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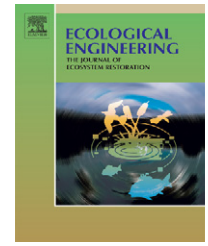

Commentary

Natural capital: The limiting factor A reply to Aronson, Blignaut, Milton and Clewell

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1. Introduction

Ecological engineering, ecological economics and ecological restoration are all emerging transdisciplinary fields dedicated to tackling wickedly complex problems at the interface of the economic system and the global ecosystems that sustain and contain it. Though these fields emerge from different disciplinary backgrounds, each espouses a systems approach, and each offers a critical part of the solution to the problems we face in the 21st century (Mitsch and Jorgensen, 2003; Daly and Farley, 2004; Society for Ecological Restoration International Science and Policy Working Group, 2004). As emerging transdisciplines, each is still struggling to build consensus on the terminology, methodologies and tools that characterize more mature areas of studies: given our common goals, this consensus should be built across all three fields. Dialogue among the practitioners of these complementary transdisciplines is therefore essential, and we welcome this opportunity for dialogue with Aronson, Blignaut, Milton and Clewell (hereafter referred to as “our colleagues”). This is not a dialogue about the fact that natural capital is the limiting factor in economic production, a point about which we all agree. It is rather a dialogue about how best to communicate this fact to conventional economists, decision makers and the public in general.

Concerning our colleagues’ introduction, we agree with virtually everything they say, and believe they have said it very well. There is a bit we would like to add to the discussion, however.

First, we would like to stress one of the most important roles of natural capital that has perhaps received inadequate attention in their introduction: the ability of natural systems to absorb and recycle waste. The laws of thermodynamics tell us not only that all economic production requires natural capital inputs, but also that all economic production generates waste (Georgescu-Roegen, 1971), and we know from experience that waste can degrade natural capital. The role of natural capital in providing a sink for waste may prove more limiting than its role as a source of raw materials.

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Second, we would like to further clarify why neoclassical economics tends to ignore the importance of natural capital. Neoclassical economists assume there is no absolute resource scarcity—as any resource becomes scarce, its price increases, providing incentives to develop substitutes. For example, 200 years ago, biomass was the major source of fuel for societies everywhere, but as forests grew scarce, prices rose, and we developed substitutes. Coal, petroleum, natural gas and uranium have since emerged as important resources so that, due to technology, we have more resources available to us today than we did 200 years ago. As these resources grow scarce, their prices will increase and the neoclassical economists assume that the market will again develop substitutes. All that matters is relative scarcity. The problem is that humans, like all other species, rely for their survival and economic welfare on intangible, non-marketed ecosystem services such as climate stabilization, water regulation, waste absorption and so on. Though increasingly scarce, the majority of these ecosystem services have no price, and therefore no feedback from markets signaling their scarcity and no market incentive to produce them.

Third, we would like to emphasize that the Millennium Ecosystem Assessment supports what ecological economists have been saying for years. When the economy grows, it does not expand into a void, but rather into the finite sustaining and containing biosphere. In the process, we lose natural capital and the vital life support functions it supplies. What ecological economists recognize is that it is not the net impact on human welfare that is relevant, but rather the marginal impact. We know from the law of diminishing marginal utility that the more economic goods and services we have, the less valuable an additional unit becomes, and the more we degrade the ecosystem, the greater the risk of catastrophic, nonlinear changes. At some point, rising marginal costs exceed diminishing marginal benefits and additional growth is uneconomic. This is why we must distinguish between economic growth, which is a physical increase in the rate at which the economy transforms natural resources into economic output and waste, and economic development, which is an increase in human welfare for a given level of resource use.

Fourth, we would like to further emphasize the implications of the increasing scarcity of natural capital for our market based economic system. Individuals choose how much of a market good they want to consume, but all members of society 'consume' the same level of ecosystem services, whether or not they contribute to their provision. As a result, a market system leads to sub-optimal production. Consumption of a market good such as gasoline by one person leaves less for everyone else, so it makes sense to ration consumption through price. In contrast, one person's 'consumption' of climate stability, clean air, flood prevention and most other ecosystem services (with the notable exception of waste absorption capacity), does not reduce the amount available for others. Rationing use through prices (if possible) reduces social benefits without changing social costs, so the market system leads to sub-optimal consumption. Neoclassical economists concentrate on markets, but markets fail to efficiently allocate our scarcest resources: we need an economic system capable of sustainably, fairly and efficiently allocating them.

Finally, we agree with our colleagues that ecological restoration is critically important, but argue that it is undermined by continued economic growth (though not by economic development). Economic growth relies on the extraction of renewable and non-renewable resources. The loss of renewable resources degrades ecosystems, as do the waste emissions from the use of non-renewable resources. Economic growth also promotes the conversion of ecosystems to roads, urban areas, agriculture and wasteland. Admittedly, some ecosystems may recover in growing economies, and some pollution levels may decline, but these improvements are off-set by ecological degradation elsewhere on the planet. Large scale ecological restoration ultimately requires an end to economic growth.

2. Dialoguing with Aronson, Blignaut, Milton and Clewell

Here we will address our colleague's points one by one.

The first issue our colleagues have with our diagram is our use of the term ecosystem instead of biosphere. We believe that the word ecosystem conveys the notion of complexity and the need for systems thinking. Another paper coauthored by Farley (Boumans et al., 2002) uses the term biosphere to describe all life on the planet, and this term may indeed be most appropriate when the focus is on ecological restoration. In the same paper, anthroposphere is equivalent to human-made capital and populations, lithosphere includes all non-renewable minerals and fossil fuels, hydrosphere includes all water flows and atmosphere has its standard meaning. If we add to this geosphere to describe Ricardian land (the notion of land as a physical substrate that captures sunlight and rain) we would have a unified system of terms to describe humans and their artifacts, renewable resources, non-renewable resources, water, air and land, all of which have distinct characteristics that affect their allocation. These separate spheres interact in complex ways to generate the global ecosystem and the ecosystem services it provides.

Our position is that no term is perfect, and as long as all terms are appropriately defined, which term is used is not critically important. That said, we both recognize that we are trained as economists, and though we are knowledgeable about ecology, we admit that ecologists are probably better qualified to decide on an appropriate label for the sustaining and containing system.

The second issue our colleagues have with our diagram is whether we have exaggerated the relative change in flows of economic and ecosystem services as we have moved from an empty to a full planet (we will return to the use of these adjectives below). Our colleagues point out "that growing economic services have made possible huge increases in human numbers but not, on average, human welfare. The human population has grown, as has the proportion that can be classified as ecological refugees." (Aronson et al., in this issue) This is another point well taken.

There are actually several factors relevant to the relative change in service flows. One is an ethical debate: how do we measure human welfare? Is average welfare the relevant concept, or total welfare summed across all people? If the latter, then the fact that we have gone from less than a billion to over six billion people over the past 200 years suggests a dramatic increase in the rate of flow of economic services even if average welfare has stayed the same. If we focus on average welfare, improvements in life expectancy, nutrition, health and literacy across most of the world might still support a significant increase in arrow size. Certainly we agree that the thickness of the arrow should not represent the sum of gross national product (GNP) across nations, which has increased by a factor of 36 in the last century alone (Delong, 2002). In any case, the arrows are not meant to be to scale, but are simply meant to illustrate the fact that as the economy grows, it does so at the expense of the sustaining ecosystem or biosphere.

Perhaps the most important issue is not the exact change in the width of the arrows over the last 200 years, but whether or not additional increases in economic service compensate for the inevitable reduction in ecosystem services. While our figure does not try to show this, the Index of Sustainable Economic Welfare (Daly and Cobb, 1994) and the Genuine Progress Indicator (Cobb et al., 1999) suggest that we have already crossed this threshold in many countries, and social welfare is decreasing as the economy grows. Other research suggests that economic growth correlates with greater life satisfaction, health and happiness only up to some threshold. Beyond this threshold, increases in relative wealth are more important than increases in absolute wealth, in which case economic growth in the wealthy countries may provide little or no net benefits (Easterlin, 1995; Frank, 2000; Lane, 2000; Max-Neef, 1995) while still imposing ecological costs.

Third, our colleagues argue that the term manufactured (literally hand-made) capital should replace manmade capital in our figure, to emphasize the fact that such capital is sterile, incapable of reproducing or sustaining itself. Certainly one of the key benefits of investing in natural capital is that it is capable of self-sustaining reproduction, while manmade capital is not. However, we define capital as a stock that yields a flow of benefits into the future, and hence lump fossil fuels, minerals and water into the category of natural capital, none of which are capable of reproduction.

Perhaps a more critical distinction is between stock-flow and fund-service capital (Georgescu-Roegen, 1971). Stock-flows are transformed into whatever is produced—timber into houses, steel into cars. Fund-services are the agents of transformation, which are not themselves transformed—the labourer or machine that makes cars, the car that provides the service of transportation or the forested watershed that regulates water flows and reproduces itself. Stock-flows are used up while fund-services are worn out, though fund-services provided by nature are continuously renewed through solar energy. In terms of natural capital, stock-flows are the structural elements of ecosystems. Fund-services are the ecosystem functions that result from a specific configuration of stock-flows. A wrecked car has the same structural elements as an intact car, but no longer provides the service of transportation, and a timber plantation may have many of the same structural elements as the native forest it replaces, but may no longer provide the same ecological functions (Malghan, 2006). These are useful concepts for answering the critical question in ecological restoration and ecological engineering of "what are we restoring to?" (e.g. Simenstad et al., 2005; Aronson and Le Floc'h, 1996; Middleton, 1999).

Fourth, our colleagues take issue with the placement of human welfare outside of the physical system in our figure. We do this to stress the fact that welfare is a psychological phenomenon. Admittedly, even psychological phenomena are ultimately part of the physical world, for as Eisely (1979) reminds us, "the human brain ... burns by the power of a leaf." There is no welfare without at least some physical consumption. However, our goal is to stress the fact that welfare is not tightly linked to the physical size of the economy. Research into human happiness has found only a very weak correlation with material consumption. In fact, the pursuit of material gain may actually correlate with unhappiness, and "young adults who focus on money, image and fame tend to be more depressed, have less enthusiasm for life and suffer more physical symptoms such as headaches and sore throats than others." (Bond, 2003, p. 40) The things most correlated with happiness include desiring less, friendships, marriage, religion and helping others (Holmes et al., 2003), all of which demand relatively few resources. Max-Neef (1992) has identified subsistence, protection, freedom, identify, participation, creation, idleness, affection and understanding as satiable needs that are constant across time and cultures, and most of these needs can be satisfied with minimal physical resources.

As ecological economists we argue that physical growth of the economic system must end. As economic growth is perhaps the most widely agreed upon economic goal in the world, this is seen as a radical demand, but is made less so when we stress the fact that economic development can continue to increase human welfare even as we reduce the physical size of the economy. If the current generations view sustainability as a sacrifice in welfare, we are unlikely to achieve it. By emphasizing the psychological nature of welfare, we hope to make it clear that sustainability does not imply a sacrifice of welfare, and in fact the opposite is likely to be true. We agree with Dresp (in this issue) that happy endings are important. In no way is this meant to imply that humans are not part of the natural world.

The fifth issue our colleagues have with our diagram is our use of the terms 'empty' and 'full'. They propose two alternatives, 'underdeveloped' and 'overdeveloped' and 'pre-industrial' and 'anthropocene'. As stated above, ecological economics distinguishes between economic growth, an increase in the rate of throughput and economic development or an increase in the level of welfare for a given rate of throughput. Though we do at times use them ourselves, for the purposes of this figure, the terms underdevelopment and overdevelopment offer too much ambiguity: is underdevelopment result of too little throughput, or inefficient conversion of that throughput to welfare enhancing artefacts? Could people mistake overdevelopment for too much welfare, rather than too much throughput?

Pre-industrial and anthropocene in contrast are excellent terms, in many ways superior to empty and full. However, the use of the word 'full' stresses the idea that there are physical limits to growth, while pre-industrial and anthropocene do not convey this message as clearly.

The sixth issue our colleagues raise with our diagram is the fact that we do not mention the importance of globalization. We certainly have no disagreement with the importance of globalization and address it at length elsewhere in our book, but did not feel it necessary to include everything of importance in a single figure. This is one luxury of having 450 pages to present our views! Globalization not only speeds up the processes depicted in our diagram, but is likely to make any resulting ecological collapse global as well. However, we believe that the current degree of globalization is only possible due to the abundance of cheap fossil fuels, and this era is coming to an end (Campbell and Laherrère, 1998). As we exhaust our fossil fuels and globalization declines, the rate of physical economic growth is likely to decrease. With or without globalization, continued economic growth threatens the natural capital on which our economy and species depends.

Seventh, while our figure essentially presents static snapshots of an empty and full planet, their figure suggests the dynamic conversion of natural capital stocks to human-made capital stocks, making this trade-off even more explicit. In addition, our colleagues show that the costs of restoring natural capital increase as the extent of ecosystem goods and services decline. We did not draw our figure to focus specifically on the issue of ecological restoration, and hence barely mention the need for such restoration, but certainly appreciate its importance.

There can be little doubt that the costs of ecological restoration rise as the abundance of ecosystem goods and services diminishes. When ecosystems are relatively healthy, it is possible to simply leave them alone, and they will restore themselves naturally. This has happened throughout the northeastern US and in large parts of the Amazon. However, if ecosystems fall below their minimum viable size or are subject to excessive waste emissions, climate change or other impacts, the cost and difficulty of restoration increases dramatically. For example, only some 7% remains of Brazil's Atlantic Forest, much of it replaced by fire prone grasslands (Silvano et al., 2005). Natural restoration in the presence of periodic fires is unlikely, and it is in fact quite possible that fires will overwhelm remaining forest tracts. A rough rule of thumb in island biogeography suggests that a 90% reduction in size of an ecosystem leads to a loss of 50% of the species (MacArthur and Wilson, 1967). In the Atlantic forest, it is quite possible that a massive and expensive restoration process will be required to prevent such a loss in biodiversity. We must bear in mind however that the total value of ecosystem goods and services is infinite. Whatever cost we are forced to pay for restoration is worth it if the alternative is reducing critical natural capital stocks to a level from which they can never recover. Our goal should be to minimize costs by initiating restoration activities while restoration costs are still relatively small.

Finally, our colleagues argue that our figure focuses too much on the problem and not enough on the solutions. They are right. Our textbook emphasizes an end to economic growth (not development) as one solution, and only to a lesser extent the need for ecological restoration. Both are essential.

3. Conclusion

In conclusion, we have three points to make. First, we are very grateful for the opportunity to dialogue with colleagues. We are trained as economists, and appreciate the chance to learn from ecologists. Disciplines tend to develop their own jargon and language, making communication between disciplines unnecessarily difficult. The only way to break down this barrier is to engage in dialogue, explain what we mean by our jargon, and eventually agree on a mutually acceptable language. Until such a language emerges we must be careful to define our terms, and present the terms that other researchers are using to label the same ideas. If we pursue this approach, we expect that over time one set of terms will come to dominate. And we should all strive to keep our language intelligible to the general public.

Second, in addition to overcoming the language barrier, dialogue is necessary for the cross fertilization of ideas. Economics seek to allocate scarce resources among alternative desirable ends, but we cannot do this without understanding how ecosystems function, and how economic activities affect them. Dialogue is essential to stimulate ever greater synthesis between the multiple disciplines that contribute to ecological engineering, ecological restoration and ecological economics.

Third, to understand complex systems, we need more than one model, and more than one diagram to explain it. We do not believe that our diagram is better than the one our colleagues propose, but rather that both do a good job of emphasizing slightly different concepts.

In summary, there is growing agreement across the natural and social sciences and engineering that natural capital is the limiting factor in improving human welfare. Broad swathes of civil society, non-government organizations, business and governments (with some notable and unfortunate exceptions) are slowly coming to accept this fact as well, but the need for action is urgent and the stakes are high. We must learn to communicate the seriousness and urgency of the problem rapidly and effectively if we want society to act before the growing scarcity of natural capital makes its importance painfully obvious, and the costs of restoration painfully high. We hope this dialogue contributes to that goal.

REFERENCES

Aronson, J., Blignaut, J., Milton, S., Clewell, A., in this issue. Natural Capital: the Limiting Factor. Ecol. Eng.

Aronson, J., Le Floc'h, E., 1996. Vital landscape attributes: missing tools for restoration ecology. Restor. Ecol. 4, 377–387.

Bond, M., 2003. The pursuit of happiness. New Sci. 180 (4), 40–43.

Boumans, R., Costanza, R., Farley, J., et al., 2002. Modeling the dynamics of the integrated earth system and the value of global ecosystem services using the GUMBO model. Ecol. Econ. 41, 3.

Campbell, C., Laherrère, J., 1998. The end of cheap oil. Sci. Am. 278, 78–83.

Cobb, C., Goodman, G., Wackernagel, M., 1999. Why bigger isn't better: the genuine progress indicator: 1999 Update. Available on-line at http://redefiningprogress.org/publications/pdf/gpi1999.pdf. Redefining Progress, Oakland, CA.

Daly, H., Cobb, J., 1994. For the Common Good: Redirecting the Economy toward Community, the Environment and a Sustainable Future, second ed. Beacon Press, Boston.

Daly, H., Farley, J., 2004. Ecological Economics: Principles and Applications. Island Press, Washington.

Delong, J.B., 2002. Macroeconomics, Chapter 5. McGraw-Hill Higher Education, Burr Ridge, IL.
Dresp B, in this issue. Restoring is Believing. Ecol. Eng.
Easterlin, R., 1995. Will raising the incomes of all increase the happiness of all? J. Econ. Behav. Organ. 27 (1), 35–47.
Eisely, L., 1979. The star thrower. Harcourt, 94.
Frank, R., 2000. Luxury Fever: Money and Happiness in an Era of Excess. Princeton University Press, Princeton, NJ.
Georgescu-Roegen, N., 1971. The Entropy Law and the Economic Process. Harvard University Press, Cambridge.
Holmes, B., Kleiner, K., Douglas, K., Bond, M., 2003. Reasons to be cheerful. New Sci. 180 (4), 44–47.
Lane, R., 2000. The Loss of Happiness in Market Democracies. Yale University Press, New Haven, CT.
MacArthur, R., Wilson, E.O., 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, NJ.
Malghan, D., 2006. On Being the Right Size: A Framework for the Analytical Study of Scale, Economy, and Ecosystem. Ph.D. Dissertation. University of Maryland, College Park.
Max-Neef, M., 1992. Development and human needs. In: Ekins, P., Max-Neef, M. (Eds.), Real-life Economics: Understanding Wealth Creation. Routledge, London, pp. 197–213.
Max-Neef, M., 1995. Economic growth and quality of life: a threshold hypothesis. Ecol. Econ. 15, 115–118.
Middleton, B.A., 1999. Wetland restoration. In: Flood pulsing and disturbance dynamics. John Wiley and Sons Inc., New York, NY.
Mitsch, W., Jorgensen, S., October 2003. Ecological engineering: a field whose time has come. Ecol. Eng. 20 (5), 363–377, 15.
Simenstad, C., Reed, D., Ford, M., 2005. When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecol. Eng. 26 (1), 27–39.
Silvano, R., Udvardy, S., Ceroni, M., Farley, J., 2005. An ecological integrity assessment of a Brazilian Atlantic Forest watershed based on surveys of stream health and local farmers' perceptions: implications for management. Ecol. Econ. 53, 369–385.
Society for Ecological Restoration International Science and Policy Working Group, 2004. The SER International Primer on Ecological Restoration. Society for Ecological Restoration International, Tucson, www.ser.org.