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GOALS, AGENDA, AND POLICY RECOMMENDATIONS FOR ECOLOGICAL ECONOMICS

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ABSTRACT

This introductory chapter: 1) Summarizes the state and goals of the emerging transdisciplinary field of *ecological economics*, particularly as regards issues of sustainability; 2) provides a working agenda for research, education and policy for the coming decade to ensure sustainability; 3) provides some policy guidelines and recommendations for achieving these goals.

This chapter represents, to the extent possible, the "sense of the meeting" or consensus of the workshop which produced it. This does not mean that all the workshop participants agree with all that is said here; we can only offer one perspective. The following chapters by individual workshop participants elaborate the themes we describe and give more detailed and varied perspectives.

OVERVIEW OF THE BOOK

The book is divided into three major parts following this introductory chapter. Part I focuses on defining the basic world view of ecological economics, along with how (and why) it differs from conventional approaches. The ten papers in the section cover a broad range of perspectives. Boulding, Daly, and Hardin set the stage with incisive discussions of the root causes of the problems facing humanity and definitions of some basic ecological economic principles to build on. Page, Christensen, Norgaard and Howarth, and Norton offer perceptive insights into the problems of sustainability, discounting, and valuation. Martinez-Alier outlines some of the historical precedents for ecological economics. Funtowicz and Ravetz, and Perrings round out the section with their unique contributions on the role of uncertainty in an *ecological economic* world view and develop appropriate ways to deal with this uncertainty.

Part II of the book focuses on accounting, modeling, and analysis of ecological economic systems. It begins with El Serafy's discussion of the environment as capital. Peskin, Hueting, and Faber and Proops offer different perspectives on and methods for incorporating natural capital and services into national income accounting. Hannon and Ulanowicz extend and generalize these concepts to deal with ecosystems and combined ecological economic systems. Braat and Steetskamp offer a more elaborate modeling system for regional analysis and Cleveland rounds out the section with an analysis of resource scarcity from an ecological economics perspective.

Part III of the book deals with institutional changes necessary to achieve sustainability, and includes case studies. The first five papers in the section deal with incentives and instruments. Colin Clark offers an analysis of the perverse incentives that work against sustainability, while Costanza and Farber deal with methods to alter incentives to assure sustainability. Cumberland, and d'Arge and Spash apply these concepts to intergenerational transfers, while Zylicz attacks international transfers. Following the papers on transfers, two papers, by Mary Clark and Zucchetto, discuss the role of education in furthering the goals of ecological economics and sustainability. The section ends with five papers that offer case studies of ecological economic problems and approaches. Mitsch defines the field of ecological engineering and compares the experiences of the United States and China. Jansson takes an ecological economic look at the Baltic Sea region, Tiezzi et al. look at integrated agro-industrial ecosystems, and Cavalcanti looks at the Brazilian situation. Finally Goodland et al. offer a detailed analysis and policy recommendations for the management of moist tropical forests.

While the chapters overlap to some degree in their coverage of certain basic themes, the multiple perspectives enrich the reader's understanding of the pluralistic nature of *ecological economics.*

AN ECOLOGICAL ECONOMIC WORLD VIEW

Increasing awareness that our global ecological life support system is endangered is forcing us to realize that decisions made on the basis of local, narrow, short-term criteria can produce disastrous results globally and in the long run. We are also beginning to realize that traditional economic and ecological models and concepts fall short in their ability to deal with global ecological problems.

Ecological economics is a new *transdisciplinary* field of study that addresses the relationships between ecosystems and economic systems in the broadest sense. These relationships are central to many of humanity's current problems and to building a sustainable future but are not well covered by any existing scientific discipline.

By *transdisciplinary* we mean that *ecological economics* goes beyond our normal conceptions of scientific disciplines and tries to integrate and synthesize many different disciplinary perspectives. One way it does this is by focusing more directly on the problems, rather than the particular intellectual tools and models used to solve them, and by ignoring arbitrary intellectual turf boundaries. No discipline has intellectual precedence in an endeavor as important as achieving sustainability. While the intellectual tools we use in this quest are important, they are secondary to the goal of solving the critical problems of managing our use of the planet. We must transcend the focus on tools and techniques so that we avoid being "a person with a hammer to whom everything looks like a nail." Rather we should consider the task, evaluate existing tools' abilities to handle the job, and design new ones if the existing tools are ineffective. *Ecological economics* will use the tools of conventional economics and ecology as appropriate. The need for new intellectual tools and models may emerge where the coupling of economics and ecology is not possible with the existing tools.

How Is Ecological Economics Different from Conventional Approaches?

Ecological economics (EE) differs from both conventional economics and conventional ecology in terms of the breadth of its perception of the problem, and the importance it attaches to environment-economy interactions. It takes this wider and longer view in terms of space, time and the parts of the system to be studied.

Figure 1.1 illustrates one aspect of the relationship: the domains of the different subdisciplines. The upper left box represents the domain of "conventional" economics, the interactions of economic sectors (like mining, manufacturing, or households) with each other. The domain of "conventional" ecology is the lower right box, the interactions of ecosystems and their components with each other. The lower left box represents the inputs from ecological sectors to economic sectors. This is the usual domain of *resource* economics and environmental impact analysis: the use of renewable and nonrenewable natural resources by the economy. The upper right box represents the "use" by ecological sectors of economic "products." The products of interest in this box are usually unwanted by-products of production and the ultimate wastes from consumption. This is the usual domain *of environmental* economics and environmental impact analysis: pollution and its mitigation, prevention and mediation. *Ecological economics* encompasses and transcends these disciplinary boundaries. *Ecological economics* sees the human economy as part of a larger whole. Its domain is the entire web of interactions between economic and ecological sectors.

Table 1.1 presents some of the other major differences between *ecological economics* (EE) and conventional economics (CEcon) and conventional ecology (CEcol). These issues are covered in more detail and from a number of different perspectives in Part I of this book. The basic world view of CEcon is one in which individual human consumers are the central figures. Their tastes and preferences are taken as given and are the dominant determining force. The resource base is viewed as essentially limitless due to technical progress and infinite substitutability. Ecological economics takes a more holistic view with humans as one component (albeit a very important one) in the overall system. Human preferences, understanding, technology and cultural organization all co-evolve to reflect broad ecological opportunities and constraints. Humans have a special place in the system because they are responsible for understanding their own role in the larger system and managing it for Sustainability. This basic world view is similar to that of CEcol, in which the resource base is limited and humans are just another (albeit seldom studied) species. But EE differs from CEcol in the importance it gives to humans as a species, and its emphasis on the mutual importance of cultural and biological evolution.

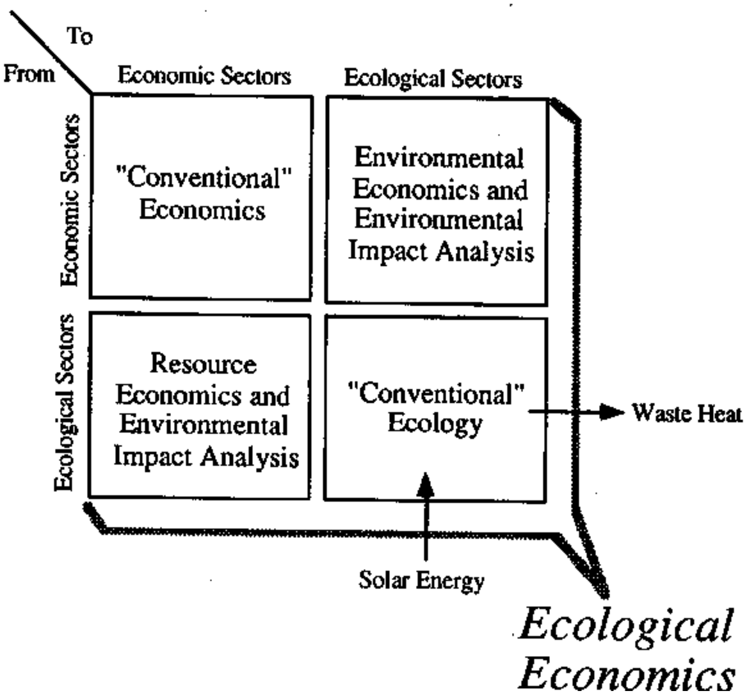

FIGURE 1.1 Relationship of domains of *Ecological Economics* and conventional economics and ecology, resource and environmental economics, and environmental impact analysis.

TABLE 1.1 Comparison of "Conventional" Economics and Ecology with *Ecological Economics*

	"Conventional" Economics	"Conventional" Ecology	Ecological Economics
Basic World View	Mechanistic, Static, Atomistic Individual tastes and preferences taken as given and the dominant force. The resource base viewed as essentially limitless due to technical progress and infinite substitutability	Evolutionary, Atomistic Evolution acting at the genetic level viewed as the dominant force. The resource base is limited. Humans are just another species but are rarely studied.	Dynamic, Systems, Evolutionary Human preferences, understanding, technology and organization co-evolve to reflect broad ecological opportunities and constraints. Humans are responsible for understanding their role in the larger system and managing it sustainably
Time Frame	Short 50 yrs max, 1-4 yrs. usual	Multiscale Days to eons, but time scales often define non-communicating sub-disciplines	Multi-Scale Days to eons, multiscale synthesis
Space Frame	Local to International Framework invarient at increasing spatial scale, basic units change from individuals to firms to countries	Local to Regional Most research has focused on smaller research sites in one ecosystems, but larger scales have become more important	Local to Global Hierarchy of scales
Species Frame	Humans Only Plants and animals only rarely included for contributary value	Non-Humans Only Attempts to find "pristine" ecosystems untouched by humans	Whole Ecosystem Including Humans Acknowledges interconnections between humans and rest of nature
Primary Macro Goal	Growth of National Economy	Survival of Species	Ecological Economic System Sustainability
Primary Micro Goal	Max Profits (firms) Max Utility (indivs) All agents following micro goals leads to macro goal being fulfilled. External costs and benefits given lip service but usually ignored	Max Reproductive Success All agents following micro goals leads to macro goal being fulfilled.	Must Be Adjusted to Reflect System Goals Social organization and cultural institutions at higher levels of the space/time hierarchy ameliorate conflicts produced by myopic pursuit of micro goals at lower levels
Assumptions About Technical Progress	Very Optimistic	Pessimistic or No Opinion	Prudently Skeptical
Academic Stance	Disciplinary Monistic, focus on mathematical tools	Disciplinary More pluralistic than economics, but still focused on tools and techniques. Few rewards for integrative work.	Transdisciplinary Pluralistic, focus on problems

The concept of *evolution* is a guiding notion for both ecology and ecological economics (see Boulding, this volume). Evolution is the process of change in complex systems through selection of transmittable traits. Whether these traits are the shapes and programmed behavioral characteristics of organisms transmitted genetically or the institutions and behaviors of cultures which are transmitted through cultural artifacts, books and tales around the campfire, they are both evolutionary processes. Evolution implies a dynamic and adapting nonequilibrium system, rather than the static equilibrium system often assumed in conventional economics. Evolution does *not* imply change in a particular direction (i.e., progress).

Ecological economics uses an expanded definition of the term "evolution" to encompass both biological and cultural change. Biological evolution is slow relative to cultural evolution. The price human cultures pay for their ability to adapt rapidly is the danger that they have become too dependent on short-run payoffs and thereby usually ignore long-term payoffs and issues of sustainability. Biological evolution imposes a built-in long-run constraint that cultural evolution does not have. To ensure sustainability, we may have to reimpose long-run constraints by developing institutions (or using the ones we have more effectively) to bring the global, long-term, multispecies, multiscale, whole systems perspective to bear on short-term cultural evolution.

The issue of humans' role in shaping the combined biological and cultural evolution of the planet is of critical importance. Humans are conscious of the processes of biological and cultural evolution and cannot avoid being anthropocentric. But in the long run, if humans are to manage the whole planet effectively, we must develop the capacity to take a broader *biocentric* perspective and to treat our fellow species with respect and fairness. We must also recognize that most natural systems are self-regulating and that the best "managerial strategy" is often to leave them alone.

The time frame, space frame, and species frame of EE all tend to be broader than CEcon and are more similar to the "frames" of CEcol. But there is an explicit recognition of the need for integrated, multiscale analysis. This view is also beginning to take hold in CEcol but it is all but absent from CEcon. In practice, CEcol all but ignores humans, CEcon ignores everything but humans, and EE tries to manage the whole system and acknowledges the interconnections between humans and the rest of nature. We must acknowledge that the human system is a subsystem within the larger ecological system. This implies not only a relationship of interdependence, but ultimately a relation of dependence of the subsystem on the larger parent system. The first questions to ask about a subsystem are: How big is it relative to the total system, how big can it be, and how big should it be? These questions of scale are only now beginning to be asked (see Daly, this volume).

The presumed goals of the systems under study are also quite distinct, especially at the macro (whole system) level. The macro goal of EE is sustainability of the combined ecological economic system. CEcol's macro goal of species survival is similar to sustainability, but is generally confined to single species and not the whole system. CEcon emphasizes growth rather than sustainability at the macro level. At the micro level, EE is unique in acknowledging the two-way interdependencies between the micro and macro levels. The conventional sciences lend to view all macro behavior as the simple aggregation of micro behavior. In EE, social organization and cultural institutions at higher levels of the space/time hierarchy ameliorate conflicts produced by myopic pursuit of micro goals at lower levels, and vice versa.

Perhaps the key distinctions between EE and the conventional sciences lie in their academic stances, and their assumptions about technical progress. As already noted, EE is transdisciplinary, pluralistic, integrative, and more focused on problems than on tools.

CEcon is very optimistic about the ability of technology to ultimately remove all resource constraints to continued economic growth. CEcol really has very little to say directly about technology, since it tends to ignore humans altogether. But to the extent that it has an opinion, it would be pessimistic about technology's ability to remove resource constraints because all other existing natural ecosystems that don't include humans are observed to be resource limited. EE is prudently skeptical in this regard. Given our high level of uncertainty about this issue, it is irrational to *bank on* technology's ability to remove resource constraints. If we guess wrong then the result is disastrous—irreversible destruction of our resource base and civilization itself. We should, at least for the time being, assume that technology will *not* be able to remove resource constraints. If it does, we can be pleasantly surprised. If it does not, we are still left with a sustainable system. EE assumes this prudently skeptical stance on technical progress.

A RESEARCH AGENDA FOR ECOLOGICAL ECONOMICS

To achieve sustainability, several steps are necessary including innovative research. This research should not be divorced from the policy and management process, but rather integrated with it. The research agenda for ecological economics that we suggest below is a snapshot, a first guess, intended to begin the process of defining topics for future ecological economic research rather than be the final word. The list of topics can be divided into five major parts: 1) sustainability: maintaining our life support system; 2) valuation of natural resources and natural capital; 3) ecological economic system accounting; 4) ecological economic modeling at local, regional, and global scales; and 5) innovative instruments for environmental management. Some background on each of these topics is given below, followed by a nonprioritized list of the major research questions.

Sustainability: Maintaining Our Life-Support System

Background

"Sustainability" does not imply a static, much less a stagnant, economy, but we must be careful to distinguish between "growth" and "development." Economic growth, which is an increase in quantity, cannot be sustainable indefinitely on a finite planet. Economic development, which is an improvement in the quality of life without necessarily causing an increase in quantity of resources consumed, may be sustainable. Sustainable growth is an impossibility. Sustainable development must become our primary long-term policy goal (see Boulding, this volume, and Daly, this volume, for more on these ideas).

The most obvious danger of ignoring the role of nature in economics is that nature is the economy's life support system, and by ignoring it we may inadvertently damage it beyond it's ability to repair itself. Indeed, there is much evidence that we have already done so. Several authors have stressed the fact that current economic systems do not *inherently* incorporate any concern about the sustainability of our natural life support system and the economies which depend on it (e.g., Costanza and Daly 1987; Hardin, this volume, C. Clark, this volume). Pearce (1987) discusses the reasons for the inability of existing forms of economic organization (free market, mixed, planned) to guarantee sustainability. In an important sense, sustainability is merely justice with respect to future generations. This includes future generations of other species, even though our main interest may be in our own species.

Sustainability has been variously construed (cf. Pezzey 1989; World Commission on Environment and Development 1987) but a useful definition is the amount of consumption that can be continued indefinitely without degrading capital stocks—including "natural capital" stocks (see El Serafy, this volume). In a business, capital stock includes long-term assets such as buildings and machinery that serve as the means of production. Natural capital is the soil and atmospheric structure, plant and animal biomass, etc., that, taken together, forms the basis of all ecosystems. This natural capital stock uses primary inputs (sunlight) to produce the range of ecosystem services and physical natural resource flows. Examples of natural capital include forests, fish populations and petroleum deposits. The natural resource flows yielded by these natural capital stocks are, respectively, cut timber, caught fish, and pumped crude oil. We have now entered a new era in which the limiting factor in development is no longer manmade capital but remaining natural capital. Timber is limited by remaining forests, not sawmill capacity; fish catch is limited by fish populations, not by fishing boats; crude oil is limited by the accessibility of remaining petroleum deposits, not by pumping and drilling capacity. Most economists view natural and manmade capital as substitutes rather than complements. Consequently, neither factor can be limiting. Only if factors are complementary can one be limiting. Ecological economists see manmade and natural capital as fundamentally complementary and therefore emphasize the importance of limiting factors and changes in the pattern of scarcity. This is a fundamental difference that needs to be reconciled through debate and research.

Definitions of sustainability are also obviously dependent on the time and space scale we are using. Rather than trying to determine the *correct* time and space scale for sustainability we need to concentrate on how the different scales interact and how we might construct *multiscale* operational definitions of sustainability.

While acknowledging that the sustainability concept requires much additional research, we devised the following working definition of sustainability: *Sustainability* is a relationship between dynamic human economic systems and larger dynamic, but normally slower-changing ecological systems, in which 1) human life can continue indefinitely, 2) human individuals can flourish, and 3) human cultures can develop; but in which effects of human activities remain within bounds, so as not to destroy the diversity, complexity, and function of the ecological life support system.

Major Research Questions

- What do we mean by (and how do we quantify) "health" and "sustainability" in ecological and economic systems?
- What is the hierarchy (in time and space) of goals for these systems and how is sustainability defined at different levels in the hierarchy? What conflicts arise between setting overall system sustainability goals and providing subgroup, or cultural, autonomy?
- What are the sustainable levels of population and per capita resource use, and what are the paths to achieve these?
- What kinds of actions can benefit the future without harming the present?
- How can sustainability criteria be incorporated in quantitative indices of national income, wealth, and welfare? (See also "Ecological Economic Modeling at Local, Regional and Global Scales" below.)
- What is the degree of substitutability between natural and manmade capital, and ecological and economic services, and how does this influence sustainability?
- Do the basic assumptions underlying current economic and ecological paradigms need to be revised to incorporate sustainability criteria and what are the implications of alternative assumptions?
- How can basic ecological models and principles be incorporated into operational definitions of sustainability?
- What can we learn from the study of historical human societies and natural systems that have proven to be sustainable about the general characteristics of sustainable systems?
- How can we design better institutions and instruments to assure sustainability?
- What are the conditions by which international trade may be made both economically equitable and environmentally sustainable for all parties?

Valuation of Ecosystem Services and Natural Capital

Background

To achieve sustainability, we must incorporate ecosystem goods and services into our economic accounting. The first step is to determine values for them comparable to those of economic goods and services. In determining values, we must also consider how much of our ecological life support systems we can afford to lose. To what extent can we substitute manufactured for natural capital, and how much of our natural capital is irreplaceable (El Serafy, this volume)? For example, could we replace the radiation screening services of the ozone layer which are currently being destroyed?

Some argue that we cannot place economic value on such "intangibles" as human life, environmental aesthetics, or long-term ecological benefits. But, in fact, we do so every day. When we set construction standards for highways, bridges and the like, we value human life—acknowledged or not—because spending more money on construction would save lives. To preserve our natural capital, we must confront these often difficult choices and valuations directly rather than denying their existence.

Because of the inherent difficulties and uncertainties in determining values, ecological economics acknowledges several different independent approaches. There is no consensus on which approach is right or wrong—they all tell us something—but there is agreement that better valuation of ecosystem services is an important goal for ecological economics.

The conventional economic view defines value as the expression of individualistic human preferences, with the preferences taken as given and with no attempt to analyze their origins or patterns of long-term change. For goods and services with few long-term impacts (like tomatoes or bread) that are traded in well-functioning markets with adequate information, market ("revealed preference") valuations work well.

But ecological goods and services (like wetland sewage treatment or global climate control) are long-term by nature, are generally not traded in markets (no one owns the air or water), and information about their contribution to individual's well-being is poor. To determine their value, economists try to get people to reveal what they would be willing to pay for ecological goods and services in hypothetical markets. For example, we can ask people the maximum they would pay to use national parks, even if they don't have to actually pay it. The quality of results in this method depends on how well informed people are; it does not adequately incorporate long-term goals since it excludes future generations from bidding in the markets. Also, it is difficult to induce individuals to reveal their true willingness to pay for natural resources when the question is put directly. Contingent referenda (willingness to be taxed as a citizen along with other citizens, as opposed to willingness to pay as an individual) is superior to ordinary willingness to pay studies in this regard.

In practice, valuation or shadow pricing of environmental functions may require some collectively set quantitative standard. Then shadow prices can be calculated subject to the constraint represented by that standard (see Hueting, this volume).

An alternative method for estimating ecological values assumes a biophysical basis for value (see Costanza 1980; Cleveland et al. 1984; Costanza et al. 1989; Costanza, this volume; Cleveland, this volume). This theory suggests that in the long run humans come to value things according to how costly they are to produce, and that this cost is ultimately a function of how organized they are relative to their environment. To organize a complex structure takes energy, both directly in the form of fuel and indirectly in the form of other organized structures like factories. For example, a car is a much more organized structure than a lump of iron ore; therefore, it takes a lot of energy (directly and indirectly) to organize iron ore into a car. The amount of solar energy required to grow forests can therefore serve as a measure of their energy cost, their organization, and hence, according to this theory, their value.

The point that must be stressed is that the economic value of ecosystems is connected to their physical, chemical, and biological role in the long-term, global system—whether the present generation of humans fully recognizes that role or not. If it is accepted that each species, no matter how seemingly uninteresting or lacking in immediate utility, has a role in natural ecosystems (which *do* provide many direct benefits to humans), it is possible to shift the focus away from our imperfect short-term perceptions and derive more accurate values for long-term ecosystem services. Using this perspective we may be able to better estimate the values contributed by, say, maintenance of water and atmospheric quality to long-term human well-being. Obviously, these services are vital and of infinite value at some level. The valuation question relates to marginal changes, incremental tradeoffs between, say, forested land and agricultural land on a scale of hundreds of acres rather than hundreds of square miles. The notion of safe minimum standards championed by a few economists seems relevant to the protection of critical levels of natural capital against excess myopic marginal conversion, or large-scale conversion, into manmade capital. Of course, in a perfect system, marginal valuations would become prohibitive if the safe minimum standard were transgressed. But systems are far from perfect and redundancy in the interest of prudence is not extravagance.

Major Research Questions

- How do we measure the value of ecosystem services and natural capital? Under what conditions can values be translated to single scales e.g., money, utility or energy?
- Do measures based on subjective preferences (contingent valuation, contingent referenda, willingness to pay) have any relationship to values based on ecosystem functioning and energy flows?
- What is the appropriate discount rate to apply to ecosystem services?
- What (or where) are the thresholds of irreversible degradation for natural resources?

Ecological Economic System Accounting

Background

Gross National Product, as well as other related measures of national economic performance have come to be extremely important as policy objectives, political issues and benchmarks of the general welfare. Yet GNP as presently defined ignores the contribution of nature to production, often leading to peculiar results.

For example, a standing forest provides real economic services for people: by conserving soil, cleaning air and water, providing habitat for wildlife, and supporting recreational activities. But as GNP is currently figured, only the value of harvested timber is calculated in the total. On the other hand, the billions of dollars that Exxon spent on the Valdez cleanup—and the billions spent by Exxon and others on the more than 100 other oil spills in the last 16 months—all actually *improved* our apparent economic performance. Why? Because cleaning up oil spills creates jobs and consumes resources, all of which add to GNP. Of course, these expenses would not have been necessary if the oil had not been spilled, so they shouldn't be considered "benefits." But GNP adds up all production without differentiating between costs and benefits, and is therefore not a very good measure of economic health.

In fact, when resource depletion and degradation are factored into economic trends, what emerges is a radically different picture from that depicted by conventional methods.

For example, Herman Daly and John Cobb (Daly and Cobb 1989) have attempted to adjust GNP to account mainly for depletions of natural capital, pollution effects, and income distribution effects by producing an "index of sustainable economic welfare" (ISEW). They conclude that while GNP in the United States rose over the 1956-1986 interval, ISEW remained relatively unchanged since about 1970. When factors such as loss of farms and wetlands, costs of mitigating acid rain effects, and health costs caused by increased pollution, are accounted for, the US economy has not improved at all. If we continue to ignore natural ecosystems, we may drive the economy down while we think we are building it up. By consuming our natural capital, we endanger our ability to sustain income. Daly and Cobb acknowledge that many arbitrary judgments go into their ISEW, but claim nevertheless that it is less arbitrary than GNP as a measure of welfare. John Cobb and his group at Claremont have continued work on the index and their procedure is worth mentioning as a model for scholarly debate. Cobb sent the ISEW to a number of standard economists for criticism, offering an honorarium and contracting to publish their criticisms along with a revised version of the ISEW that would take account of their criticism, or else explain why that could not or should not be done. The result has been a fruitful interchange and better mutual understanding.

There are a number of additional promising approaches to accounting for ecosystem services and natural capital being developed (see El Serafy, Hannon, Hueting, Peskin, Faber and Proops, and Ulanowicz, this volume) and this area promises to be a major focus of research in ecological economics. The approaches are based on differing assumptions, but share the goal of attempting to quantify ecological economic interdependencies and arriving at overall system measures of health and performance. The economist Wassily Leontief (1941) was the first to attempt detailed quantitative descriptions of complex systems to allow a complete accounting of system interdependencies. Leontiefs input-output (I-O) analysis has become a standard conceptual and applied tool in economic accounting. Isard (1972) was the first to attempt combined ecological economic system I-O analysis. Combined ecological economic system I-O models have been proposed by several other authors as well (Daly 1968; Victor 1972; Cumberland 1987). Ecologists have also applied I-O analysis to the accounting of material transfers in ecosystems (Hannon 1973,1976, 1979, this volume; Costanza and Neill 1984; Costanza and Hannon 1989). We refer to the total of all variations of the analysis of ecological and/or economic networks as *network analysis.*

Network analysis holds the promise of allowing an integrated quantitative treatment of combined ecological economic systems and the "pricing" of commodities in ecological and/or economic systems (Costanza, this volume; Hannon, this volume; Costanza and Hannon 1989; Ulanowicz 1980, 1986, this volume; Wulff et al. 1989). This kind of analysis may provide the basis for a quantitative and general index of system health applicable to both ecological and economic systems.

Major Research Questions

- How can we create better systems of national, regional and global accounting to include natural resource depletion and ecological impacts?
- How can we develop systems for accounting for and managing transnational environmental impacts?
- How can we develop network based measures of system health that are applicable t both ecological and economic systems?
- How can we use network based measures of system interdependence (such as energ intensities) to evaluate components in both ecological and economic systems?

Ecological Economic Modeling at Local, Regional, and Global Scales

Background

Since ecosystems are being threatened by a host of human activities, protecting and preserving them requires the ability to understand the direct and indirect effects of human activities over long periods of time and over large areas. Computer simulations are now becoming important tools to investigate these interactions and in all other areas of science as well. Without the sophisticated global atmospheric simulations now being done, our understanding of the potential impacts of increasing CO2 concentrations in the atmosphere due to fossil fuel burning would be much more primitive. Computer simulations can now be used to understand not only human impacts on ecosystems, but also our economic dependence on natural ecosystem services and capital, and the interdependence between ecological and economic components of the system (see, for example Braat, this volume; Costanza et al. 1990).

Several recent developments make such computer simulation modeling feasible, including the accessibility of extensive spatial and temporal data bases and advances in computer power and convenience. Computer simulation models are potentially one of our best tools to help understand the complex functions of integrated ecological economic systems.

But even with the best conceivable modeling capabilities, we will always be confronted with large amounts of uncertainty about the response of the environment to human actions (see Funtowicz and Ravetz, this volume). Learning how to effectively manage the environment in the face of this uncertainty is critical (see Perrings, this volume).

The research program of ecological economics will pursue an integrated, multiscale transdisciplinary, and pluralistic, approach to quantitative ecological economic modeling while acknowledging the large remaining uncertainty inherent in modeling these system; and developing new ways to effectively deal with this uncertainty.

Major Research Questions

- What are appropriate model structures for a range of urban, agricultural, and natura subsystems, at several hierarchical scales?
- How can these models best be tested, scaled and integrated?
- How can existing data sources (i.e., remote sensing images, national accounting data best be utilized in building, calibrating and testing ecological economic models a multiple scales?

- What role does biological diversity play in the health and sustainability of ecological economic systems?
- How can simulation modeling results best be used in system accounting and natural ecosystem valuation?
- What are the most appropriate roles of simulation, analytical, and optimization models? What should be their relationship to accounting frameworks?
- How are changes in the quality and cost of natural resources, i.e., rain forests, tropical seas, or grasslands to be measured? How do such changes affect economic welfare?
- Are there general system principles which govern the economy-ecology relationship?
- What viewpoints, modeling mechanisms system variables and other tools or techniques from economic models can be usefully applied to ecosystem models, and vice versa.
- How can intergenerational distribution be addressed analytically as well as ethically?
- What is the appropriate role of chaotic modeling in analyzing ecological economic problems with large degrees of uncertainty?
- How can we develop a philosophy of modeling which is open to the emergence of novelty and consistent with the evolutionary, dynamic, whole systems, multiscale paradigm?
- How do we model the interactions among local, regional, and global levels of ecological economic systems?

Innovative Instruments for Environmental Management

Background

Current systems of regulation are not very efficient at managing environmental resources for sustainability, particularly in the face of uncertainty about long-term values and impacts. They are inherently reactive rather than proactive. They induce legal confrontation, obfuscation, and government intrusion into business. Rather than encouraging long-range technical and social innovation, they tend to suppress it. They do not mesh well with the market signals that firms and individuals use to make decisions and do not effectively translate long-term global goals into short-term local incentives.

We need to explore promising alternatives to our current command and control environmental management systems, and to modify existing government agencies and other institutions accordingly. The enormous uncertainty about local and transnational environmental impacts needs to be incorporated into decision-making. We also need to better understand the sociological, cultural, and political criteria for acceptance or rejection of policy instruments.

One example of an innovative policy instrument currently being studied is a flexible environmental assurance bonding system designed to incorporate environmental criteria and uncertainty into the market system, and to induce positive environmental technological innovation (Perrings 1989; Costanza and Perrings 1990; Perrings, this volume).

In addition to direct charges for known environmental damages, a company would be required to post an assurance bond equal to the current best estimate of the largest potential future environmental damages; the money would be kept in interest-bearing escrow accounts. The bond (plus a portion of the interest) would be returned if the firm could show that the suspected damages had not occurred or would not occur. If they did, the bond would be used to rehabilitate or repair the environment and to compensate injured parties. Thus, the burden of proof would be shifted from the public to the resource-user and a strong economic incentive would be provided to research the true costs of environmentally damaging activities and to develop cost-effective pollution control technologies. This is an extension of the "polluter pays" principle to "the polluter pays for uncertainty as well." Other innovative policy instruments include tradeable pollution and depletion quotas at both national and international levels. Also worthy of mention is the newly emerging Global Environmental Facility of the World Bank that will provide concessionary funds for investments that reduce global externalities.

Major Research Questions

- What regulatory or incentive-based instruments are most appropriate for assuring sustainability?
- How can government and other institutions be modified to better account and respond to environmental impacts?
- What is the appropriate role for economic incentives and disincentives in managing ecological economic systems?
- What sociological, political, ethical, or other factors have limited acceptance of economic incentive-based instruments, and can these factors be addressed?
- How can we develop experimental economics in order to predict behavioral responses to new management instruments? What role might computer modeling play in this development?
- What is the impact of social security systems for limiting population growth?
- How do we equitably limit world population without oppressive programs?
- How do we develop mechanisms to lengthen the time horizons of institutions at all levels?
- What institutions are most effective at preserving the pool of genetic information; preserving the ecological knowledge of indigenous peoples; and facilitating cultural adaptations to environmental and/or technological change?
- What international institutions are available or necessary to assure local and global sustainability?
- Why are excise taxes on materials and energy (which are relatively effective and simple to conceptualize and design) so hard to implement politically, and can the obstacles to implementing these mechanisms be removed?

POLICY RECOMMENDATIONS

The following represents a limited set of policy recommendations on which the workshop participants reached general consensus. It is not prioritized, nor is it comprehensive, nor does it imply that all the participants were in complete agreement.

But it does represent the spectrum of policy recommendations that the workshop participants felt comfortable with as a starting point for further discussion.

Sustainability as the Goal

We should institute a consistent goal of sustainability in all institutions at all levels from local to global. We should strive to address prevailing values and decision-making processes by increasing the awareness of institutions and persons about ecological sustainabilily. We should promote long-term thinking, the use of a systems approach in decision-making, and use of "ecological auditors" (i.e., trained environmental professionals) by public and private institutions whose activities affect the environment.

For example, the World Bank is an important global institution that directly affects economic policy, and those policies severely affect the environment, especially in developing nations. We recommend that the bank and similar institutions require that all projects meet the following criteria: For renewable resources, the rate of harvest should not exceed the rate of regeneration (sustainable yield) and the rates of waste generation from projects should not exceed the assimilative capacity of the environment (sustainable waste disposal). For nonrenewable resources, the rates of waste generation from projects shall not exceed the assimilative capacity of the environment and the depletion of the nonrenewable resources should require comparable development of renewable substitutes for that resource. These are safe, minimum sustainability standards; and once met, the bank should then select projects for funding that have the highest rates of return based on other, more traditional economic criteria.

We recognize that this policy will be difficult at first, and that the policies will likely shift as more information is developed about managing for sustainability. However, there is a need for major institutions not only to affirm, but to operationalize the goal of sustainability, because of the global scope of their programs and because of the impact their example will provide for smaller institutions worldwide. We recognize that goal setting is an ethical issue, and that it is absurd to ignore the normative preconditions of policy, however necessary it may be to avoid mixing normative and positive statements in analysis. Both economists and ecologists, if they want to talk about policy, must offer much more explicit ethical support for their goals, whether sustainability or growth.

Maintaining Natural Capital to Assure Sustainability

A minimum necessary condition for sustainability is the maintenance of the total natural capital stock at or above the current level. While a lower stock of natural capital may be sustainable, given our uncertainty and the dire consequences of guessing wrong, it is best to at least provisionally assume that the we are at or below the range of sustainable stock levels and allow no further decline in natural capital. This "constancy of total natural capital" rule can thus be seen as a prudent minimum condition for assuring sustainability, to be abandoned only when solid evidence to the contrary can be offered. There is disagreement between technological optimists (who see technical progress eliminating all resource constraints to growth and development) and technological skeptics (who do not see as much scope for this approach and fear irreversible use of resources and damage to natural capital). By maintaining total system natural capital at current levels (preferably by using higher severance and consumption taxes), we can satisfy both the skeptics (since resources will be conserved for future generations) and the optimists (since this will raise the price of natural capital resources and more rapidly induce the technical change they predict). By limiting physical growth, only development is allowed and this may proceed without endangering sustainability.

Improving Our Use of Policy Instruments

We need to use a wide variety of policy instruments including regulation, property rights, permits, marketable permits, fees, subsidies and bonds to assure sustainability. Criteria for use of policy instruments are: equity, efficiency, scientific validity, consensus, frugality and environmental effectiveness. We should institute regulatory reforms to promote appropriate use of financial, legal and social incentives. We may use market incentives where appropriate in allocation decisions. In decisions of scale, individual freedom of choice must yield to democratic collective decision making by the relevant community.

Economic Incentives: Linking Revenues and Uses

We should implement fees on the destructive use of natural capital to promote more efficient use, and ease up on income taxes, especially on low incomes in the interest of equity. Fees, taxes and subsidies should be used to change the prices of activities that interfere with sustainability versus those that are compatible with it. This can be accomplished by using the funds generated to support an alternative to undesirable activities that are being taxed. For example, a tax on all greenhouse gases, with the size of the tax linked to the impact of each gas could be linked to development of alternatives to fossil fuel. Gasoline tax revenues could be used to support mass transit and bike lanes. Current policies that subsidize environmentally harmful activities should be stopped. For example, subsidies on virgin material extraction should be stopped. This will also allow recycling options to effectively compete. Crop subsidies that dramatically increase pesticide and fertilizer use should be eliminated, and forms of positive incentives should also be used. For example, debt for nature swaps should be supported and should receive much more funding. We should also offer prestigious prizes for work that increases awareness of, or contributes to, sustainability issues, such as changes in behavior that develop a culture of maintenance (i.e., cars that last for 50 years) or promotes capital and resource saving improvements (i.e., affordable, efficient housing and water supplies).

Ecological Economic Research

While economics has developed many useful tools of analysis, it has not directed these tools toward the thorny questions that arise when considering the concept and implementation of sustainability. In particular, we need to better understand preference formation, and especially time preference formation. We also needs to understand how individual time preferences and group time preferences may differ, and how the preferences of institutions that will be critical to the success or failure of sustainability are established. We have heretofore paid too little attention to ecological feedbacks. An understanding of these will be critical to the implementation of sustainability goals, whatever they may be. We need to concentrate on the valuation of important non-market goods and services provided by ecosystems. We need to better understand the effects of various regulatory instruments that can be utilized to attain sustainability. This may require experimental testing of behavior in a laboratory context. Most importantly, we need to study how positive sustainability incentives can be employed to induce reluctant participants to lengthen their time horizons and think globally about their resource policies.

We also need to develop an ecological history of the planet (to complement the existing human economic history) that would contain trends of resource use, development and exhaustion, changes in science and technology, etc. We should promote the use (as one of a bundle of decision-making tools) of broad benefit/cost analyses that includes the consideration of all market and non-market costs and benefits.

Ecological Economics Education

Our education system is currently characterized by overspecialization and disciplinary isolation. We need to develop transdisciplinary curricula and job and academic support systems for both specialists and generalises. This needs to be combined with an emphasis on the value of general education and personal development, versus the more narrow training of professional technical specialists.

We need to develop an ecological economics core curriculum and degree granting programs that embody the skills of both economics and ecology. This implies a curriculum with some blending of physical, chemical and biological sciences and economics. Within this curriculum quantitative methods are essential, but they should be problem directed rather than just mathematical tools for their own sake.

There is a need to develop a capacity for experimentation that provides ecological economics with a solid empirical base built upon creative and comprehensive theory. We need to develop extension programs that can effectively transfer information among both disciplines and nations.

We should promote at all levels education that weaves together fundamental understanding of the environment with human economic activities and social institutions, and promotes research that facilitates this interweaving process. Particularly, awareness by the media of the common benefits of sustainability should be promoted to insure accuracy in reporting, and the media should be encouraged to use opportunities to educate others through mechanisms such as special reports and public service announcements. We should promote education of broadly-trained environmental scientists, whose jobs will be to provide on-going environmental assessment as an addition to the decision-

making processes of various institutions, and as an addition to the assessments now being provided by economic analysts. The ISEE and other international institutions can (and should) provide a vehicle to help students and others focus on "big picture" questions and problems.

Institutional Changes

Institutions with the flexibility necessary to deal with ecologically sustainable development are lacking. Indeed, many financial institutions are built on the assumption of continuous exponential growth and will face major restructuring in a sustainable economy. Many existing institutions have fragmented mandates and policies, and often have not optimally used market and non-market forces to resolve environmental problems. They also have conducted inadequate benefit/cost analyses by not incorporating ecological costs; used short-term planning horizons; inappropriately assigned property rights (public and private) to resources; and made inappropriate use of incentives.

There is a lack of awareness and education about sustainability, the environment, and causes of environmental degradation. In addition, much environmental knowledge held by indigenous peoples is being lost, as is knowledge of species, particularly in the tropics. Institutions have been slow to respond to new information and shifts in values, for example, concerns about threats to biodiversity or the effects of rapid changes in communications technologies. Finally, many institutions do not freely share or disseminate information, do not provide public access to decision making, and do not devote serious attention to determining and representing the wishes of their constituencies.

Many of these problems are a result of the inflexible bureaucratic structure of many modern institutions. Experience (i.e., Japanese industry) has shown that less bureaucratic, more flexible, more peer-to-peer institutional structures can be much more efficient and effective. We need to de-bureaucratize institutions so that they can effectively respond to the coming challenges of achieving sustainability.

REFERENCES

Cleveland, C. J., R. Costanza, C. A. S. Hall, and R. Kaufmann. 1984. Energy and the United States Economy: A Biophysical Perspective. *Science* 225:890-897.

Costanza, R. 1980. Embodied Energy and Economic Valuation. *Science* 210:1219-1224.

Costanza, R. and H. E. Daly. 1987. Toward an Ecological Economics. *Ecological Modelling* 38:1-7

Costanza, R. and B. M. Hannon. 1989. Dealing with the "Mixed Units" Problem in Ecosystem Network Analysis. In F. Wulff, J. G. Field, and K. H. Mann, eds., *Network Analysis of Marine Ecosystems: Methods and Applications,* pp. 90-115. Coastal and Estuarine Studies Series. Heidelberg: Springer-Verlag.

Costanza, R. and C. Neill. 1984. Energy Intensities, Interdependence, and Value in Ecological Systems: A Linear Programming Approach. *Journal of Theoretical Biology* 106:41-57

Costanza, R. and C. H. Perrings. 1990. A Flexible Assurance Bonding System for Improved Environmental Management. *Ecological Economics* 2:57-76.

Costanza, R., S. C. Farber, and J. Maxwell. 1989. The Valuation and Management of Wetland Ecosystems. *Ecological Economics* 1:335-361.

Costanza, R., F. H. Sklar, and M. L. White. 1990. Modeling Coastal Landscape Dynamics. *BioScience* 40:91-107

Cumberland, J. H. 1987. Need Economic Development be Hazardous to the Health of the Chesapeake Bay? *Marine Resource Economics* 4:81-93.

Daly, H. 1968. On Economics as a Life Science. *Journal of Political Economy* 76:392-406.

Daly, H. E. and J. B. Cobb, Jr. 1989. *For The Common Good: Redirecting the Economy Toward Community, the Environment, and a Sustainable Future.* Boston: Beacon.

Hannon, B. 1973. The Structure of Ecosystems. *J. Theo. Biology* 41:535-46.

Hannon, B. 1976. Marginal Product Pricing in the Ecosystem. *J. Theo. Biology* 56:256-267.

Hannon, B., 1979, Total Energy Costs in Ecosystems. *J. Theo. Biology,* 80:271-293.

Isard, W. 1972. *Ecologic-Economic Analysis for Regional Development.* New York: The Free Press.

Leontief, W. 1941. *The Structure of American Economy, 1919-1939.* New York: Oxford University Press.

Pearce, D. 1987. Foundations of an Ecological Economics. *Ecological Modelling.* 38:9-18.

Perrings, C. 1989. Environmental Bonds and the Incentive to Research in Activities Involving Uncertain Future Effects. *Ecological Economics* 1:95-110.

Pezzey, J. 1989. Economic Analysis of Sustainable Growth and Sustainable Development. Environment Department Working Paper No. 15. Washington, D.C.: The World Bank.

Ulanowicz, R. E.: 1980. An Hypothesis on the Development of Natural Communities. /. *theor. Biol.* 85: 223-245.

Ulanowicz, R. E. 1986. *Growth and Development: Ecosystems Phenomenology.* New York: Springer-Verlag.

Victor, P. A. 1972. *Pollution, Economy and Environment.* Toronto: University of Toronto Press

World Commission on Environment and Development. 1987. *Our Common Future.* Oxford: Oxford University Press.

Wulff, F., J. G. Field and K. H. Mann. 1989. *Network Analysis of Marine Ecosystems: Methods and Applications.* Coastal and Estuarine Studies Series. Heidelberg: Springer-Verlag.