papers*. Paper 177.
<https://digitalcommons.usu.edu/eri/177>

This Article is brought to you for free and open access by the Economics and Finance at DigitalCommons@USU. It has been accepted for inclusion in Economic Research Institute Study Papers by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.

Economic Research Institute Study Paper

ERI #2000-01

**CONTEMPORARY RESEARCH IN ECOLOGICAL
ECONOMICS: FIVE OUTSTANDING ISSUES**

by

AMITRAJEET A. BATABYAL

**Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530**

January 2000

**CONTEMPORARY RESEARCH IN ECOLOGICAL
ECONOMICS: FIVE OUTSTANDING**

Amitrajeet A. Batabyal, Associate Professor

**Department of Economics
Utah State University
3530 Old Main Hill
Logan, UT 84322-3530**

The analyses and views reported in this paper are those of the author(s). They are not necessarily endorsed by the Department of Economics or by Utah State University.

Utah State University is committed to the policy that all persons shall have equal access to its programs and employment without regard to race, color, creed, religion, national origin, sex, age, marital status, disability, public assistance status, veteran status, or sexual orientation.

Information on other titles in this series may be obtained from: Department of Economics, Utah State University, 3530 Old Main Hill, Logan, Utah 84322-3530.

Copyright © 2000 by Amitrajeet A. Batabyal. All rights reserved. Readers may make verbatim copies of this document for noncommercial purposes by any means, provided that this copyright notice appears on all such copies.

**CONTEMPORARY RESEARCH IN ECOLOGICAL
ECONOMICS: FIVE OUTSTANDING**

Amitrajeet A. Batabyal

ABSTRACT

In recent times, ecologists and economists have drawn attention to the fact ecological and economic systems are jointly determined. Once this is recognized, it seems rather obvious that ecological-economic systems ought to be studied as one system. However, because this recognition has been very recent, a number of important issues in ecological economics remain poorly understood. Consequently, the purpose of this paper is to identify and discuss five of these outstanding issues.

Key words: ecological-economic system, keystone species, natural capital, optimal management, persistence, resilience, substitutability

CONTEMPORARY RESEARCH IN ECOLOGICAL ECONOMICS: FIVE OUTSTANDING

INTRODUCTION

All over the world, ecological systems are used to conduct economic activities such as fishing, grazing, and hunting. As a result of this systematic use, ecological systems are constantly being subjected to perturbations. These perturbations result in two interlinked sets of effects: a set of economic effects and a set of ecological effects. The ecological effects determine the evolution of the underlying ecological system(s). Similarly, the economic effects affect the relevant economic system(s).

For our purpose, what matters is that these two effects together determine the nature of the subsequent economic activities that may be carried out on these ecological systems, and the ability of the underlying ecological systems to support these economic activities. These interlinkages between ecological and economic systems led S. V. Ciriacy-Wantrup (1965) to conclude that ecological and economic systems are jointly determined. In a subsequent paper, Ciriacy-Wantrup (1971, p. 36) argued that “economics...can contribute to conceptual clarification and more effective public action in the important area where the concerns of ecology and economics meet.” Since then, Perrings et al. (1995a), Perrings (1996, 1998), Dasgupta (1996), Dasgupta and Maler (1997), and others have commented on the fact that for a wide variety of ecological and economic issues, it is appropriate to view and study ecological-economic systems as one system.

Although the nexuses between ecology and economics were noted by Ciriacy-Wantrup (1965) more than three decades ago, the view that ecological-economic systems are jointly determined has gained currency only very recently. Consequently, a number of important issues in ecological economics remain inadequately understood, or not understood at all. Given this state of

affairs, in this paper, I discuss five of these outstanding issues. I hope that the contents of this paper will give members of the research and policy communities a sense for what is currently known about these issues and what kinds of questions need to be addressed to improve our understanding of the ways in which interdependent ecological-economic systems function. The reader should note that in the rest of this paper, I shall use the terms “ecological-economic system” and “ecosystem” interchangeably.

The first issue involves the substitutability between different kinds of natural capital. In an ecological-economic system, production processes will typically employ produced and natural capital of many kinds. Consequently, if one knows very little about the substitutability between different kinds of natural capital, then, *inter alia*, one cannot be sure whether extant production processes are allocating scarce resources efficiently.

The above issue relates to the second issue which concerns the role of stability concepts such as “persistence” and “resilience” in measuring ecosystem health. The continuance of economic activities such as fishing and grazing depends on the ability of ecosystems to support these activities. In other words, ecosystem health matters, and hence it is important to have measures of the health of a given ecosystem. The concepts of persistence and resilience are two salient measures of ecosystem health.

Related to this, the third and the fourth issues concern the effects of economic activities on the health of an ecosystem, and the relationships between human activities and the keystone species of an ecosystem. Increasing our stock of knowledge about these two issues will enable us to understand how human activities affect particularly vital members of ecosystems, namely, the keystone species. Moreover, such knowledge will also have an important effect on the way in which we manage our ecosystems.

The optimal management of ecological-economic systems constitutes the fifth issue of this paper. As Dasgupta (1996, p. 389) has noted, “ecosystems...recycle nutrients, control floods, filter pollutants, assimilate waste, pollinate crops, operate the hydrological cycle, and maintain the gaseous composition of the atmosphere.” This tells us that ecosystems have a profound effect on the well-being of humans. Consequently, if we are to sustain human well-being, then it is very important that we manage our ecosystems effectively. Let us now discuss each of these five issues in greater detail.

SUBSTITUTABILITY AND NATURAL CAPITAL

Humans depend on ecosystems for a number of services. Examples include timber from forest ecosystems and fish from aquatic ecosystems. The ability of ecosystems to provide these services is contingent on the performance of ecological functions such as biogeochemical cycling. The species of an ecosystem play various roles in the performance of these ecological functions. Consider any two species, say species x and species y, of an ecosystem. The notion of substitutability asks whether x and y play the same role in the performance of a specific ecological function. If the answer to this question is yes, then with respect to this ecological function, we say that x and y are substitutes. Further, since the species of an ecosystem are examples of natural capital, this is an instance of the substitutability between two kinds of natural capital. The reader should note that the emphasis in this section is mainly on natural and not produced capital. As Dasgupta (1996) has noted, natural capital refers to minerals, ores, fossil fuels, and to the totality of all the ecosystems of the world. In contrast, produced capital refers to either commodities for final use (automobiles, refrigerators) or to commodities that are used to produce other commodities (screwdrivers, conveyer belts).

The study of this kind of substitutability is important in ecological economics for at least two reasons. First, knowledge of the substitutability between different kinds of natural capital is essential for making prudent species conservation decisions. Second, a knowledge of this kind of substitutability is helpful in valuing the stock of, say a nation's, natural capital. In turn, this valuation exercise is useful—see Maler (1991) and Dasgupta (1995)—in correctly computing this nation's net national product (NNP).

Since the publication of "The Limits to Growth," by Meadows et al. (1972), a considerable amount of research has attempted to determine whether exhaustible resources (a kind of natural capital) are, in fact, limits to economic growth. Economists such as Solow (1974), Hartwick (1978), and Dixit et al. (1980) have shown that a constant level of consumption can be sustained indefinitely if there exist substitutes for natural capital, and if appropriate investments in these substitutes are made to compensate for the loss of natural capital. To see the implication of this result, consider the following simple example: Suppose that the use of electrical wire is an important part of the growth process of some economy. Electrical wire is manufactured using two inputs: copper (natural capital) and wiring equipment (produced capital). The Solow-Hartwick-Dixit et al. result tells us that as long as substitutes exist for copper, and society makes adequate investments to develop these substitutes, the fact that the total available supply of copper is finite does not limit this economy's growth possibilities.

As Daly and Cobb (1989), and Turner (1992) have noted, current debate on the substitutability between natural and produced capital concerns the extent of substitutability between these two kinds of capital. This is salient because if there are lots of substitutes for natural capital, then the extent of substitutability between these two kinds of capital will be high. In turn, this means that the exhaustibility or the finiteness of many kinds of natural capital will not be a matter of great

concern to society. On the other hand, if there are few substitutes for natural capital, then the extent of the substitutability between natural and produced capital will be low. Society then will have to use natural capital more carefully, and invest additional resources to develop the required substitutes.

In contrast with this ample interest in the substitutability between natural and produced capital, the question of the substitutability between different kinds of natural capital has received little attention from ecologists and economists. In fact, as Perrings (1996) has noted, until very recently, economists frequently assumed that environmental resources that are substitutes in human consumption are also substitutes in the performance of ecological functions. This means that until recently, economists would erroneously assume that halibut and salmon, which might reasonably be considered to be substitutes in human consumption, are also substitutes in the performance of ecological functions in the ecosystems in which they naturally exist. Although this assumption has been discarded, as Perrings (1996) has noted, it is still true that the complementarity between species in many ecosystems is poorly understood. Why is it important to understand the nature and the extent of substitutability between different kinds of natural capital? As Schindler (1990) and Costanza et al. (1995) have noted, this is because the resilience of ecosystems is generally a function of this substitutability.

Put differently, the provision of essential ecosystem services, on which much of humankind depends, is a function of ecosystem resilience. In turn, the resilience of ecological functions in many ecosystems is an increasing function of the number of substitute species that can perform those functions. This is why substitutability is an important concept in ecological economics. To comprehend all the ramifications of this notion of substitutability, a number of currently unanswered questions need to be answered. These include the following: What is the nature of the functional relationship between ecosystem resilience and the number of substitute species in an ecosystem that

can perform a given set of ecological functions? What is the minimum combination of environmental resources that will enable an ecosystem to function under the expected range of economic and ecological conditions? Finally, what is the effect of incorrect and/or inadequate knowledge about inter-species substitutability on species conservation decisions?

PERSISTENCE, RESILIENCE, AND ECOSYSTEM HEALTH

Let us first define persistence and resilience. Persistence refers to “how long a variable lasts before it is changed to a new value...” (Pimm, 1991, p. 14). Resilience refers to “the amount of disturbance that can be sustained [by an ecosystem] before a change in [this ecosystem’s] control or structure occurs.” (Holling et al., 1995, p. 50). As a result of economic activities and other natural phenomena, ecosystems are constantly being subjected to perturbations or shocks. These shocks affect the health of an ecosystem. A healthy ecosystem is one that is able to maintain its ecological character over time and is consequently able to provide a flow of essential services to society. There are many ways in which one can measure the impact of perturbations on ecosystem health. Ecologists such as Pimm (1991, pp. 13-14) have identified the concepts of “persistence,” “resilience,” “resistance,” and “variability.” Each concept is useful in focusing on a particular aspect of an ecosystem’s health. However, the notions of persistence and resilience have the greatest potential in enabling society to understand the ecosystem health effects of different kinds of perturbations. To see why, note that an important objective of ecological economics is to study the effects of changes in ecosystems over time and under uncertainty. The concepts of persistence and resilience are most directly concerned with changes in the states of ecosystems. In addition to this, a good understanding of ecosystem persistence and resilience will enable society to prudently use the flow of essential services that ecosystems provide. Because the health of ecosystems is directly affected by the prudence that

society demonstrates in its use of these ecosystem services, persistence and resilience will play an important role in evaluating the impact that alternate patterns of use have on the health of ecosystems.

To better understand the role of, say, resilience in determining the health of an ecosystem, consider the following example from Dasgupta and Maler (1997). Under normal conditions, the semi-arid grasslands of East and South Africa are periodically subject to intense grazing by large herbivores. This grazing leads to a dynamic balance between two functionally different groups of grasses. The first group, which tolerates drought and grazing, has the capacity to hold soil and water. The second group is able to hold plant biomass and hence this latter group has a competitive advantage over the first group in those periods in which grazing is not intensive. In this way, a diversity of plant species is maintained. This diversity serves two ecological functions: drought protection and productivity. Grazing by large herbivores that intermittently changes from intense pulses to durations in which recovery is permitted forms a part of the overall dynamics of these ecosystems. When fixed management rules such as the stocking of ranch cattle at a sustained and moderate level are applied to these grasslands, it is possible for the periodically intense pulses of grazing to change to a more modest, but persistent, level of grazing. This potential state of affairs, which would be the result of deliberate management policy, supports the competitive advantage of the productive, but drought sensitive grasses, at the expense of the drought resistant grass. This reduces the functional diversity and hence the resilience of these semi-arid grasslands. The health of this ecosystem is detrimentally affected because these grasslands can come to be dominated by woody shrubs that are of low value for grazing.

To study the roles of persistence and resilience in measuring ecosystem health, researchers will need to focus on three specific objectives. Although there exist a number of studies of

persistence, and particularly resilience (see Pimm (1991), Steinman et al. (1991), Cottingham and Carpenter (1994), Neubert and Caswell (1997)), most of these studies have analyzed deterministic ecosystems, i.e., ecosystems in which there is no uncertainty. However, as Bromley (1989, 1992) and others have noted, public policy with regard to ecosystem use must account for the presence of uncertainty. Consequently, the first objective involves the provision of apposite mathematical definitions of persistence and resilience for stochastic ecosystems. This is necessary because all natural ecosystems are subject to continuous environmental perturbations. Indeed, as Ives (1995) has noted, in such stochastic ecosystems, a deterministic equilibrium is never reached. Consequently, to apply generally, concepts such as persistence and resilience need to be defined for stochastic systems.

Most of the ecology literature has described resilience as an asymptotic property of ecosystems. Consequently, the short term, transient behavior of ecosystems, immediately following a perturbation has been overlooked (Neubert and Caswell, 1997). In this context, "short term" refers to a finite time period. It is important to stress the finiteness of the time period for the following two reasons: First, as Neubert and Caswell (1997) have pointed out, for a given perturbation, the transient response of an ecosystem may be at least as important as its asymptotic response. Second, for most practical purposes, researchers are interested in the ecosystem impacts of perturbations over a finite, but possibly long, period of time. Note that an implication of this discussion is that all else being equal, society would be more interested in those perturbations that have longer lasting impacts on ecosystems. This tells us that the second objective for the research community is to construct measures of ecosystem health that focus on the transient dynamics of ecosystems following perturbations.

The third objective will require researchers to concentrate on empirically knowable variables, and to recognize that a lack of carefully conducted empirical studies has prevented the research community from increasing its understanding of the effects of perturbations on ecosystem health. The first part of this objective says that in constructing measures of ecosystem health, researchers ought to focus on variables such as the number of species in an ecosystem, and the population size of a particular species. In principle, these variables are empirically knowable. In contrast, if a constructed measure of ecosystem health depends on variables that cannot be determined using statistical techniques, or are otherwise empirically unknowable, then it will be impossible to operationalize such a measure of ecosystem health. Consequently, the practical use of such a measure will be very limited. The second part of this objective says that following the work of Hassel (1979) and Krebs (1985, pp. 291-300), ecologists and economists will need to conduct careful empirical studies of the ecosystem health effects of phenomena such as the interactions between predators and their prey. Specific examples of such studies include the analysis of predator-prey relationships in which there are multiple predator and prey species.

ECONOMIC ACTIVITIES AND ECOSYSTEM HEALTH

Since time immemorial, human beings have made use of the many services that are provided by ecosystems. Examples of such services include groundwater from underground aquifers, timber from forests, fish from the oceans, and grazing on rangelands. Consequently, it is no surprise that the level of economic activity tends to affect the health of ecosystems. Why is it important to study the effects that economic activities have on the health of ecosystems? Very generally, it is important to do so because as economists and ecologists such as Dasgupta (1982) and Walker (1993) have noted, excessive levels of economic activity can have an adverse impact on the health of an ecosystem and

therefore lead to drastic reductions in the provision of essential ecosystem services. Economic activities also affect the functioning of ecosystems in a number of specific ways. First, they have an impact on the flow of services such as the availability of plant food that are consumed indirectly by humans. Second, they alter the biological diversity (biodiversity) of ecosystems. Finally, they challenge the resilience of ecosystems. In these specific but interrelated ways, economic activities have a direct bearing on the ability of ecosystems to provide the services on which much of human activity depends.

To study the impact of economic activities on the health of an ecosystem, it is useful to differentiate between activities that are undertaken as a part of one's livelihood, and those that are undertaken primarily for recreational purposes. Activities such as the collection of firewood, the grazing of cattle, and the use of groundwater for drinking purposes are examples of the former kind of activity. Boating, camping, and hiking are examples of the latter kind of activity. While it is possible for some activities, such as fishing, to fall into both these categories, the point of this distinction is twofold. First, it is to recognize that while both kinds of activities affect ecosystem health, the former kinds of activities generally tend to have much stronger impacts on ecosystem health. This is because these livelihood based activities are essential for survival in normal times. Moreover, the intensity with which they are pursued tends to increase during times of acute economic stress. As Dasgupta (1996) has noted, this is particularly true in developing countries where poverty itself can be a cause of environmental degradation.

Second, while there now exists a fairly large literature—see Vatn and Bromley (1995)—on the effects and the valuation of recreational activities, albeit primarily in the context of western countries, the same cannot be said about our stock of knowledge regarding the effects of livelihood based economic activities on ecosystem health. The reader should note that as used in this section,

the term “valuation” refers to the total value of an activity or resource. As Mendelsohn and Shaw (1996) and Georgiou et al. (1997) have pointed out, this total value includes the use (consumptive) value and the non-use (non-consumptive) value. It should be noted that although there does exist a sizeable literature on the valuation of recreational and other activities, as Perrings et al. (1995a) have noted, a lot of work by ecologists and economists still needs to be done to improve our understanding of the total value of ecosystem services. This discussion tells us that livelihood based economic activities are important for survival, particularly the survival of resource-dependent poor people in developing countries, and that these activities generally have stronger effects on the health of ecosystems. Despite this, relative to our knowledge of the ecosystem impacts of recreational economic activities, much less is known about the ecosystem effects of livelihood based economic activities.

A number of specific questions regarding the impacts of livelihood based economic activities on ecosystem health, remain unanswered. We need to know more about the manner in which the health of an ecosystem evolves when the services that this ecosystem provides are utilized at a constant rate over time, and the impact on ecosystem health of changes in the pattern of economic activities associated with changing livelihoods. In addition to this, we need to expand our knowledge about the effects on ecosystem health of economic policies that apply fixed rules in order to achieve constant yields. Examples of such policies include the maintenance of fixed sizes of cattle-herds or wildlife and fixed sustainable yields of fish and timber. Finally, it would be helpful to know more about the effect on ecosystem health of open access versus alternate communitarian and non-communitarian arrangements over ecosystem use. In this context, the expression “alternate communitarian arrangements” refers to the different ways in which small (local) communities might choose to use the flow of services provided by, for instance, ponds, streams, and threshing grounds.

KEYSTONE SPECIES AND HUMAN ACTIVITIES

Robert Paine (1974) and Charles Krebs (1985, p. 572) have noted that in any ecosystem, a particular role may be occupied by a single species, and the presence of that role may be critical to the ecosystem. Such species are called keystone species, and there is a large literature in ecology—see Paine (1974), Duggins (1980), Estes et al. (1982), Costanza et al. (1995), and Holling et al. (1995)—on keystone species. However, as Dasgupta (1996) has noted, until very recently, economists have paid no attention to keystone species in their studies of ecological-economic systems. Further, as Perrings et al. (1995a) have noted, economists in general have not recognized that it is important to develop analytical tools that can be used to determine the social value of keystone species. This state of affairs has two implications for research in ecological economics. First, it points to the paucity of society's knowledge about the interface between human activities and the well-being of keystone species, and thereby tells us that it is important to fill this lacuna in our stock of knowledge. Second, it suggests a number of specific research questions about the nexus between human activities and keystone species.

Keystone species are functionally distinct biological entities. Consequently, as compared to some other species in an ecosystem, the loss of a keystone species will generally have a much greater effect on the other species of the ecosystem, and on ecosystem functions. Although this is well known, what is not as well known is the extent to which human induced activities such as grazing have keystone species-specific effects. For instance, grazing is an important human induced activity in the semi-arid grasslands of East Africa. The elephant is a keystone species in many parts of this area (Laws, 1970; Krebs, 1985, p. 573). Grazing by ranch cattle affects the functionally different groups of grasses in these grasslands and hence has an impact on the availability of food for ungulates in general. In this context, a question of interest for ecological economists is the following:

To what extent does this grazing by ranch cattle affect the availability of food and the feeding habits of elephants? In addition, the health of an ecosystem depends on the welfare of the keystone species in that ecosystem. Therefore, the construction of measures of ecosystem health ought to incorporate the activities of keystone species into these measures. In other words, researchers need to study the functional relationships between human activities and keystone species, and between the keystone species and the health of ecosystems.

Finally, studies by Paine (1966, 1974) and others have yielded a number of generalizations concerning rocky intertidal communities. In these communities, the starfish is a keystone species. As Holling et al. (1995) have noted, in such communities, environmental disturbances can perform the same role as starfish in maintaining species diversity. Consequently, it is important to study the extent to which human activities can mimic the role played by environmental disturbances. Studies of these questions will provide useful insights into the nexus between human activities and keystone species.

OPTIMAL MANAGEMENT OF ECOSYSTEMS

For too long, ecologists and economists have approached the task of managing ecosystems in their separate ways, each behaving as if the other did not exist. For instance, standard texts in ecology such as Krebs (1985) make no mention of the roles that humans play in determining the structure and the evolution of ecosystems. Similarly, economics textbooks such as Hartwick and Olewiler (1986) pay little attention to ecological matters. As Dasgupta (1996) has noted, this separation has led economists to think of the environmental resource-base as a limitless stock of capital. In turn, an isolationist attitude to ecosystem management has led ecologists to view the human presence as

an insignificant part of the ecological landscape. As a result, ecologists have generally tended to ignore the role that economic factors play in the management of ecosystems.

This non-cooperative state of affairs is fundamentally at odds with the results of recent research in ecological economics. *Inter alia*, these results—see Perrings et al. (1995b), Swanson (1995), and Perrings (1998)—have emphasized the fact that ecological-economic systems are jointly determined. To reiterate, they ought to be studied as one system. The recent but broad acceptance of this fact has led to a number of research ventures between ecologists and economists on the subject of optimal ecosystem management. Why is this subject important? As indicated in the introductory section, ecosystems supply humankind with a flow of services. Many of these services provide the underpinning for all human activities. Consequently, as Dasgupta and Maler (1997) have noted, these services are of fundamental value. Because these services are valuable, it is important that society use (consume) these services optimally. In turn, this means that it is essential to optimally manage the ecosystems that provide these services.

Many significant questions about the optimal management of jointly determined ecosystems remain to be answered. In the remainder of this section, I shall focus on three specific questions. The reader should note that ecosystems occupy space, and this paper is all about ecosystems. This means that all the issues of this paper, and the management issue in particular, have a spatial dimension to them. While ecologists have traditionally studied space and the significance of spatial variability, economists have not. Fortunately, as Krugman (1998) has noted, in the last few years interest in spatial economics has increased dramatically and economists have now begun to systematically analyze issues related to the location of economic activity.

Perrings et al. (1995c) have noted that species that are not keystone species now but may become keystone species under different environmental conditions possess insurance value. This

means that when environmental conditions change, if these species do become keystone species, then they will perform the ecological functions that were previously performed by some other species. In this way, these species contribute towards the resilience of an ecosystem, and hence they possess insurance value. This observation leads to the question of the design of flexible management regimes. The mechanism design literature in economics—see Kreps (1990, part IV), Fudenberg and Tirole (1991, chapter 7), and Batabyal (1995, 1996, 1997, 1998a, 1998b)—is relevant here. Specifically, how do we design flexible management regimes that, *inter alia*, will recognize the potential insurance value of some species? In this context, it should be noted that the designers of such regimes, i.e., federal and/or state management agencies, generally do not have all the pertinent information about ecosystems available to them. For instance, these designers may not know the growth function of a particular species that is believed to possess insurance value. This means that this design problem is characterized by the existence of one or more sources of uncertainty. Consequently, it is pertinent to ask how the presence of uncertainty affects the design of flexible management regimes.

A second question concerns the appropriate space in which management activities ought to be carried out. For instance, it is possible to conceptualize the effects of human activities on ecosystems as perturbations or shocks. It is also clear that in economics, authorities responsible for resource management have often focused on time as the relevant decision variable. Examples include the regulation of fishing and hunting season lengths. Time is a relevant decision variable because the regulation of time, i.e., season lengths, is similar to the regulation of fishing or hunting effort. Further, as Hartwick and Olewiler (1986, pp. 298-317) have noted, under some circumstances, this kind of regulation will lead to a socially optimal equilibrium. So, given specific management objectives such as the maximization of social welfare from economic activities or the minimization

of the average social cost of economic activities, it is germane to ask about the desirability of managing shocks as opposed to time.

The third and final question relates to the conservation aspect of management. Holling et al. (1995) have noted that if we are interested in maximizing the persistence of all the species in an ecosystem, then it is important to minimize the likelihood of changes in ecosystem function. Human activities affect ecosystem functions. Therefore, it is essential to study the extent to which human activities result in changes in ecosystem functions. Further, as Schindler (1990) has noted, some functional groups are represented by a single species. Consequently, management regimes that pay special attention to the conservation of these single species must be designed. Put differently, researchers will need to study the management of ecosystems by analyzing the links between the social benefits from conservation, the persistence of ecosystem species, and changes in ecosystem functions.

CONCLUSIONS

The analysis of jointly determined ecological-economic systems calls for the adoption of a unified approach. In particular, to address this paper's five most important issues, this unified approach will need to pay equal attention to the ecological and the economic aspects of the problem of comprehending the static and the dynamic behavior of ecological-economic systems. If this unified approach is adopted, then one can expect to see three principal results.

First, the research community will have a much better idea about the kinds of phenomena that can be effectively studied using currently available theoretical and empirical tools. Further, the adoption of this kind of integrated approach will encourage other scholars to engage in research in ecological economics. Second, our understanding of the interdependencies between ecological and

economic systems will improve. Finally, in the context of the integrated approach to ecosystem management I have described, social welfare is an increasing function of ecosystem health. In turn, the health of an ecosystem depends, inter alia, on the policies that an ecosystem manager has in place to ensure that the services provided by the ecosystem are utilized wisely. Consequently, the approach I have described will produce concrete results on the effects—for instance on costs—of alternate management practices. In other words, by focusing on the optimal management of ecological-economic systems, light will be shed on how changes in ecosystem health translate into changes in social welfare.

ACKNOWLEDGMENTS

I thank an anonymous referee and Brij Gopal for their helpful comments on a previous version of this paper. I acknowledge financial support from the Faculty Research Grant program at Utah State University and from the Utah Agricultural Experiment Station, Utah State University, Logan, UT 84322-4810, by way of grant UTA 024. Approved as journal paper # 6086. The usual disclaimer applies.

REFERENCES

- Batabyal, A. A. 1995. The design perspective in resource and environmental economics. *Resource and Energy Economics* 17: 317-325.
- Batabyal, A. A. 1996. An agenda for the design and study of international environmental agreements. *Ecological Economics* 19: 3-9.
- Batabyal, A. A. 1997. Developing countries and environmental protection: the effects of budget balance and pollution ceiling constraints. *Journal of Development Economics* 54: 285-305.
- Batabyal, A. A. 1998a. Developing countries and international environmental agreements: the case of perfect correlation. *International Review of Economics and Finance* 7: 85-102.

- Batabyal, A. A. 1998b. Developing countries and environmental protection: the effects of ex ante versus ex post contracting. *Journal of Regional Science* 38: 237-251.
- Bromley, D. W. 1989. Entitlements, missing markets, and environmental uncertainty. *Journal of Environmental Economics and Management* 17: 181-194.
- Bromley, D. W. 1992. Entitlements and public policy in environmental risks. pages 1-21, In: Bromley, D. W. and Segerson, K. (Editors) *The Social Response to Environmental Risk: Policy Formulation in an Age of Uncertainty*. Kluwer Academic Publishers, Boston.
- Ciriacy-Wantrup, S. V. 1965. Relations between ecology and economics. pages 3-5, In: *Proceedings: Fourth Annual Tall Timbers Fire Ecology Conference*. Tall Timbers Research Station, Tallahassee.
- Ciriacy-Wantrup, S. V. 1971. The economics of environmental policy. *Land Economics* 47: 36-45.
- Costanza, R., Kemp, M., and Boynton, W. 1995. Scale and biodiversity in coastal and estuarine ecosystems. pages 84-125, In: Perrings, C., Maler, K. G., Folke, C., Holling, C. S., and Jansson, B. (Editors) *Biodiversity Loss. Economic and Ecological Issues*. Cambridge University Press, Cambridge.
- Cottingham, K. L., and Carpenter, S. R. 1994. Predictive indices of ecosystem resilience in models of north temperate lakes. *Ecology* 75: 2127-2138.
- Daly, H. E., and Cobb, J. B. 1989. *For the Common Good*. Beacon Press, Boston. 534 pages.
- Dasgupta, P. 1982. *The Control of Resources*. Basil Blackwell, Oxford. 223 pages.
- Dasgupta, P. 1995. Optimal development and the idea of net national product. pages 111-143, In: Goldin, I. and Winters, L. A. (Editors) *The Economics of Sustainable Development*. Cambridge University Press, Cambridge.
- Dasgupta, P. 1996. The economics of the environment. *Environment and Development Economics* 1: 387-428.
- Dasgupta, P. and Maler, K. G. 1997. The resource basis of production and consumption: an economic analysis. pages 1-32, In: Dasgupta, P. and Maler, K. G. (Editors) *The Environment and Emerging Development Issues, Volume 1*. Clarendon Press, Oxford.
- Dixit, A., Hammond, P., and Hoel, M. 1980. On Hartwick's rule for regular maximin paths of capital accumulation and resource depletion. *Review of Economic Studies* 47: 551-556.
- Duggins, D. O. 1980. Kelp beds and sea otters: an experimental approach. *Ecology* 61: 447-453.

- Estes, J. A., Jameson, R. J., and Rhode, E. B. 1982. Activity and prey selection in the sea otter: influence of population status on community structure. *American Naturalist* 120: 242-258.
- Fudenberg, D. and Tirole, J. 1991. *Game Theory*. MIT Press, Cambridge. 616 pages.
- Georgiou, S., Whittington, D., Pearce, D., and Moran, D. 1997. *Economic Values and the Environment in the Developing World*. Edward Elgar, Cheltenham. 167 pages.
- Hartwick, J. M. 1978. Substitution among exhaustible resources and intergenerational equity. *Review of Economic Studies* 45: 347-354.
- Hartwick, J. M., and Olewiler, N. D. 1986. *The Economics of Natural Resource Use*. Harper and Row, New York. 530 pages.
- Hassell, M. P. 1979. The dynamics of predator-prey interactions: polyphagous predators, competing predators and hyperparasitoids. pages 283-306, In Anderson, R. M., Turner, B. D., and Taylor, L. R. (Editors) *Population Dynamics*. Blackwell, Oxford.
- Holling, C. S., Schindler, D. W., Walker, B. W., and Roughgarden, J. 1995. Biodiversity in the functioning of ecosystems: an ecological synthesis. pages 44-83, In: Perrings, C., Maler, K. G., Folke, C., Holling, C. S., and Jansson, B. O. (Editors) *Biodiversity Loss. Economic and Ecological Issues*. Cambridge University Press, Cambridge.
- Ives, A. R. 1995. Measuring resilience in stochastic systems. *Ecological Monographs* 65: 217-233.
- Krebs, C. J. 1985. *Ecology*, 3rd edition. Harper and Row, New York. 801 pages.
- Kreps, D. M. 1990. *A Course in Microeconomic Theory*. Princeton University Press, Princeton. 850 pages.
- Krugman, P. 1998. Space: the final frontier. *Journal of Economic Perspectives* 12: 161-174.
- Laws, R. M. 1970. Elephants as agents of habitat and landscape change in East Africa. *Oikos* 21: 1-15.
- Maler, K. G. 1991. National accounting and environmental resources. *Environmental and Resource Economics* 1: 1-15.
- Meadows, D. H., Meadows, D. L., Randers, J., and Behrens, W. W. 1972. *The Limits to Growth*. Universe Books, New York. 205 pages.
- Mendelsohn, R. and Shaw, D., (Editors). 1996. *The Economics of Pollution Control in the Asia Pacific*. Edward Elgar, Cheltenham. 354 pages.

- Neubert, M. G. and Caswell, H. 1997. Alternatives to resilience for measuring the responses of ecological systems to perturbations. *Ecology* 78: 653-665.
- Paine, R. T. 1966. Food web complexity and species diversity. *American Naturalist* 100: 65-75.
- Paine, R. T. 1974. Intertidal community structure: experimental studies on the relationship between a dominant competitor and its principal predator. *Oecologia* 15: 93-120.
- Perrings, C. 1996. Ecological resilience in the sustainability of economic development. pages 231-252, In: Faucheux, S., Pearce, D., and Proops, J. (Editors) *Models of Sustainable Development*. Edward Elgar, Cheltenham.
- Perrings, C. 1998. Resilience in the dynamics of economy-environment systems. *Environmental and Resource Economics* 11: 503-520.
- Perrings, C., Maler, K. G., Folke, C., Holling, C. S., and Jansson, B. 1995a. Introduction: framing the problem of biodiversity loss. pages 1-17, In: Perrings, C., Maler, K. G., Folke, C., Holling, C. S., and Jansson, B. (Editors) *Biodiversity Loss: Economic and Ecological Issues*. Cambridge University Press, Cambridge.
- Perrings, C., Maler, K. G., Folke, C., Holling, C. S., and Jansson, B., (Editors). 1995b. *Biodiversity Loss: Economic and Ecological Issues*. Cambridge University Press, Cambridge. 332 pages.
- Perrings, C., Maler, K. G., Folke, C., Holling, C. S., and Jansson, B. 1995c. Unanswered questions. pages 301-308, In: Perrings, C., Maler, K. G., Folke, C., Holling, C. S., and Jansson, B. (Editors) *Biodiversity Loss: Economic and Ecological Issues*. Cambridge University Press, Cambridge.
- Pimm, S. L. 1991. *The Balance of Nature?* University of Chicago Press, Chicago. 434 pages.
- Schindler, D. W. 1990. Natural and anthropogenically imposed limitations to biotic richness in freshwaters. pages 425-462, In: Woodwell, G. (Editor) *The Earth in Transition*. Cambridge University Press, Cambridge.
- Solow, R. M. 1974. Intergenerational equity and exhaustible resources. *Review of Economic Studies* 41: 29-46.
- Steinman, A. D., Mulholland, P. J., Palumbo, A. V., Flum, T. F., and DeAngelis, D. L. 1991. Resilience of lotic ecosystems to a light-elimination disturbance. *Ecology* 72: 1299-1313.
- Swanson, T. M. (Editor). 1995. *The Economics and Ecology of Biodiversity Decline: The Forces Driving Global Change*. Cambridge University Press, Cambridge. 162 pages.
- Turner, R. K. 1992. Speculations on weak and strong sustainability. CSERGE GEC Working Paper 92-26. CSERGE and UCL, London.

Vatn, A. and Bromley, D. W. 1995. Choices without prices without apologies. pages 3-25, In: Bromley, D. W. (Editor) Handbook of Environmental Economics. Blackwell, Oxford.

Walker, B. H. 1993. Rangeland ecology: understanding and managing change. *Ambio* 22: 80-87.