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Anastasios Xepapadeas, Steve Carpenter, Sara Aniyar, Kenneth Arrow, Gretchen Daily, Partha Dasgupta, Paul Ehrlich, Carl Folke, Geoff Heal, Michael Hoel, Nils Kautsky, Simon Levin, Jane Lubchenco, Karl-Göran Mäler, Elinor Ostrom, Thomas Rosswall, David Starrett and Brian Walker. 2004.

The Beijer Institute of Ecological Economics
The Royal Swedish Academy of Sciences
Box 50005 SE-104 05 Stockholm Sweden
Phone: +46 8 673 95 00 Fax: +46 8 15 24 64
E-mail: beijer@beijer.kva.se

Sustainability's Compass: Indicators of Genuine Wealth

Anastasios Xepapadeas[1], Steve Carpenter[2], Sara Aniyar[3], Kenneth Arrow[4], Gretchen Daily[5], Partha Dasgupta[6], Paul Ehrlich[5], Carl Folke[7], Geoff Heal[8], Michael Hoel[9], Nils Kautsky[7], Simon Levin[10], Jane Lubchenco[11], Karl-Göran Mäler[3], Elinor Ostrom[12], Thomas Rosswall[13], David Starrett[4], Brian Walker[14]

[1]Department of Economics, University of Crete, Rethymno 74100, Crete, Greece
[2]Center for Limnology, University of Wisconsin, Madison, Wisconsin 53706 USA
[3]The Beijer Institute, Royal Swedish Academy of Sciences, 104 05 Stockholm, Sweden
[4]Dept. of Economics, Stanford University, Stanford, California 94305 USA
[5]Dept. of Biological Sciences, Stanford University, Stanford, California 94305 USA
[6]Faculty of Economics, Cambridge University, Sidgwick Avenue, Cambridge CB3 9DD, UK
[7]Dept. of Systems Ecology, Stockholm University, S-10691 Stockholm, Sweden
[8]Program on Information and Resources, Columbia University, New York, NY 10027 USA
[9]Dept. of Economics, University of Oslo, Box 1095 Blindern, 0317 Oslo, Norway
[10]Dept. of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08544 USA
[11]Dept. of Zoology, Oregon State University, Corvallis, Oregon 97331 USA
[12]Workshop on Political Theory and Policy Analysis, Indiana University, Bloomington, Indiana 47403 USA
[13]International Foundation for Science, Grev Turegatan 19, 114 38 Stockholm, Sweden
[14]CSIRO Sustainable Ecosystems, GPO Box 284, Canberra, ACT 2601, Australia

Introduction

Sustainability of the Earth's social, economic and ecological systems concerns the status, trends and future prospects for these systems as a whole.[1] Preserving or enhancing the flows of goods and services that humans derive from ecosystems is a condition for sustainability. These flows are multidimensional and complex, with many tradeoffs that are poorly understood. Yet, humanity must make decisions now that will affect ecosystem goods and services for decades into the future. These decisions will rely on indicators of future condition of the whole social, economic and ecological system, but how should these indicators be chosen? Economics and ecology converge on indicators that represent forward-looking measures of the capacity of ecosystems to supply a non-decreasing flow of goods and services.

Economics: Non-Declining Wealth

Non-declining genuine wealth is a consequence of a simple, yet illuminating, definition of sustainability.[2] Genuine wealth, defined in an inclusive way, is the accounting worth of an economy's capital assets, with the capital base consisting of produced, human, and natural capital.[2,3,4]

Importantly, this concept includes the future capacity of ecosystems to support human well-being. Changes in genuine or inclusive wealth, measured in constant accounting prices, represent genuine investment, or net change in capital.[3,5] This is because accounting prices reflect the discounted value of the future flow of changes in welfare due to changes in the stock of the capital base.[3] A basic advantage of genuine wealth over other commonly used indices such as GDP or the Human Development Index, is that wealth (by using accounting prices to value changes in the capital base) is a forward-looking measure that reflects expected future changes in well-being. For example, wealth is related to measures of literacy and education that reflect the future productive capacity of people.[3]

The capital base, however, is highly heterogeneous, including combinations of tangible and intangible items, some of which have no markets.[6,7] This presents a major difficulty in measuring genuine wealth, although, as shown below, it is not impossible to overcome these difficulties in order to produce some approximations. With the exception of produced capital, the market does not supply forward-looking measures of social value that reflect accounting prices. One of these problematic components of genuine wealth is natural capital, such as that associated with biodiversity or the capacity of ecosystems to supply goods and services despite environmental shocks.

The notion of wealth distinguishes between the current productive capacity of a system and its capacity to produce in the future. The future productive capacity of the system is closely associated with the concept of resilience.[8,9,10] More resilient systems are less likely to be degraded to configurations that reduce inclusive wealth.

Ecology: Non-Decreasing Resilience

Resilience is measured by the change that can be tolerated before an ecosystem moves to a different configuration, controlled by different processes and yielding a different flow of ecosystem services.[11,12] Once such a shift has occurred, restoration of the original condition may be expensive or impossible. Massive shifts have been documented for freshwater, marine, rangeland, forest and arctic ecosystems.[12,13] Frequently such shifts in ecosystems have severe impacts on natural capital and flows of ecosystem goods and services.

While each shift in ecosystem services has unique site-specific characteristics, there are general patterns that arise in case after case.[13] Among these are: slowly-changing variables that control the basins of attraction for various ecosystem states; feedbacks that can rapidly change direction at critical thresholds; and stochastic shocks that can trigger rapid collapse when resilience is sufficiently low. Often the slowly-changing variables provide clues to resilience.

For example, resilience of lake water quality is related to concentrations of phosphorus in soils and sediments, which change more slowly than phosphorus concentrations in lake water and provide a useful leading indicator of water quality.[11] Lake eutrophication is a familiar example (Box 1). For the ecological-economic system composed of a lake and its agricultural catchment, one can study the optimal control of ecosystem service flows – inclusive wealth as defined above. For a wide range of realistic conditions, the optimal trajectories possess different characteristics. There could be monotonic convergence or cyclic convergence to an oligotrophic or a eutrophic steady state depending on initial conditions.[14,15] However, the clear water state can be maintained for long periods of time by management according to practical, measurable indicators of resilience. Soil P concentration should be kept relatively low, and the target level for soil P is lower for lakes that have more P in the sediments (hence greater potential recycling). A simple way to stabilize soil P is to create incentives for farm P budgets that balance (i.e. imports of P in fertilizer and animal feed equal exports of P in grain, produce, dairy products, eggs and meat). For example, farm exports of P (in the form of food) could be tied to marketable credits for purchase of P (such as fertilizer or animal feed).[16]

In the lake example, the accounting price for P reflects the present value of a change in well-being associated with the specific lake system resulting from a change in the P concentration. Thus if accumulated P (or its inverse) is regarded as our environmental capital, its value can be measured locally using a fixed accounting price. If we take a global approach, then accounting prices change, and their change should provide the signal for the direction of change of inclusive wealth for the lake system. Thus in the lake case, although the system is fairly complex, our understanding of the physical and economic processes involved allows us to approximate the wealth concept as a proxy for well-being associated with the lake system. In this system we obtain two interrelated types of signals regarding the possible loss of resilience of the system because of perturbations, which could be reflected in a fast movement from a desirable oligotrophic state to an undesirable eutrophic state. One is the concentration of P: an increase in P could indicate that the system is moving towards a threshold point after which it would move fast to a eutrophic basin of attraction. At the same time the accounting price for P should change, indicating that the move to the eutrophic region will reduce the present value of the benefit flow from the lake.[17] Thus changes in the P concentration or its accounting price can be regarded as sufficient indicators of the resilience of the flow of services from the lake system, to perturbations. We want these indicators to be forward looking. In the lake example, indicators based on soil P will be more successful in having the forward looking property than those based on water. On the other hand, accounting prices are forward looking by construction, although admittedly much harder to estimate.

Similarly, the resilience of rangelands is related to dynamics of woody vegetation, which changes more slowly than grass biomass and serves as a leading indicator of rangeland productivity.[11] In these well-studied cases, we know enough about the processes driving the system to devise indicators. Because this is not always the case, data collection as part of the indicator-building task could be used in learning the structure of ecosystem processes and devising better indicators of wealth associated with natural capital.

In general, the ecological variables that control resilience should be kept within certain bounds, and these bounds change depending on other variables that control critical feedbacks. The probability of a state shift also depends on the disturbance regime, which is affected by ecosystem properties as well as events outside the ecosystem. Despite the enormous differences in detail among ecosystems, the general challenge is the same: to avert a slow loss of resilience followed by a stochastic shock that leads to a long-lasting change in ecosystem service flows.

Indicators that provide the signals needed to maintain resilience and reduce the risk of long-lasting losses of ecosystem goods and services are surrogates for the natural capital component of wealth. Wealth indicators must be tied to slowly-changing ecological variables that govern resilience. In this sense, ecological wealth can be thought of as providing insurance against possible shocks that move the system to an undesirable state and, as a result, might reduce the flow of useful ecosystem services.

In the lake case a clear lake – low P concentrate – can be thought of as indicating a high value of ecological wealth. This wealth – clear state – can be thought of as providing insurance against a possible shock that causes an increase in the P concentrate, in the sense that it prevents the system from going over the threshold, losing its resilience, and moving towards an undesirable eutrophic basin of attraction. Similar examples of a relationship between wealth in the form of environmental capital, providing insurance against loss of valuable ecosystem services due to perturbations, and resilience can be found in cases including forests, fish biomass, wetlands, and so forth. Correspondingly, the accounting prices for ecological resilience can be thought of as the insurance premium we are willing to pay for this insurance.

Forward-Looking Indicators

Wealth, accounting prices, and ecological resilience are all forward-looking by design. They reveal the guardrails within which complex social and ecological systems can sustain a particular level of human well-being. While the theoretical meaning of inclusive wealth is clear, precise calculation of wealth is difficult, especially when we want to capture the forward-looking aspects that we seek. A pragmatic approach is needed, analogous to the various indicators used by governments to gauge economic activity, or by securities markets to evaluate performance of investments. Society routinely bases important decisions upon, and pays considerable sums to measure, indicators such as GDP or the various stock-market indices. Such indices are known to be insufficient statistics but nevertheless provide a well-understood basis for comparison across nations and across years. Natural capital is surely worthy of comparable attention. An appropriate set of wealth indicators could help guide humanity toward sustainability.

Recent estimates of genuine wealth,[18] where changes in natural capital are reflected in CO_2 damages, energy minerals and forest depletion, show a striking difference between the picture that emerges of the development path of an economy when genuine wealth per capita is used as a yardstick instead of the conventional GDP per capita. As shown in table 1 column 4, there are economies which cannot be regarded as sustainable because genuine wealth per capita, before adjustments for changes in total factor productivity (TFP) is taken into account, is declining, while for the same economies GDP per capita is increasing. When technological change is accounted for through TFP adjustments, there is an overall improvement regarding the sustainability of some individual economies as shown in column 3 of table 1. It should be noted however that the contribution of TFP to the sustainability criterion of genuine wealth growth is expected to be overestimated. This is because conventional TFP estimates are likely to be biased upwards because they do not take into account the depletion of environmental capital.[19]

In estimating particular indices, transparency is essential; the procedure for calculating the index must be well-understood and repeatable by all. The index will necessarily be measured by sampling an arbitrary (but clearly stated and widely-agreed-upon) set of ecosystems, of specified spatial extent and distribution, at specified time intervals.

Indices that represent future changes in natural capital will be instrumental in enhancing the insurability of environmental risks. Liability insurers are highly exposed to environmental risks, which are characterized by ambiguous probability that an environmental loss will occur and by ambiguity of the value of the loss itself.[20] By using early warning indicators to characterize the adaptive capacity of ecosystems, the probability of losses will become less ambiguous. Furthermore, by valuing environmental assets using forward-looking accounting prices, the ambiguity about the value of the loss will also be reduced. The reduction in ambiguity leads to a reduction in premiums. The effect of wealth indicators on insurance premiums is analogous to those of the Eco-Management and Audit Scheme (EMAS) or ISO 14000. Eventually, these reductions in ambiguity will reduce the vulnerability of the re-insurance sector (defined as the relationship between probable maximum losses, the probability of the catastrophic event, and the sector's capacity to pay for these losses).

Substitutability is a critical issue in designing an index of inclusive wealth. For market goods, pricing reflects the tradeoffs that people are willing to make between different priorities, for example food and shelter. How can such tradeoffs be assessed for fundamentally different aspects of ecological wealth, such as the future supply of soil fertility and water quality, or the future supply of a predator and its prey? At what spatial scale should ecological wealth be assessed – nations, major river basins, the world? How should wealth be aggregated across spatial units or different types of ecosystems? This is an area of great importance for future research. It is clear that in dealing with ecological wealth, one has to accept conditions of limited substitutability, or thresholds above which substitution is not possible. Until these tradeoffs are understood, a variety of disaggregated indicators should be employed that represent diverse aspects of ecosystem wealth.

Ecosystem resilience implies some pragmatic solutions to these problems. For example, freshwater ecosystem resilience and agricultural production could be maintained by balancing farm phosphorus budgets through market mechanisms, without detailed understanding of site specific complexities of the phosphorus cycle or the individual decisions of millions of farmers.[21]

Similar rules of thumb can be devised for other types of ecosystems, where the foundations of resilience may lie in wilderness and unconverted ("undeveloped") land and habitat; diversity of crops and animals in the food base (including genetic diversity), species biodiversity, and diversity of habitats; institutions that facilitate conservation by individual landowners, local people, and government at multiple levels; and markets to capture externalities such as emissions of pollutants, fertilizers, pesticides and herbicides.

Activities to build ecosystem wealth can be initiated now. If action is combined with measurements of indicators of inclusive wealth, society will establish the empirical baseline needed to improve management of our common wealth in the future.

Box 1. Lake Eutrophication

Eutrophication is a state of lakes characterized by toxic blooms of algae, episodes of anoxia, fish kills, and loss of freshwater ecosystem services such as drinking water, water for irrigation and industrial use, fisheries, and recreation.[22] The fundamental cause is enrichment with phosphorus (P).[23] P is an element in agricultural fertilizers and livestock feed which tends to accumulate in soil (Figure 1A). Erosion washes the soil into streams and lakes, where it dissolves and becomes available to algae, including toxic bloom-forming species which are favored at high P concentrations. P also accumulates in sediments. It is rapidly recycled from sediments during episodes of anoxia, which are caused by decay of dead algae.

A minimal model of P dynamics in lakes (Figure 1B) includes processing of P by outflow and sedimentation (straight line), and inputs plus recycling (curved lines). Two hypothetical lakes are shown in Figure 1B. Lake 2 has higher average input from the soil (intercepts of curved lines) and a higher maximum rate of recycling (height of curved lines). Both lakes have identical outflow and sedimentation. Steady states occur where the straight and curved lines intersect. Both lakes have three steady states. The middle one is an unstable repeller, and the upper and lower ones are locally stable attractors. The steady state at low P concentration is the clear-water state, and the steady-state at high P concentration is the turbid or eutrophic state.

Resilience of a state is measured by the distance (in P units) from a stable steady state to the unstable steady state. The resilience of the clear-water state is greater for lake 1 than for lake 2. Resilience is related to the size of a stochastic shock that the system can absorb without changing states. A shock which moves the system from one stable state past the unstable steady state will shift the system to the other stable state. For example, a P input event that is larger than the resilience of the clear-water state will push the lake past the unstable steady state, and recycling will then drive the P level to the eutrophic steady state.

Soil P affects the probability distribution of input events to the lake (Figure 1C). These input events are driven by variable and unpredictable storms and snowmelt, so we model them as a random variable. The logarithm of inputs usually fits a Student-t or gamma distribution. The watershed of lake 2 has high-P soils causing a higher mean input rate (Figure 1B) and broader distribution of stochastic shocks (Figure 1C). Therefore, there is a relatively high probability of a shock large enough to move lake 2 out of the clear-water state.

Utility is derived from activities that cause P loading to the lake, such as intensive use of fertilizers or animal-intensive farming. These utilities increase (with decreasing slope) as P loading rate increases (Figure 1D). Utilities are also associated with water quality as measured by the amount of P in the lake water. These utilities are ecosystem services that may not have markets, such as water for diverse human uses, fisheries, or recreation. These utilities increase with P and low P levels (Figure 1E), because a small amount of P supports production of ecosystem services such as fishes and waterfowl. Above an optimal level of P in the lake, however, utility declines.

Figure Caption:

Figure 1. (A) Flows of phosphorus (P) from agricultural sources (fertilizer, manure) into soil, lake water, and sediments. (B) Rates of P flow into and out of lake water, as a function of P mass in the water. Straight line is loss flux by hydrologic outflow and sedimentation. Curved line is mean loading from the watershed plus recycling from sediments and consumers. Lake 1 has low mean loading and low recycling, lake 2 has high mean loading and high recycling. (C) Probability distributions of annual load for Lake 1, with low mean loading, and Lake 2, with high mean loading. (D) Utility generated annually by agricultural activities that cause loading of P to

the lake. (E) Utility generated annually by ecosystem services such as fresh water for human use, fish, and recreation.

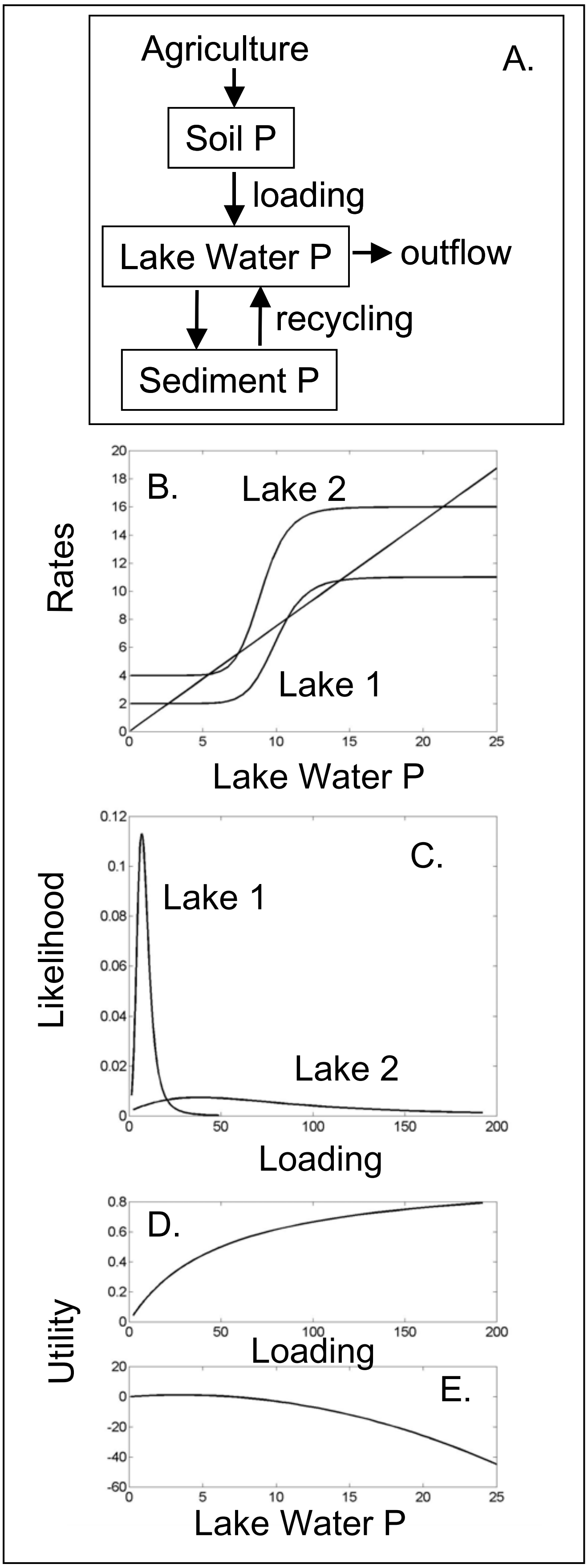
Agriculture
A.
Soil P
loading
Lake Water P
outflow
recycling
Sediment P
B.
Lake 2
Lake 1
Rates
Lake Water P
C.
Lake 1
Lake 2
Likelihood
Loading
D.
Utility
Loading
E.
Lake Water P

Table 1. Growth Rate of Per-Capita Genuine Wealth and Per Capita GDP (*)

Country	Genuine Investment as Percent of GDP (1)	Growth Rate of Per-capita Genuine Wealth - before TFP adjustment (2)	Growth Rate of Per-capita Genuine Wealth - after TFP adjustment (3)	Growth Rate of Per Capita GDP (4)
Bangladesh	7.09	-1.09	0.30	1.88
India	9.46	-0.57	0.54	2.96
Nepal	13.31	-0.24	0.63	1.86
Pakistan	8.75	-1.35	0.59	2.21
China	22.73	2.06	8.33	7.77
Sub-Saharan Africa	-2.08	-3.05	-2.58	-0.01
Middle East and North Africa	-7.09	-3.43	-3.82	0.74
United Kingdom	7.38	1.30	2.29	2.19
United States	8.94	0.72	0.75	1.99

(*) Source: Arrow et al. 2003

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