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Toward consilience between biology and economics: the contribution of Ecological Economics

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Abstract

During its ten year history *Ecological Economics* has made a real difference in the way economists look at the natural world and in the way biologists look at the economy. In this survey article we examine the contributions to the *Journal* in terms of E.O. Wilson's concept of 'consilience', that is, his argument that the methods and assumptions of any field of study should be consistent with the known and accepted facts in other disciplines. In particular, we examine the contributions of ecological economics to reconciling the economic theory of the consumer and producer with biophysical reality.

Keywords: Biodiversity; Consilience; Environmental valuation; Evolutionary economics; Production theory; Scale; Utility theory; Weak and strong sustainability

1. Introduction

In the first issue of *Ecological Economics* Robert Costanza stressed that the new field addresses 'the relationships between ecosystems and economic systems in the broadest sense', (Costanza, 1989p. 1). Also in that issue, Paul Ehrlich (Ehrlich, 1989, p. 9) called for a deeper level of cooperation between biologists and economists: 'A certain frankness and willingness both to give and to receive criticism (and to reject erroneous criticism) is required if ecologists and economists–basically members of sister disci-

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plines–are to forge an understanding that will permit them to work together to solve the human predicament'. In the years since its birth *Ecological Economics* has attempted to reconcile not only the conflict between economies and ecosystems, but also to integrate the theoretical approaches of biology and economics. This reconciliation requires a degree of interdisciplinarit that goes beyond mere cooperation between economists and biologists. It requires that practitioners from one discipline actually learn something about the theory and the content of the other discipline.

Ten years after *Ecological Economics* was launched, the rest of the academic world seems to be catching up to the original vision. It is clear that we are on a wave of truly interdisciplinary understanding and cooperation between biologists and economists. Not surprisingly, support for ecological economics among biologists continues to be strong (Pimm, 1997; Ehrlich, 1997). The basic concerns that led to the creation of ecological economics are now almost conventional wisdom in the scientific community. In her Presidential Address to the American Association for the Advancement of Science, the biologist Jane Lubchenco, presented what amounts to a manifesto for ecological economics:

> As the magnitude of human impacts on the ecological systems of the planet becomes apparent, there is increased realization of the intimate connections between these systems and human health, the economy, social justice and national security. The concept of what constitutes 'the environment' is changing rapidly. Urgent and unprecedented environmental and social changes challenge scientists to define a new social contract. This contract represents a commitment on the part of all scientists to devote their energies and talents to the most pressing problems of the day, in proportion to their importance, in exchange for public funding. The new and unmet needs of society include more comprehensive information, understanding, and technologies for society to move toward a more sustainable biosphere–one which is ecologically sound, economically feasible, and socially just. (Lubchenco, 1998, p. 491)

Biologists have now accepted the fact that we cannot save the 'environment' in isolation from the other problems of economy and society, a basic tenet of ecological economics (Daly, 1992). Ecological economics is broader than nature conservation (Norton, 1995a).

Biologists and other scientists are beginning to challenge mainstream economists to make their theories more realistic. E.O. Wilson (Wilson, 1998, p. 197) writes:

> They can be summarized in two labels: Newtonian and hermetic. Newtonian, because economic theorists aspire to find simple, general laws that cover all possible economic arrangements. Universality is a logical and worthy goal, except that the innate traits of human behavior ensure that only a minute set of such arrangements is possible or even probable...The models also fall short because they are hermetic–that is, sealed off from the complexities of human behavior and the constraints imposed by the environment.

Wilson's categorization of economics is particularly relevant to the debate between economists and ecologists regarding the valuation of ecosystem functions. Both the scientific findings of ecology and the theoretical approaches of that discipline conflict with some of the basic assumptions of neoclassical economic theory. Scientific findings from ecology show increasing tensions between economic systems and ecological systems (Ayres, 1993, Ayres, 1995; Farrow, 1995; Gowdy and McDaniel, 1995). Ecological theory is also important because it has the potential to revolutionize the way economists think about the economy and the natural world (Binswanger, 1993; Costanza and Patten, 1995; Norton, 1995a; Lunney et al. 1997; Ring, 1997). Central to ecological theory are concepts like irreversibility, uncertainty, and holism which can enrich and expand the scope of economic theory.

It should be pointed out that not all agree that there is a conflict between economy and ecology. Vedeld (1994) argues that economy and ecology do not deal with the same issues. Economists focus on the market as a supplier of advice about human preferences, while ecologists study natural systems and processes. The laws of economics and the laws of ecology, he argues, are not contradictory, but rather incommensurable; they apply to two different systems. This may be true of neoclassical theory and biology, but most ecological economists would argue that economics should be broadened to encompass more than the study of market or pseudo-market values. Referring to the different subject matters of economics and ecology, and to their areas of overlap, Costanza (Costanza, 1989, p. 1) writes: '*Ecological Economics* aims to extend these areas of overlap. It will include neoclassical environmental economics and ecological impact studies as subsets, but will also encourage new ways of thinking about the linkages between ecological and economic systems'.

In this survey we focus on the contributions this *Journal* has made during the last 10 years in addressing Wilson's criticism of the hermetic nature of standard economics. We take as our starting point Wilson's argument that one feature of any good scientific theory or model is 'consilience', that is, the assumptions of one branch of knowledge should conform to the accepted facts of other branches: 'Units and processes of a discipline that conform with solidly verified knowledge in other disciplines have proven consistently superior in theory and practice to units and processes that do not conform' (Wilson, 1998, p. 198). Using the issue of biodiversity as an example, we show that ecological economics has come a long way in addressing the issue of consilience raised by Wilson. In the spirit of consilience, ecological economists have expanded the subject matter of utility theory by recognizing the complexity and the social context of human behavior and likewise have expanded the economic theory of production by taking explicit account of the constraints imposed by the environment. Within ecological economics, human behavior is recognized as being more than that of isolated individuals making allocation decisions at the margin in well-organized markets. The issue of environmental constraints has been taken up in a variety of contexts including the debate about the scale of economic activity vis-a-vis the finite planet earth.

2. Production theory and the scale of economic activity

The neoclassical theory of production is hermetic in the sense that economic production is seen as a self-contained circular flow process unconnected to the anthropology, biology, or physics of the rest of the world. In standard economic theory, scarcities of particular inputs are temporary and can be overcome by substitution driven by changes in relative prices (Amir, 1989; Klaassen and Opschoor, 1991; Victor, 1991; Bromley, 1998). Unwanted effects of outputs of the production process (externalities) also reflect Pareto inefficient relative prices and can also be taken care of within the market system. In contrast to this world view, a major concern of ecological economics over the past decade has been the issue of the scale of economic activity viz-a-viz the global environment, an issue that was virtually ignored until the pioneering work of Boulding (1966) and Georgescu-Roegen (1971).

Georgescu-Roegen's work has been the subject of many articles in the *Journal* (Khalil, 1990; Daly, 1995; Lozada, 1995) and a special issue (September 1997) was dedicated to him. Unfortunately, very few students had the opportunity to work directly with Georgescu-Roegen. Fortunately, one of those who did was Herman Daly. Daly not only popularized Georgescu's economic theories, he also formulated a theory of his own that was able to grab the imagination of a large general audience, namely, the concept of the steady-state economy. Daly's arguments about the negative effects of economic growth have been confirmed by scientific findings of the last 10 years which have shown convincingly that economic activity is changing many of the biophysical characteristics of the planet. Global climate change, biodiversity loss, world-wide acidification of lakes and streams, and rising nitrogen levels are only a few of the negative global effects of human activity.

The adverse impact of economic activity on the earth's biological diversity clearly illustrates the relationship between the scale of economic activity and the limited ability of our planet to absorb the effects of economic growth. The issue of biodiversity loss has been the subject of many articles in *Ecological Economics*, articles that have made the importance of preserving biodiversity a central theme of ecological economics. The diverse justifications given for preserving biodiversity reflect the pluralism and interdisciplinarity of ecological economists. Some focus on ecological reasons: maintaining ecosystem productivity (e.g. against erosion, as a nutrient recycling or absorption of CO_2); maintaining ecosystem stability, and preserving the ability to keep a wide range of future options open (Norton, 1989; Tisdell, 1990; Stahler, 1994; Gowdy and McDaniel, 1995; Norton-Griffiths and Southey, 1995; Tacconi and Bennett, 1995; Smith, 1996; Brown, 1998). Biodiversity has also been recognized as a key element for the evolution or coevolution of socio-economic systems (Klaassen and Opschoor, 1991; Norgaard, 1995).

Economic reasons for preserving biodiversity include: maintaining the productivity of forest and agricultural industries (as a future source of inputs for the pharmaceutical or agriculture industries, the economic value of the aesthetic or cultural aspects of biodiversity and as a income source in the eco-tourism industry (Norton, 1989; Tisdell, 1990; Stahler, 1994; Norton-Griffiths and Southey, 1995; Tacconi and Bennett, 1995; Smith, 1996; Swanson, 1996; Fearnside, 1997; Brown, 1998).

Finally, from a philosophical point of view: some argue that we should preserve biodiversity because species have rights on their own or because we have a responsibility to leave bequests to future generations (Norton, 1989; Tisdell, 1990; Stahler, 1994 and Brown 1998) or that biodiversity loss has a negative impact on indigenous people (Tacconi and Bennett, 1995).

With the growing evidence of the adverse human impact on the earth's biological, geochemical, and atmospheric processes, driven by the growth of the world market economy, it is clear that the scale of human activity is an important consideration in any complete and realistic economic theory (Daly, 1992; Schröder, 1995). Neoclassical theory, with its exclusive emphasis on allocation within well-defined markets, cannot address the issue of the scale of economic activity with respect to a finite environment. The importance of scale has been dismissed by some ecological economists. Duchin (1996) criticizes the concept for not being operational, and Norgaard (1995) maintains that the concept is too mechanical in that it does not take into account coevolutionary potential. Norgaard (Norgaard, 1995, p. 129) agrees, however, that the notion of 'limits' is far superior to that of 'non-limits'. In spite of its limitations the issue of scale is an idea that confronts head-on the conflict between the evolution of market economies and evolutionary processes in nature (Gowdy and McDaniel, 1995; Norton, 1995a; Ring, 1997; Luks, 1998).

Niles Eldredge (Eldredge, 1995, p. xv) links the concepts of scale, evolution, and the global Gaia to argue that the human species is evolving back into a situation of nature-imposed constraints on our activity: 'For 10 000 years, all but a remnant handful of hunting-gathering societies have been living outside the normal, local-ecosystem confines of nature. That is why our cultural heritage proclaims us to be something apart from, even over and above, the beasts of the field. But we have now reached the next crucial phase: *We have become the first species on earth to interact as a whole with the global system*'. For about 99% of our existence as a species we lived as hunters and gatherers within the limits of local ecosystems. With the adoption of agriculture, human societies were able to exploit a variety of environments and, as a result, human populations increased far beyond those that could be supported using local resources alone. With the industrial age, and the dramatic increase in the scale of population and economic activity, humans have re-emerged into a world of limits. This makes the issue of scale central to the relationship between biological and economic systems.

Within the scale-of-human-activity debate two approaches within ecological economics are apparent. These may be termed static and dynamic approaches to the scale question. On the one hand, there are those like Daly (and arguably Georgescu-Roegen) who argue that once limits on throughput are established, the market economy can operate relatively freely to allocate resources within those established limits. On the other hand, some ecological economists take a more dynamic approach and argue that growth and increasing resource use is necessary to a smoothly operating market system in spite of its long-run ecological unsustainability. As Daly recognizes, an uncontrolled market will not recognize ecological limits. A non-growing economy, however, is incompatible with the dynamics of global capitalism. Capitalist accumulation drives both market expansion and environmental destruction. Along these lines, Ayres (1995) argues that economic growth is politically necessary but environmentally destructive. Gowdy and McDaniel (1995) also take the position that fundamental conflicts exist between the evolution of economic and biological systems. An issue of *Ecological Economics* (November 1995) was devoted to an examination of the topic of economic growth, carrying capacity and the environment. Other commentaries on economic growth and the environment include Ekins (1993), Goodland and Daly (1993), Kaufmann (1995), Martinez-Alier (1995), Wetzel and Wetzel (1995), de Bruyn and Opschoor (1997), Lunney et al. (1997) and Ricker (1997).

The key point here was made forcefully by Ayres. The market economy is a magnificent machine for calling forth new technologies and new substitutes for environmental inputs into the production process. The conflict between 'cowboy' and 'spacemen' (Boulding, 1966) economists is really between those who see the economic system as a self-contained and independent entity, and those who do not. These two groups are talking about two different systems, the economy and the natural world. Ayres (Ayres, 1993, p. 195) points out that neo-Malthusians have traditionally emphasized natural resources only as inputs into the economic process while 'spacemen' tend to focus on the entire environmental matrix that supports all life on the planet:

> There are many, including myself, who believe that given a reasonably free market, technology can generally be depended upon to find a substitute for almost any scarce material resource input (except energy itself). However, there are no plausible technological substitutes for climatic stability, stratospheric ozone, air, water, topsoil, vegetation—especially forests—or species diversity. Degradation of most of these is irreversible. In every case, total loss would be catastrophic to the human race, and probably lethal. Although technology can create (and money can buy) many things, it cannot create a substitute for the atmosphere or the biosphere. Technological optimism, in this regard, is simply misguided.

An important aspect of consilience is recognizing the difference between economic substitution and ecosystem functions. Söllner (1997) points out that the finiteness of the earth may be acknowledged by neoclassical economics but deemed irrelevant because of substitution possibilities. Even among ecological economists there is a difference of opinion as to the degree of substitutability of human-made capital for environmental features (Victor, 1991; Pearce and Atkinson, 1993; Kaufmann, 1995; Martinez-Alier, 1995; Cabeza-Gutés, 1996; van den Bergh, 1999). Again, as Ayres, Georgescu-Roegen, Wilson, and numerous others point out, neoclassical economics seals itself off from nature and society. In terms of sustainability, all that matters is that discounted per capita consumption be non-declining, so long as those consequences do not have economic impacts which offset the gains of using the environment as an economic resource (weak sustainability) (Pearce and Atkinson, 1993).

It is critically important to keep in focus the difference between sustaining the consumption of market goods and sustaining environmental processes such as the smooth functioning of ecosystems. The question of how much do biophysical limits constrain the economic process (Cleveland and Ruth, 1997; Ruth, 1995) is different from the question of how much does economic activity constrain ecological processes. As the fates of numerous past civilizations show, it is possible to have a growing population and economy long after the exhaustion of natural resources essential to long-term survival. On Easter Island, for example, the population peaked then collapsed more than 300 years after the last tree had been cut down (Bahn and Flenley, 1992). Even in open economies the same pattern of overshot-and-collapse seems to be the rule, not the exception (Tainter, 1988; McDaniel and Gowdy, 1999). The time lag between irreversible resource degradation and the ultimate consequences is one of the most sobering aspects of the political-economic-environmental nexus.

A simple but frequently forgotten point is that there is a difference between input substitution in the production of goods and services, and the alleged ability to produce substitutes for the atmosphere or biosphere (Ayres, 1993; Ekins, 1993; Gowdy and McDaniel, 1995; Wetzel and Wetzel, 1995). Consilience implies that the assumptions incorporated in the economic models and production function should be consistent with physical reality (van den Bergh and Nijkamp, 1991; Amir, 1994; Ruth, 1995). *Ecological Economics* has contributed both to the debate on natural resources and economic output, and to the debate about economic output and its effect on the natural world.

3. Utility theory and the natural world

The hermetic nature of production theory has resulted in the neglect of the scale of the impact of the economy on the natural world. Neoclassical utility theory is also hermetic in that it sees decisions made by individuals as independent of space, time, and the biophysical world. In the neoclassical theory of the consumer, only human preferences count. It does not matter where these preferences come from or what the consequences for the rest of the world are. The distinction between use value and exchange value has disappeared in modern economics. As Bromley, (1998, p. 233) puts it:

> Utility, which to Pareto and early economists signified usefulness, was transformed into the realm of feeling, thus displacing the more awkward term ‘ophelimity’. And now there is no longer a place in economic discourse for the concept of usefulness. So the province of sustainability must, if it is to be true to the precepts of received dogma, concern not usefulness to future generations, but their level of welfare. In blunt terms, the atmosphere must be useful for future generations to be able to breathe but because future generations will otherwise suffer a loss in utility.

In the standard economic view, essential features of the natural world, such as biological diversity, have value only if humans think they do. In neoclassical utility theory only human feelings count. There is no reality outside of human perceptions so there is no need to consider the effects of consumption on the environment. If we believe, however, that humans are a biological species which has evolved in a very specific and very complex physical environment–within certain limits of atmospheric composition, temperature, and ecosystem features–then to focus solely on human preferences is a dangerous approach to environmental policy. There are many things we do not place great positive value on–microbes and insects, for example–that are absolutely essential to our survival. Klaassen and Opschoor (1991) point out that from an evolutionary perspective, in order to protect future biodiversity, we may want to preserve an ecosystem even if it has no apparent economic benefit.

Ecological economists have tried to bring the economic theory of the consumer closer to biophysical reality. Söderbaum (1994) argues that willingness to pay represents human feelings which may or may not adequately reflect the importance of environmental features, for example, in maintaining life-support systems. If the lifestyles and preferences of people are unsustainable, then willingness-to-pay measures for environmental features will only reflect these unsustainable consumption practices, not ecological integrity. Norgaard (Norgaard, 1989a p. 308), makes a similar argument: ‘if people are not very willing then the environment is not very valuable’. Söderbaum (1994) and Norton et al. (1998) make the case that preferences should also be seen as an environmental policy instrument, not as given and unchangeable as neoclassical economics presents it (Stigler and Becker, 1977). Reconciling economic theory with the basic findings of modern psychology remains an important task for ecological economists.

The thorny issue of ecosystem valuation and evaluation, and the contradictions between the rules of market behavior and the rules which govern ecosystems is far from being resolved. Nevertheless, *Ecological Economics* has provided a forum for the discussion of this issue from all sides (see, for example, the special issue of *Ecological Economics* on 'issues in ecosystem valuation: improving information for decision making' August 1995). A reflection of the importance of this controversy is the article in *Nature* by Costanza et al. (1997). The article was the cover story and has had an enormous impact in the media with stories appearing in *Science*, *The New York Times*, and *US News and World Reports*. A special issue of *Ecological Economics* (April 1998), 'The value of ecosystem services' was devoted to the study of the issues surrounding it. A particularly useful paper in that issue was that of Turner et al. (1998) which sets out a protocol for the economic valuation of environmental attributes. More critical commentaries are presented by Ayres (1998), Hueting et al. (1998), Rees (1998) and Toman (1998). The impact of the *Nature* article shows the increasing importance of Ecological Economics, probably as a consequence of the public awareness of environmental problems.

There have been also other diverse contributions of *Ecological Economics* to ecosystem valuation and evaluation issues. A major valuation issue has been the appropriateness or not of using monetary indicators–market prices or willingness to pay (WTP) or to accept (WTA) measures–to value environmental resources and functions and the use of Cost-Benefit Analysis (CBA). While some authors have defended monetary valuation methods, others have criticized such instruments and methods for a variety of reasons: individuals have lexicographic preferences and so they cannot express WTP since they 'refuse to make a trade-off' (Spash and Hanley, 1995 p. 191), valuation depends on the distribution of income and property rights endowment (Lintott, 1996; Martinez-Alier and O'Connor, 1996), the omission in cost-benefit analysis of impacts that cannot be easily monetized (Schulze, 1994; Sagoff, 1998), the incommensurability of values (Munda, 1996). Also important is the fact that valuation depends not only on economic and biological functions but also on the institutional context (Freeman, 1991; Opschoor and van der Straaten, 1993).

While many ecological economists have been critical of WTP measures, contributions have also been made indicating the context in which these measures can legitimately be employed. Bateman et al. (1995), for example, report results of the effects of altering the methods of eliciting willingness-to-pay responses. They recommend an iterative bidding procedure which has the effect of greatly reducing protest bids.

Criticisms of standard valuation methods have led to the proposal of various methods of valuation and evaluation that differ from conventional cost-benefit analysis and which incorporate concepts like uncertainty, irreversibility, complexity and the incommensurability of wants. These alternatives include valuation and evaluation methods such as: procedural rationality in environmental decision-making (Faucheux and Froger, 1995), multi-criteria analysis (van Pelt, 1993; Munda et al., 1995; Joubert et al., 1997), dynamic ecological-economic modeling (Liu et al., 1994; Ruitenbeek, 1994; Higgins et al., 1997; Weston and Ruth, 1997), sustainable development records (Bergstrom, 1993), integrated value theory (Lockwood, 1997), and discursive ethics (O'Hara, 1996). Funtowicz and Ravetz (1994) propose that some of these methods are part of a new paradigm of 'post-normal science' where the old reductionist scientific procedures which ignore uncertainty and evolutionary context are no longer valid.

Other important evaluation and management issues include the inappropriateness of marginal pricing for biodiversity (Gowdy, 1997), species extinction and market prices (Farrow, 1995), and within-species diversity, a valuable part of ecosystems, but a property difficult if not impossible to adequately capture in prices.

4. Evolutionary concepts in economics

The application of analogies from evolutionary theory in biology to ecological economics has also been important in making economic theory more realistic. One of the most limiting features of neoclassical theory is that it is static. It is a system of rules for allocating a fixed amount of goods among consumers with given tastes and among firms with given production techniques. An important area of reconciliation between biology and economics is the 'greening' of economic theory to incorporate irreversible change, contingency, and pure uncertainty.

Although evolutionary theory and concepts have a long history in economics, most economists have used evolutionary theory only to justify the neoclassical model. Recently, however, ecological economists have incorporated new developments in evolutionary theory such as multilevel selection, path dependency, and coevolution (Norgaard, 1989b, 1994; Gowdy, 1994, 1997; Norton et al., 1998). Co-evolutionary economics considers not only the evolutionary process but also emphasizes the relationships and inter-dependence between the natural, social and economic systems.

Evolutionary or co-evolutionary economic concepts are extensively used by ecological economists. Examples are the co-evolution of cultural and physical and genetic systems (Ring, 1997), and sustainable development as an evolutionary process with continuous feedbacks between a changing economy and environment (Klaassen and Opschoor, 1991). A number of contributions by ecological economists emphasize the evolution of institutions. Norton et al. (1998) stress the importance of economic and cultural evolution within an institutional framework. They point out that it is impossible to address the questions of preferences and values, and the scale of economic activity, within the static framework of neoclassical economics. Mohr (1994) uses an evolutionary framework to describe changing environmental norms. He refers to Sugden (1986) who argues that norms spread by analogy (instead of sexual reproduction) and that the institution reinforces a variety of norms, for example, separating insiders and outsiders (Mohr, 1994, p. 235). He also points out that norms need to be based on common knowledge, which acts as a constraint for their diffusion.

5. Insights from economics to ecology

The influence of economics on biology and ecology has a long history. Both Charles Darwin and Alfred Russel Wallace developed their ideas of evolution through natural selection after reading the economic texts of Thomas Malthus describing competitive markets (Hodgson, 1993). Economic concepts have been applied in ecology since the beginning of this century (Rapport and Turner, 1977) and optimization models based on economic theory have been widely used by biologists (Maynard Smith, 1978).

Ecological Economics has provided a forum for biologists and economists to work together on a number of theoretical and practical issues. Biologists have successfully applied a number of economic concepts to ecological problems. Perrings and Walker (1997) use a model of constrained optimization to examine three rangeland variables, woody plants, grasses, and livestock. They develop a model of optimal management taking into account exogenous shocks, the existence of a number of state possibilities, and 'creative destruction' in the form of fire disturbance. Norton (Norton, 1995a,b) also discusses the importance of resilience in environmental management. He argues that the neoclassical economic concept of weak sustainability is a poor guide to protect biological resilience and also argues for the use of dynamic, multi-equilibrium models in ecosystem management. In a pioneering attempt to integrate economic and ecological information, Bockstael et al. (1995) present a model for the Patuxent River drainage basin in Maryland which directly addresses the methodological and conceptual conflicts between ecological and economic valuation schemes. Hannon (1998) presents an interesting application of economic accounting principles to examine the question: How might nature value man?

A number of economic notions such as property rights and debt-for-nature swaps have been applied by ecological economists (Chambers et al., 1994; Kling, 1994; Lant, 1994). Most of the articles in *Ecological Economics* applying economic concepts to ecosystems are written exclusively by economists. There is nothing wrong with this *per se* but it would be nice to see more contributions from biologists such as Walker (Perrings and Walker, 1997) and Luks (1998) who are also well-versed in economics.

One area of interdisciplinary collaboration has been fisheries management. Spurred by the collapse of several of the world's major fisheries (Ruitenbeek, 1996), there seems to be an emerging consensus that the old dichotomy of private property versus government ownership is a false one. Susan Hanna (Hanna, 1997) calls for the development of new institutional capital to make the transition from a 'frontier' to a 'commons' approach to fisheries management. Components include (1) a conception of the fishery as an integrated ecosystem, (2) identification of shareholders and the development of decision-making processes that include all relevant interests, (3) incentive structures that promote long-term stability include adaptability to change. Charles (1994) is critical of the 'rationality paradigm' and also calls for a multiple objective approach to fisheries management integrating ecological, social, and economic concerns. Powell (1998) makes a similar case in a discussion of communal land tenure policies in the South Pacific.

One of the most intractable issues in integrating economics and biology is that of discounting the future. Discounting has been a central topic for discussion in the valuation arena in *Ecological Economics* (Hueting, 1991; Schulze, 1994; Azar and Sterner, 1996; Martinez-Alier and O'Connor, 1996; Rabl, 1996) and can only be briefly mentioned here. The question of discounting involves ethics, equity, and the conflicting time-scales of economies and ecosystems, among other issues. In the case of biological features the issue of discounting is intertwined with the issue of substitutability. If natural and manufactured capital are substitutes, then the Harwick-Solow rule for sustainability is appropriate and the discounting problem is solved by the non-declining capital stock criterion (see Bromley 1998).

6. Concluding thoughts

Science has entered the age of the breakdown of disciplinary boundaries. For some sciences this transition is going smoothly, for others it is not. For the natural sciences, perhaps, the change is relatively easy because it does not involve a rethinking of basic assumptions. The integration of economics with the physical and biological sciences has proved far more difficult. For a variety of reasons, the economics profession has been particularly guilty of parochialism and resisting ideas which challenge its core assumptions. This resistance to change is partly due to a justified pride in being unique among the social sciences in having a well-developed mathematical framework to explain market exchange, partly due to its role in justifying existing power and privilege relationships, and partly due to the ability of the theory to insulate itself from empirical tests of its basic assumptions. The last point is critical to the above discussion. Although empirical analysis is one of the defining characteristics of neoclassical economics–econometricians are held in the highest esteem in the profession–analysis is usually formulated in ways that accept the basic premises of neoclassical theory. But in fact, as discussed above, when basic assumptions such as transitivity, smooth and continuous indifference curves and isoquants, and substitution for natural and manufactured capital, are empirically tested, they frequently fail to hold true.

Ecological economics has played a valuable role in putting economics on a firm footing with respect to biological reality. We argue above that this is because ecological economics has taken interdisciplinarity seriously. Following the traditional division of economics into consumption and production, ecological economics has helped ground the consumer in social and ecological context, and to ground the firm in biophysical reality.

References

Amir, S., 1989. On the use of ecological prices and system-wide indicators derived therefrom to quantify Man's impact on the ecosystem. Ecol. Econ. 1, 203–231.

Amir, S., 1994. The role of thermodynamics in the study of economic and ecological systems. Ecol. Econ. 10, 125–142.

Ayres, R.U., 1993. Cowboys, cornucopians and long-run sustainability. Ecol. Econ. 8, 189–207.

Ayres, R.U., 1995. Economic growth: politically necessary but *not* environmentally friendly. Ecol. Econ. 15, 97–100.

Ayres, R.U., 1998. The price-value paradox. Ecol. Econ. 25, 17–19.

Azar, C., Sterner, T., 1996. Discounting and distributional considerations in the context of global warming. Ecol. Econ. 19, 169–184.

Bahn, P., Flenley, J., 1992. Easter Island Earth Island. Thames and Hudson, London.

Bateman, I. J., Langford, I.H., Turner, R.K., Willis, K.G., Garrod, G.D., 1995. Elicitation and truncation effects in contingent valuation studies. Ecol. Econ. 12, 161–179.

van den Bergh, J.C.J.M., Nijkamp, P., 1991. Operationalizing sustainable development: dynamic ecological economic models. Ecol. Econ. 4, 11–33.

van den Bergh, J.C.J.M., 1999. Materials, capital, direct/indirect substitution and mass balance production functions, Land Economics. forthcoming.

Bergstrom, S., 1993. Value standards in sub-sustainable development. On limits of ecological economics. Ecol. Econ. 7, 1–18.

Binswanger, M., 1993. From microscopic to macroscopic theories: entropic aspects of ecological and economic processes. Ecol. Econ. 8, 209–234.

Bockstael, N., Costanza, R., Strand, I., Boynton, W., Bell, K., Wainger, L., 1995. Ecological economic modeling and valuation of ecosystems. Ecol. Econ. 14, 143–159.

Boulding, K., 1966. The economics of the coming spaceship earth. In: Jarrett, H.E. (Ed.), Environmental Quality in a Growing Economy. Johns Hopkins Press, Baltimore, MD, pp. 3–14.

Bromley, D.W., 1998. Searching for sustainability; The poverty of spontaneous order. Ecol. Econ. 24, 231–240.

Brown, K., 1998. The political ecology of biodiversity, conservation and development in Nepal's Terai: Confused meanings, means and ends. Ecol. Econ. 24, 73–88.

de Bruyn, S.M., Opschoor, J.B., 1997. Development in the throughput-income relationship: theoretical and empirical observations. Ecol. Econ. 20, 255–268.

Cabeza-Gutés, M., 1996. The concept of weak sustainability. Ecol. Econ. 17, 147–156.

Chambers, C., Chambers, P., Whitehead, J., 1994. Conservation organizations and the option value to preserve: an application to debt-for-nature swaps. Ecol. Econ. 9, 135–143.

Charles, A., 1994. Towards sustainability: the fishery experience. Ecol. Econ. 11, 201–212.

Cleveland, C.J., Ruth, M., 1997. When, where, and by how much do biophysical limits constrain the economic process: A survey of Nicholas Georgescu-Roegen's contribution to ecological economics. Ecol. Econ. 22, 203–224.

Costanza, R., 1989. What is ecological economics? Ecol. Econ. 1, 1–7.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Naeem, S., Limburg, K., Paruelo, J., O'Neill, R.V., Raskin, R., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Costanza, R., Patten, B., 1995. Defining and predicting sustainability. Ecol. Econ. 15, 193–196.

Daly, H.E., 1995. On Nicholas Georgescu-Roegen's contributions to ecological economics: an obituary essay. Ecol. Econ. 13, 149–154.

Daly, H.E., 1992. Allocation, distribution, and scale: towards an economics that is efficient, just, and sustainable. Ecol. Econ. 6, 185–193.

Duchin, F., 1996. Ecological economics: the second stage. In: Costanza, R., Segura, O., Martinez-Alier, J. (Eds.), Getting Down to Earth: Practical Applications of Ecological Economics. Island Press, Washington, D.C, pp. 285–300.

Ehrlich, P., 1989. The limits to substitution: metaresource depletion and a new economic-ecologic paradigm. Ecol. Econ. 1, 9–16.

Ehrlich, P., 1997. A World of Wounds: Ecologists and the Human Dilemma. Ecology Institute, Oldendorf/Luhe, Germany.

Ekins, P., 1993. Limits to growth' and 'sustainable development': grappling with ecological realities. Ecol. Econ. 8, 269–288.

Eldredge, N., 1995. Dominion. University of California Press, Berkeley.

Farrow, S., 1995. Extinction and market forces: two case studies. Ecol. Econ. 13, 115–123.

Faucheux, S., Froger, G., 1995. Decision-making under environmental uncertainty. Ecol. Econ. 15, 29–42.

Fearnside, P.M., 1997. Environmental services as a strategy for sustainable development in rural Amazonia. Ecol. Econ. 20, 53–70.

Freeman, A.M. III, 1991. Valuing environmental resources under alternative management regimes. Ecol. Econ. 3, 247–256.

Funtowicz, S.O., Ravetz, J.R., 1994. The worth of a songbird: ecological economics as a post-normal science. Ecol. Econ. 10, 197–207.

Georgescu-Roegen, N., 1971. The Entropy Law and the Economic Process. Harvard University Press, Cambridge, MA.

Gowdy, J.M., 1994. Coevolutionary Economics. Kluwer, Boston.

Gowdy, J.M., 1997. The value of biodiversity: markets, society, and ecosystems. Land Econ. 73, 25–41.

Gowdy, J.M, McDaniel, C.N., 1995. One world, one experiment: addressing the biology-economics conflict. Ecol. Econ. 15, 181–192.

Goodland, R., Daly, H., 1993. Why northern income growth is not the solution to southern poverty. Ecol. Econ. 8, 85–101.

Hanna, S., 1997. The new frontier of American fisheries governance. Ecol. Econ. 20, 221–234.

Hannon, B., 1998. How might nature value man? Ecol. Econ. 25, 265–279.

Higgins, S.I., Turpie, J.K., Costanza, R., Cowling, R.M., Le Maitre, D.C., Marais, C., Midgley, G.F., 1997. An ecological economic simulation model of mountain fynbos ecosystems. Dynamic, evolution and management. Ecol. Econ. 22, 155–169.

Hodgson, G., 1993. Economics and Evolution. University of Michigan Press, Ann Arbor.

Hueting, R., 1991. The use of the discount rate in a cost-benefit analysis for different uses of a humid tropical forest area. Ecol. Econ. 3, 43–57.

Hueting, R., Reijnders, B., de Boer, J., Lambooy, J., Jansen, H., 1998. The concept of environmental function and its valuation. Ecol. Econ. 25, 31–35.

Joubert, A.R., Leiman, A., de Klerk, H.M., Katua, S., Aggenbach, J.C., 1997. Fynbos (fine bush) vegetation and the supply of water: a comparison of multi-criteria decision analysis and cost-benefit analysis. Ecol. Econ. 22, 123–140.

Kaufmann, R.K., 1995. The economic multiplier of environmental life support: can capital substitute for a degraded environment? Ecol. Econ. 12, 67–79.

Khalil, E.L., 1990. Entropy law and exhaustion of natural resources: is Nicholas Georgescu-Roegen's paradigm defensible? Ecol. Econ. 2, 163–178.

Klaassen, G.A.J., Opschoor, J.B., 1991. Economics of sustainability or the sustainability of economics: different paradigms. Ecol. Econ. 4, 93–116.

Kling, C.L., 1994. Environmental benefits from marketable discharge permits or an ecological vs. economical perspective on marketable permits. Ecol. Econ. 11, 57–64.

Lant, C., 1994. The role of property rights in economic research on U.S. wetlands policy. Ecol. Econ. 11, 27–34.

Lintott, J., 1996. Environmental accounting: useful to whom and for what? Ecol. Econ. 16, 179–190.

Liu, J., Cubbage, F.W., Pulliam, H.R., 1994. Ecological and economic effects of forest landscape structure and rotation length: simulation studies using ECOLECON. Ecol. Econ. 10, 249–263.

Lockwood, M., 1997. Integrated value theory for natural areas. Ecol. Econ. 20, 83–93.

Lozada, G.A., 1995. Georgescu-Roegen's defense of classical thermodynamics revisited. Ecol. Econ. 14, 31–44.

Lubchenco, J., 1998. Entering the century of the environment: a new social contract for science. Science 279, 491–497.

Luks, F., 1998. Throughput, scale, material input. In: Köhn, J., Gowdy, J., Hinterberger, F., van der Straaten, J. (Eds.), Sustainability in Question: The Search for a Conceptual Framework. Edward Elgar, London forthcoming.

Lunney, D., Pressey, B., Archer, M., Hand, S., Godthelp, H., can Curtin, A., 1997. Integrating ecology and economics: illustrating the need to resolve the conflicts of space and time. Ecol. Econ. 23, 135–144.

Martinez-Alier, J., 1995. The environment as a luxury good or 'too poor to be green'? Ecol. Econ 13, 1–10.

Martinez-Alier, J., O'Connor, M., 1996. Ecological and Economic Distribution Conflicts. In: Costanza, R., Segura, O., Martinez-Alier, J. (Eds.), Getting Down to Earth. Island Press, Washington D.C./California, pp. 153–183.

Maynard Smith, J., 1978. Optimization theory in evolution. Annu. Rev. Ecol. Systematics 9, 31–56 Reprinted in G. Hodgson, Economics and Biology. Edward Elgar, Aldershot, U.K., 1995.

McDaniel, C., Gowdy, J., 1999. Paradise For Sale. University of California Press, Berkeley.

Mohr, E., 1994. Environmental Norms, Society and Economics. Ecol. Econ. 9, 229–239.

Munda, G., 1996. Cost-benefit analysis in integrated environmental assessment: some methodological issues. Ecol. Econ. 19, 157–168.

Munda, G., Nijkamp, P., Rietveld, P., 1995. Qualitative multicriteria evaluation for environmental management. Ecol. Econ. 10, 97–112.

Norgaard, R.B., 1989a. Three dilemmas of environmental accounting. Ecol. Econ. 1, 303–314.

Norgaard, R.B., 1989b. The case for methodological Pluralism. Ecol. Econ. 1, 37–57.

Norgaard, R.B., 1994. Development Betrayed. The end of progress and a coevolutionary revisioning of the future. Routledge, London and New York.

Norgaard, R.B., 1995. Metaphors we might survive by. Ecol. Econ. 15, 129–131.

Norton, B.G., 1989. Intergenerational equity and environmental decisions: a model using Rawls' veil of ignorance. Ecol. Econ. 1, 137–159.

Norton, B.G., 1995a. Evaluating ecosystem states: two competing paradigms. Ecol. Econ. 14, 113–128.

Norton, B.G., 1995b. Resilience and options. Ecol. Econ. 15, 133–136.

Norton, B., Costanza, R., Bishop, R.C., 1998. The evolution of preferences: why 'sovereign' preferences may not lead to sustainable policies and what to do about it. Ecol. Econ. 24, 193–211.

Norton-Griffiths, M., Southey, C., 1995. The opportunity costs of biodiversity conservation in Kenya. Ecol. Econ. 12, 125–139.

O'Hara, S., 1996. Discursive ethics in ecosystems valuation and environmental policy. Ecol. Econ. 16, 95–107.

Opschoor, H., van der Straaten, J., 1993. Sustainable development: an institutional approach. Ecol. Econ. 7, 203–222.

Pearce, D. W., Atkinson, G.D., 1993. Capital theory and the measurement of sustainable development; an indicator of 'weak' sustainability. Ecol. Econ. 8, 103–108.

van Pelt, M.J.F., 1993. Ecologically sustainable development and project appraisal in developing countries. Ecol. Econ. 7, 19–42.

Perrings, C., Walker, B., 1997. Biodiversity, resilience, and the control of ecological-economic systems: the case of fire-driven rangelands. Ecol. Econ. 22, 73–83.

Pimm, S., 1997. The value of everything. Nature 387, 231–232.

Powell, P., 1998. Traditional production, communal land tenure, and policies for environmental preservation in the South Pacific. Ecol. Econ. 24, 89–101.

Rabl, A., 1996. Discounting of long-term costs: what would future generations prefer us to do? Ecol. Econ. 17, 137–145.

Rapport, D., Turner, J., 1977. Economic models in ecology. Science 195, 367–373 Reprinted in G. Hodgson, Economics and Biology. Edward Elgar, Aldershot, U.K., 1995.
Rees, W., 1998. How should a parasite value its host? Ecol. Econ. 25, 49–52.
Ricker, M., 1997. Limits to economic growth as shown by a computable general equilibrium model. Ecol. Econ. 21, 141–158.
Ring, I., 1997. Evolutionary strategies in environmental policy. Ecol. Econ. 23, 237–250.
Ruitenbeek, J.H., 1994. Modelling economy–ecology linkages in mangroves; economic evidence for promoting conservation in Bituni Bay, Indonesia. Ecol. Econ. 10, 233–247.
Ruitenbeek, J.H., 1996. The great Canadian fishery collapse: some policy lessons. Ecol. Econ. 19, 103–106.
Ruth, M., 1995. Thermodynamic constraints of optimal depletion of copper and aluminium in the United States: a dynamic model of substitution and technical change. Ecol. Econ. 15, 197–214.
Sagoff, M., 1998. Aggregation and deliberation in valuing environmental public goods: a look beyond contingent pricing. Ecol. Econ. 24, 213–230.
Schröder, T., 1995. Daly's optimal scale of economic activity. Ecol. Econ. 14, 163–164.
Schulze, P.C., 1994. Cost-Benefit analysis and environmental policy. Ecol. Econ. 9, 197–199.
Söderbaum, P., 1994. Actors, ideology, markets. Neoclassical and institutional perspectives on environmental policy. Ecol. Econ. 10, 47–60.
Söllner, F., 1997. A reexamination of the role of thermodynamics for environmental economics. Ecol.. Econ. 22, 175–201.
Spash, C.L., Hanley, N., 1995. Preferences, information and biodiveristy preservation. Ecol. Econ. 12, 191–208.
Smith, F., 1996. Biological diversity, ecosystem stability and economic development. Ecol. Econ. 16, 191–203.
Stahler, K., 1994. Biological diversity: the international management of genetic resources and its impacts on biotechnology. Ecol. Econ. 11, 227–236.
Stigler, G.J., Becker, G.S., 1977. De Gustibus Non Est Disputandum. Am. Econ. Rev. 67, 76–90.
Sugden, R., 1986. The Economics of Rights, Cooperation and Welfare. Basil Blackwell, Oxford.
Swanson, T., 1996. The reliance of northern economies on southern biodiversity: biodiversity as information. Ecol. Econ. 17, 1–8.
Tacconi, L., Bennett, J., 1995. Economic implications of intergenerational equity for biodiversity conservation. Ecol. Econ. 12, 209–223.
Tainter, J., 1988. The Collapse of Complex Societies. Cambridge University Press, Cambridge, UK.
Tisdell, C., 1990. Economics and the debate about preservation of species, crop varieties and genetic diversity. Ecol. Econ. 2, 77–90.
Toman, M., 1998. Why not to calculate the value of the world's ecosystem services and natural capital. Ecol. Econ. 25, 57–60.
Turner, R., Adger, W., Brouwer, R., 1998. Ecosystem services value, research needs, and policy relevance: a commentary. Ecol. Econ. 25, 61–65.
Vedeld, P.O., 1994. The environment and interdisciplinarity. Ecological and neoclassical economical approaches to the use of natural resources. Ecol. Econ. 10, 1–14.
Victor, P., 1991. Indicators of sustainable development: some lessons from capital theory. Ecol. Econ. 4, 191–213.
Weston, R.F., Ruth, M., 1997. A dynamic hierarchical approach to understanding and managing natural economic systems. Ecol. Econ. 21, 1–17.
Wetzel, K.R., Wetzel, J.F., 1995. Sizing the earth: recognition of economic carrying capacity. Ecol. Econ. 12, 13–21.
Wilson, E.O., 1998. Consilience. Alfred Knopf, New York.