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# NATURAL RESOURCE SUSTAINABILITY FROM THE GEOGRAPHICAL SIDE OF ECOLOGICAL ECONOMICS

Christopher L. Lant\*

## I. INTRODUCTION

With intellectual roots in neoclassical and institutional economics as well as ecology, ecological economics is a thriving trans-discipline that challenges the traditional theoretical constructs of both economics and ecology while offering powerful concepts of its own.<sup>1</sup> Ecological economics challenges the traditional neoclassical economics paradigm and interfaces with the discipline of geography in a unique and potentially fruitful way. However, few ecological economists have considered the spatial dimension of environmental problems or utilized geographic information systems (GIS), despite their tremendous potential contribution in empirical ecological economics studies. The purpose of this article is to illustrate the core concepts of ecological economics and, by bringing these concepts to bear in a geographical context, move them one step closer to legal and policy relevance.

## II. THE ECOLOGICAL ECONOMICS CHALLENGE TO THE NEOCLASSICAL ECONOMICS PARADIGM

Ecological economics is an environmental discourse rooted in economic rationalism.<sup>2</sup> Yet, while neoclassical economics takes efficiency and economic growth as its normative goals, ecological economics strives for sustainability. Drawing from Dryzek's taxonomy of environmental discourses, ecological economics rejects the "Promethean" denial of ecological limits to economic growth articulated by scholars such as Julian Simon<sup>3</sup> and, in more contemporary form, Bjorn Lomborg.<sup>4</sup> Rather than

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1. As a rough measure of scholars' interest in this area of study, consider the increasing volume of scholarly work published by the International Society for Ecological Economics (ISEE) in its journal, *Ecological Economics*. In its first year of publication (1989), the journal ran a mere 370 pages in length. However, between 1996 and 2004, each of its volumes exceeded 1,000 pages, culminating in 2006 and 2007 with 3,264 and 2,796 pages, respectively.

2. See John S. Dryzek, *The Politics of the Earth: Environmental Discourses* 102–120 (Oxford U. Press 1997).

3. See generally Julian L. Simon, *The Ultimate Resource* (Princeton U. Press 1981).

4. See generally Bjorn Lomborg, *The Skeptical Environmentalist: Measuring the Real State of the World* (Hugh Matthews trans., Cambridge U. Press 2001).

adopting the survivalist, Malthusian, or limits to growth perspective associated with the Club of Rome,<sup>5</sup> Paul Ehrlich,<sup>6</sup> and the Worldwatch Institute,<sup>7</sup> however, ecological economics identifies *increasing marginal ecological opportunity costs* associated with economic growth. That is, as human economies co-opt a larger and larger share of the biosphere's energy and materials and release increasing quantities of waste, the incremental ecological impacts of economic growth rise, and the flow of ecosystem services to society diminishes at an accelerating rate.

Unlike many neo-conservative environmental and natural resource economists who advocate the expansion of private property rights into the environmental commons so that markets can allocate resources more efficiently,<sup>8</sup> ecological economics focuses on the critical failures of the market and suggests that a remedy to these failures lies in taking ecological opportunity costs into account in a variety of innovative ways. Many of the institutional changes proposed reassert public rights to the environmental commons while others provide new incentives to private property owners to invest in that commons. By utilizing the analytical techniques of industrial ecology, ecological economics interfaces with the northern European school of ecological modernization<sup>9</sup> epitomized in the North American arena by the non-governmental organization Bioneers and by Hawken, Lovins, and Lovins' book *Natural Capitalism*.<sup>10</sup> Ecological economists operationalize the vague and politically malleable concept of sustainable development as a program for greatly increasing the productivity of natural resource use through revolutionary technologies that maximize recycling and biomimicry and minimize energy consumption and material throughput in the achievement of social objectives.

With roots in neoclassical rather than Marxist economics, ecological economics maintains many core concepts, such as supply and demand and marginal analysis, but also offers a critique of the neoclassical paradigm. As a point of departure and in contrast to neoclassical assumptions, the "preanalytic vision"<sup>11</sup> of ecological economists is characterized by the view that "the economy" is a subset of the biosphere.<sup>12</sup> Historically, the economy has been a relatively small subset so the effect of its growth on the rest of the biosphere has been an issue of primarily local concern, though at times economic overexpansion has resulted in local social collapse.<sup>13</sup> However, rapid growth

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5. See generally Donella H. Meadows et al., *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (Universe Bks. 1972).

6. See generally Paul R. Ehrlich, Anne H. Ehrlich & John P. Holden, *Ecoscience: Population, Resources, Environment* (W.H. Freeman & Co. 1977).

7. See generally Worldwatch Inst., *State of the World: Our Urban Future* (Linda Starke ed., W.W. Norton & Co. 2007).

8. See e.g. Terry L. Anderson & Donald R. Leal, *Free Market Environmentalism* (Westview Press 1991).

9. See generally e.g. João Rodrigues et al., *Constraints on Dematerialisation and Allocation of Natural Capital along a Sustainable Growth Path*, 54 *Ecological Econ.* 382 (2005).

10. See generally Paul Hawken, Amory Lovins & L. Hunter Lovins, *Natural Capitalism: Creating the Next Industrial Revolution* (Little, Brown & Co. 1999).

11. See Herman E. Daly, *Five Policy Recommendations for a Sustainable Economy*, in *Sustainable Planet: Solutions for the Twenty-First Century* 209 (Juliet B. Schor & Betsy Taylor eds., Beacon Press 2002).

12. The term "biosphere" refers here to the entirety of life on Earth and the planetary zones in which it occurs, for example, the oceans, lower atmosphere, land surface and lithosphere to a depth of at least one mile.

13. See e.g. Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (Viking 2005) (offering a number of case studies and a theoretical approach for analyzing environmental collapse); Don Stephen Rice & Prudence M. Rice, *Lessons from the Maya*, 19 *Latin Am. Research Rev.* 7 (1984).

in population and per capita economic productivity and diffusion of industrial technologies generated a 36-fold increase in global material output over the course of the 20th Century.<sup>14</sup> As a result, the human economy now co-opts a sizable fraction of biospheric energy and materials. Peter Vitousek and colleagues, for example, calculated in 1986 that about 40 percent of global terrestrial net primary productivity is channeled through human activities.<sup>15</sup> In addition, it is estimated that from one-third to one-half of the land surface of the Earth has been transformed to meet human needs, that carbon dioxide concentrations have increased by 30 percent, that nitrogen fixation by humans exceeds fixation by natural processes, that more than half of ocean fisheries are fully exploited, overexploited, or depleted, and that more than half of all fresh water is used by humans on its route to the ocean.<sup>16</sup> While these are rough measures and there is no consensus on what indicators are most valid, these data collectively provide a basis for concluding that global human economic activity currently constitutes a sizeable proportion of the biosphere and that this proportion continues to increase rapidly. Emerging in the 1980s alongside these developments, ecological economics concerns itself with the role the biosphere plays in supporting human life and economic activities, the impacts economic growth imposes upon it, and the part institutions play in structuring human utilization of nature.

Ecological economics critiques economic growth by introducing the concepts of ecological opportunity cost and optimal economic scale. As the economy grows over time, increasing consumption of economic goods and services brings decreasing marginal returns to human welfare, but imposes increasing marginal costs upon the biosphere, see *Figure 1*. When the marginal ecological opportunity costs of economic growth rise to the level of the diminishing marginal benefits of economic growth, the optimal size of the economy has been reached. Beyond this point, further increases in production and consumption of goods and services can constitute *uneconomic growth*—a concept that is impossible in a neoclassical economic world where resource industries and waste services are considered a subset of the economic whole.

Building on neoclassical economic factors of production such as land, labor, and capital, ecological economics offers two additional concepts that play key roles in the overall nature-society-economy system: *natural capital* and *ecosystem services*. Natural capital is a complex concept. As a renewable or nonrenewable *stock*, natural capital consists of a storehouse of biotic and geologic natural resources that await capture and utilization as sources of energy and raw materials for the production of economic goods and services. As a *fund* capable of providing a flow of services, natural capital also consists of extant ecosystems whose structural composition maintains ecological functions, including the capture of solar energy and production of atmospheric oxygen through photosynthesis and the maintenance of biogeochemical cycles and biodiversity. The study of these ecological functions forms the core of environmental science and ecology and interfaces strongly with physical geography. While ecological functions

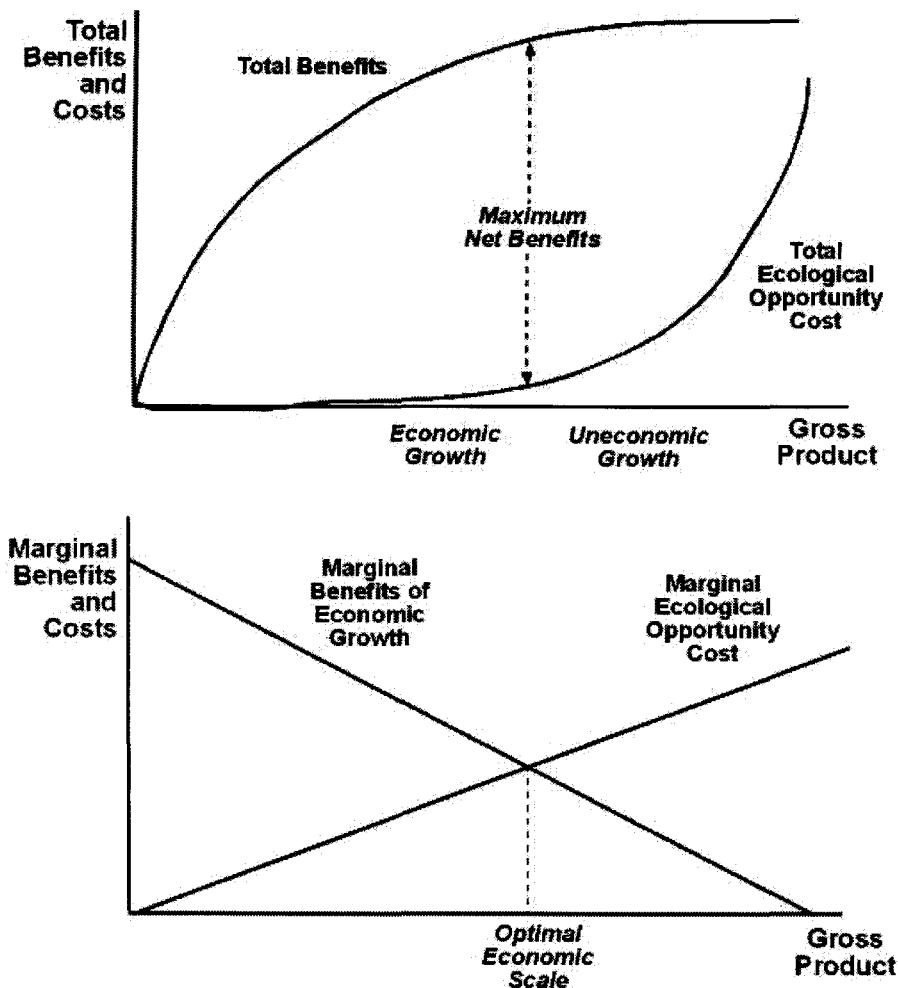
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14. Herman E. Daly & Joshua Farley, *Ecological Economics: Principles and Applications* 112 (Is. Press 2004).

15. Peter M. Vitousek et al., *Human Appropriation of the Products of Photosynthesis*, 36 *Bioscience* 368, 371 (1986).

16. See Peter M. Vitousek et al., *Human Domination of Earth's Ecosystems*, 277 *Sci.* 494, 495–97 (1997).

occurred before humans and could continue in their absence, the primary issue in ecological economics is anthropocentric—that is, ecological economics is primarily concerned with describing how changes in ecosystem function affect human well-being through the provision of ecosystem services.



**Figure 1.** The benefits and ecological opportunity costs of economic growth and the optimal size of the world economy. Optimal economic scale occurs where the net benefits of economic production are maximized; this occurs where the declining marginal benefits of economic growth equal the rising marginal ecological opportunity costs.

The Millennium Ecosystem Assessment<sup>17</sup> defines ecosystem services<sup>18</sup> as “the

17. Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: A Framework for Assessment* (Is. Press 2003) (offering the most ambitious undertaking yet to evaluate the state of Earth’s ecosystems and the implications this has for human welfare, explicitly and usefully employs the ecosystem services concept and this taxonomy to group them).

18. The term “ecosystem services” as used in this paper describes those functions performed by biological and physical processes that sustain human life; *but see e.g.* Natl. Sci. Found. Advisory Comm. for Envtl.

benefits people obtain [either directly or indirectly] from ecosystems.”<sup>19</sup> Lists of ecosystem services abound<sup>20</sup> but nearly always include (1) aesthetic, recreational, and spiritual *cultural* benefits, (2) the *provision* of food, fiber, medicines, and fresh water, (3) the *regulation* of atmospheric gases and climate, the hydrologic cycle, pest species, seed dispersal and pollination, and (4) *supporting* services such as soil formation and binding, photosynthesis, and nutrient cycling.<sup>21</sup> The identification and classification of ecosystem services is ongoing not only because knowledge is rapidly accumulating but also because the form of society’s dependence upon ecosystems is constantly changing and varies geographically. Cultural ecosystem services such as recreation and aesthetics in particular are closely tied to changing human attitudes, perceptions, and preferences.

Figure 2 captures how the ecological economics paradigm modifies the neoclassical economics paradigm in six critical ways:

1. *The economy is a distributive structure.* In accord with the second law of thermodynamics, the biosphere is powered by the entropic differential between incoming solar energy, which is free energy capable of performing work, and outgoing waste heat, which is not, see Figure 2a. To borrow from complexity theory, the biosphere is a distributive structure. The genius of Georgescu-Roegen<sup>22</sup> was his recognition that the economy is also a distributive structure nested, like a matrioshka doll, within the larger distributive structure of the biosphere, and, like that larger distributive structure, the internal organization of the economy is maintained through continuous flows of free energy and low-entropy raw materials from the biosphere and results in emission of high entropy waste to the biosphere. Therefore, the flow of matter and energy through the economy increases the level of entropy in the remainder of the biosphere, see Figure 2a.

2. *The nature-society-economy system runs on feedback loops.* The production of market goods and services depends, in various proportions and combinations, on inputs of (a) labor derived from human capital residing in households, (b) manufactured capital derived from past investments in productive capacity for economic goods and services, (c) intellectual capital, a key factor in the new knowledge economy, and (d) natural capital as low-entropy energy and raw material supplies, see Figure 2b. The output of market goods and services constitutes gross product and is allocated by the private and public sectors to household consumption, usefully thought of as an investment in human capital,<sup>23</sup> and investments in manufactured,<sup>24</sup> intellectual,<sup>25</sup> human,<sup>26</sup> or natural

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Research and Educ., *Complex Environmental Systems: Synthesis for Earth, Life, and Society in the 21st Century* 23–28 (Jan. 2003) available at [www.nsf.gov/geo/ere/ereweb/ac-ere/acere\\_synthesis\\_rpt\\_full.pdf](http://www.nsf.gov/geo/ere/ereweb/ac-ere/acere_synthesis_rpt_full.pdf) (using the term “environmental services” to include services that have a physical rather than a biological basis, for example, the filtering of ultraviolet radiation by stratospheric ozone).

19. Millennium Ecosystem Assessment, *supra* n. 17, at 53.

20. *Nature’s Services: Societal Dependence on Natural Ecosystems* 1–10 (Gretchen C. Daily ed., Is. Press 1997); Robert Costanza et al., *The Value of the World’s Ecosystem Services and Natural Capital*, 387 Nat. 253, 253–55 (1997); Earthwatch Inst. et al., *Business and Ecosystems Issue Brief: Ecosystem Challenges and Business Implications* (2006) (available at [http://pdf.wri.org/business\\_and\\_ecosystems.pdf](http://pdf.wri.org/business_and_ecosystems.pdf)).

21. E.g. Millennium Ecosystem Assessment, *supra* n. 17, at 49–70.

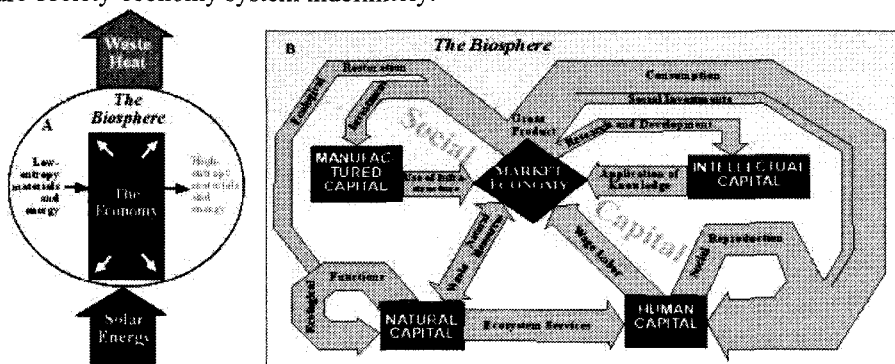
22. See generally Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Harv. U. Press 1971).

23. Consumption is an investment in human capital only up to the point where over-consumption diminishes it (as must be pointed out in the midst of an obesity epidemic).

24. Typical examples would be the construction and repair of infrastructures.

25. A typical example would be research and development.

capital.<sup>27</sup> If guarded against depreciation, these various forms of capital can sustain the nature-society-economy system indefinitely.



**Figure 2.** Ecological-economic conceptualization of the nature-society-economy system.

a) Solar energy provides the free energy that drives the biosphere, which releases high-entropy waste heat to space. Similarly, the biosphere provides the free energy and low-entropy raw materials to the economy, which, as a distributive structure, releases high-entropy waste heat and materials to the biosphere. b) The flows of value among human, intellectual, manufactured, and natural capital in the nature-society-economy system with the market serving as a transformer and allocator among forms of capital. Natural and human capital are also maintained through non-market mechanisms of ecological and social reproduction.

3. *Human capital and welfare are maintained through a combination of market goods and services, social reproduction, and ecosystem services.* Social reproduction occurs through non-market institutions such as the household and the family, residential, religious, and other forms of community, and the village that it takes to raise a child. Similarly, ecosystem services support human capital largely outside of the market system, see *Figure 2b*. The widely read and controversial paper by Costanza and colleagues<sup>28</sup> estimated the global annual value of ecosystem services at 33 trillion dollars (about \$5,000 per capita), an amount that is of the same order of magnitude as the global value of all market goods and services (world product). Whether this estimate is accurate or not, ecosystem services constitute an enormous and irreplaceable stream of value from natural to human capital.<sup>29</sup>

4. *The goal of system performance is sustainability.* Even if natural capital is viewed in an instrumental and anthropocentric way, increases in gross product can have positive, neutral, or negative long-term consequences on the sustainability of human forms of capital. If, as was often the case in frontier societies and the pre-industrial world, natural capital is in surplus,<sup>30</sup> its transformation into manufactured capital or its consumption by humans could increase the overall performance of the nature-society-

26. A typical example would be education.

27. Investments in natural capital can be made directly through ecological restoration or indirectly through natural resource conservation or reductions in waste emissions.

28. See Costanza et al., *supra* n. 20.

29. *Id.* at 259.

30. Implying that, like oxygen today, its marginal value is low or zero even if its total value is very high.

economy system. In addition, the application of intellectual capital in the form of technologies that more efficiently transform natural capital into goods and services allows for sustainable increases in gross product or, alternatively, minimizes withdrawals from natural capital. When services once provided to people through social reproduction or ecosystem services are replaced by the marketplace as a result of economic growth,<sup>31</sup> the effects on the sustainability of human capital may be positive, negative, or neutral. However, when increases in gross product draw down the value of capital stocks, especially natural capital, growth can become uneconomic. Robert Repetto first brought this issue to the attention of global financial institutions by showing that Costa Rica's rapid economic growth in the 1970s and 1980s occurred alongside a depreciation of its forest and soil resources. When natural resource depreciation was calculated, it negated four to 10 percent of net domestic product each year, offsetting the four percent annual rate of economic growth the country achieved during the same period.<sup>32</sup> Peter Bartelmus argues that the United Nations 2003 System for Integrated Environmental and Economic Accounting (SEEA-2003) system retreats from the goal of integrated accounting because it opts for physical indicators rather than monetary measures of natural capital appreciation and depreciation.<sup>33</sup>

The significance of this debate about the measurement of economic vs. ecological-economic performance is central to assessing sustainability in empirical nature-society-economy systems. Weak sustainability, as a normative criterion of performance of the nature-society-economy system, consists of maintaining the aggregate value of human, manufactured, intellectual, and natural capital. However, if these forms of capital are not completely substitutable, critical shortages in any one form of capital can cripple the entire system. Strong sustainability, on the other hand, maintains that the value of *each* form of capital must be maintained because different forms of capital are only marginally substitutable. Thus, for the nature-society-economy system to function in perpetuity, gross product must be invested in a manner that maintains or increases the value of each capital stock. Capital depreciation in any area is the harbinger of long-term system decline.

5. *Natural capital is the long-term limiting factor.* As the human economy has grown over time, the stock of natural capital has diminished, but the demand for ecosystem services derived from the natural capital fund has grown. Therefore, the marginal value of remaining natural capital and ecosystem services has increased, and this development implies that there are increasing marginal ecological opportunity costs associated with the depreciation of natural capital and concomitant reductions in ecosystem services. Since the industrial revolution, technology has greatly accelerated the production of human forms of capital such as infrastructures and computer algorithms, and this trend is likely to continue. However, natural capital can be restored only on much longer time scales that cannot respond to changing economic and social

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31. Examples would be when home food preparation is replaced by low-priced restaurants or international trade penetrates into subsistence agricultural economies.

32. See Robert Repetto, *Earth in the Balance Sheet: Incorporating Natural Resources in National Income Accounts*, 34 *Env.12*, 17–19 (Sept. 1992).

33. See Peter Bartelmus, *SEEA-2003: Accounting for Sustainable Development?* 61 *Ecological Economics* 613, 613–14 (2007).



needs. Due to this technological asymmetry, the stock of natural capital within the biosphere and the rate at which it can produce energy, raw materials, and ecosystem services are the long-term limiting factors in the nature-society-economy system. It follows that the efficiency with which the market economy can transform natural capital into human capital is the key to sustainability. Ecological economics, therefore, draws heavily on industrial ecology—the study of the flow of matter and energy through the economic system—and is complementary to an ecological modernization discourse.

6. *The tragedy of ecosystem services.* Social capital lurks in the background of the nature-society-economy system as diagrammed in *Figure 2*. Definitions of social capital abound. Putnam in *Bowling Alone* defines it as “features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit.”<sup>34</sup> For our purposes, social capital includes the institutions, rules, social norms, and interpersonal relationships that govern the nature-society-economy system. As a policy-oriented political program, ecological economics aims to reform social capital in the hope of creating a dynamic sustainable system. However, consider how capitalist society structures incentives for utilization of and investment in natural capital and the ecosystem services it provides. By analogy, Garrett Hardin’s classic essay *The Tragedy of the Commons* illustrated how, where there is open access to natural resources and the products derived from them are private property, self-asserting users will over-exploit natural capital—too many fish are caught, too many pollutants are released, too many cattle are grazed in the pasture.<sup>35</sup> Even in the management of nonrenewable resources such as oil, wildcat oil drillers created a tragedy of open access that was overcome through the institution in 1933, by Secretary of the Interior Harold Ickes, of utilization, or common control of an oil field by a consortium of investors.<sup>36</sup> Drawing upon examples such as this, Elinor Ostrom and other authors have critiqued Hardin’s thesis and offered evidence of common property, rather than open access, regimes that have achieved sustainable resource management.<sup>37</sup>

These debates have focused, however, on the management of natural capital as a stock that provides natural resources for economic use. Ecosystem services rely instead upon natural capital as a multi-purpose fund. Unlike fish, timber, or oil, once provided, ecosystem services accrue to geographical areas in a non-exclusive fashion as public goods. Once restored, wetlands, for example, can absorb carbon, nutrients, and flood waters and provide wildlife habitat. Resulting improvements in water quality, recreational opportunities, reductions in flood damages and global warming accrue to all people in the affected areas and cannot be sold only to those who paid for the wetland restoration. For the owner of the land where the wetlands could be restored, however, these ecosystem services are positive externalities. No matter how valuable they are to the community, their sale cannot generate the revenues needed to justify the investments

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34. Robert D. Putnam, *Bowling Alone: America's Declining Social Capital*, 61 J. of Democracy, 65, 67 (1995).

35. See Garrett Hardin, *The Tragedy of the Commons: The Population Problem Has No Technical Solution; It Requires a Fundamental Extension in Morality*, 162 Sci. 1243, 1245 (1968).

36. See generally Daniel Yergin, *The Prize: The Epic Quest for Oil, Money, and Power* (Simon & Schuster 1991) (offering an interesting discussion of that topic).

37. Thomas Dietz, Elinor Ostrom & Paul C. Stern, *The Struggle to Govern the Commons*, 302 Sci. 1907, 1907 (2003) (offering an excellent summary).

made and the opportunity costs incurred in restoring them. The result is that investments in natural capital are insufficient and ecosystem services are underprovided—we have what Ruhl, Kraft and Lant describe as a “[t]ragedy of [e]cosystem [s]ervices.”<sup>38</sup> The Millennium Ecosystem Assessment describes six critical challenges resulting from this tragedy of ecosystem services: water scarcity, climate change, habitat change, biodiversity loss and invasive species, overexploitation of oceans, and nutrient overloading.<sup>39</sup>

### III. GEOGRAPHICAL ECOLOGICAL ECONOMICS

The ecological economics paradigm presented above is enormously useful and insightful in considering issues of sustainability, but it fails to consider geography. How do the processes depicted in *Figure 2* and the preceding section operate through geographic space? Four questions emerge as a point of departure to guide this discussion.

1. What is the relative mobility of different forms of capital, and how do transformations among these occur over space?
2. What role do natural capital and ecosystem services play in defining places and providing benefits that accrue to people?
3. How is space currently being addressed in ecological economic studies?
4. How can space be better addressed in ecological economics?

#### A. *The Mobility of Various Forms of Capital*

It is clear that some forms of capital, such as financial capital, are so mobile that billions of dollars are routinely transferred across continents every day in the nearly costless world of the internet. Intellectual capital similarly benefits from modern space-obliterating technologies. While far from instantaneous and costless, the movement of people and the skills and knowledge they possess is increasing, whether studied at the metropolitan scale in daily commuting patterns, or at the global scale in the form of the brain drain.<sup>40</sup> Social capital, if defined in written forms or transmitted by e-mail or cellular phone, is highly mobile; if defined by interpersonal relationships built upon face-to-face communication it is tightly bound to geographically defined communities. The movement of manufactured capital in the form of produced goods is the heart of transportation, the study of which has a rich tradition in economic geography. The human and economic geography of places are partially defined by their roads, railroads, and ports, their electricity lines, water and gas pipelines, and their buildings that are geographically immobile; infrastructure and the built environment is therefore a key component of human geographies.

In the terms described above, the mobility of natural capital depends upon its form.

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38. See J.B. Ruhl, Steven E. Kraft & Christopher L. Lant, *The Law and Policy of Ecosystem Services* 102 (Is. Press 2007).

39. See Earthwatch Inst., *supra* n. 20.

40. See generally William J. Carrington & Enrica Detragiache, *How Big Is the Brain Drain?* (Intl. Monetary Fund Working Paper No. 98/102, July 1998) (available at <http://ssrn.com/abstract=882624>) (describing the concept of brain drain).

As a stock of natural resources, raw materials such as fossil fuels, ores, timber, and fresh water constitute the vast majority of freight moved by ships, railroads, pipelines, and canals. However, these components of natural capital nearly always have lower economic value per unit weight than the manufactured goods for which they serve as inputs to production or raw materials. Ore refining is, therefore, most efficiently located near the mine and thermoelectric power plants near large sources of cooling water. As a fund that provides ecosystem services, however, natural capital is essentially immobile. Moreover, climate, topography, hydrography, and other conditions that govern ecological reproduction and the formation of natural capital are tied to geographical places. There is, therefore, great variation in the ecosystem services available to different places and regions. Regions such as the Sahara Desert or the Australian outback, for example, are sparsely populated partly due to the dearth of ecosystem services they offer; in fact, meager ecosystem service provision defines these regions. When we study basic physical geography in primary and secondary school, we are often describing the geography of natural capital, though generally neglecting that this geography is dynamic, a fact perhaps first recognized by George Perkins Marsh in 1864.<sup>41</sup>

#### B. *The Dynamic Geography of Natural Capital*

While immobile, the geography of natural capital changes as a result of four factors: (a) natural dynamics in ecological reproduction processes, (b) human influences on these through activities such as land transformation and engineering of water courses, (c) direct human depreciation of natural capital funds through the introduction of waste, and (d) direct human withdrawals of natural resources as inputs to the market economy. Attributing measured environmental change to each of these four factors is no easy task. Nevertheless, in conceptualizing the role of economic activities on the dynamic geography of natural capital, consider two examples of the role of trade in natural resources. Japan, suffering from severe deforestation in the 17th and 18th centuries as population increases combined with the predominant use of wood for both energy and construction, implemented strict forest use regulations under the Tokugawa regime.<sup>42</sup> Today, the densely populated affluent country enjoys 74 percent forest cover, but is the leading importer of forestry products with 18 to 22 million cubic meters of tropical hardwood imports annually in the early 1990s compared with domestic production of only seven million cubic meters in 1990 declining to five million in 1995.<sup>43</sup> The leading source of imports is Indonesia, which exported over 12 million cubic meters of sawed and raw logs and plywood to Japan each year from 1990 to 1995. As a result, Indonesia lost 10,000 km<sup>2</sup> of forest per year in a region second only to the Amazon for species diversity. Thus, by importing most of its forest products, Japan gains the provisioning services of Indonesian forests while simultaneously preserving the ecosystem regulation

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41. George P. Marsh, *Man and Nature; Or, Physical Geography as Modified by Human Action* (Charles Scribner 1865).

42. See Diamond, *supra* n. 13, at 300–02.

43. See Peter Dauvergne, *Shadows in the Forest: Japan and the Politics of Timber in Southeast Asia 183–194* (MIT Press 1997).

and cultural services provided by its domestic forests. These services accrue locally as flood protection, soil binding, wildlife habitat, recreation, and aesthetics. Indonesia's gain in foreign exchange from Japan comes at the expense of large marginal costs in both future natural resource and ecosystem service benefits from its depreciating natural capital.

The forested New England landscape was similarly cleared for agriculture in the 18th and early 19th centuries. The region developed a manufacturing economy in the late 19th and early 20th centuries, and then de-industrialized in the late 20th century as it gained a prominent position in the global service economy. The 20th century has witnessed extensive reforestation, primarily due to natural succession on abandoned farmlands. In recent controversies involving energy-related projects, New Englanders have rejected liquid natural gas importation facilities and even offshore wind turbines for cost-competitive, environmentally sound, renewable electricity production,<sup>44</sup> despite the large per capita energy consumption evidenced in the region and the potential to reduce the emission of greenhouse gases. Like the Japanese, New Englanders have the economic and political power to choose to base their economy on less natural capital-intensive service industries while importing goods provided by the natural capital of other regions. This effectively exports wastes that require the natural capital of other regions for their assimilation. Thus, the geography of natural capital is closely tied to economic geography, the rapidly changing patterns of production and trade of which that is composed, the economic and political power that lies in locational decision-making, and the role that a region is able to fulfill in a globalized capitalist system.

Alf Hornborg, drawing from dependency theory as developed by Gunder Frank<sup>45</sup> and world systems theory as developed by Immanuel Wallerstein,<sup>46</sup> describes this phenomenon as "ecological[ly] . . . unequal exchange."<sup>47</sup> Andersson and Lindroth define it and identify its implications:

Exchange is "ecologically unequal" if there is an imbalance—calculated in [ecological footprint]—between imports and exports. It is "unsustainable" if it implies a continuous reduction of the ecological capital in at least one of the trading partners.

. . . .

[T]here is a real possibility that trade can be a subtle mechanism by which ecological sustainability is preserved in some countries by means of importing biomass and sink-capacity from other countries, where the ecological capital is instead gradually depleted. . .  
 . [I]nternational trade[, thus,] blurs the responsibility for the ecological effects of

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44. See Jeremy Firestone & Willett Kempton, *Public Opinion About Large Offshore Wind Power: Underlying Factors*, 35 *Energy Policy* 1584 (2007); Willett Kempton et al., *The Offshore Wind Power Debate: Views from Cape Cod*, 33 *Coastal Mgt.* 119 (2005).

45. Andre Gunder Frank, *Capitalism and Underdevelopment in Latin America: Historical Studies of Chile and Brazil* (Mthly. Rev. Press 1967).

46. Immanuel Wallerstein, *The Modern World System III: The Second Era of Great Expansion of the Capitalist World-Economy, 1730–1840s* (Academic Press 1989); Immanuel Wallerstein, *The Modern World System II: Mercantilism and the Consolidation of the European World-Economy, 1600–1750* (Academic Press 1980); Immanuel Wallerstein, *The Modern World System: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century* (Charles Tilly ed., Academic Press 1974).

47. Alf Hornborg, *Towards an Ecological Theory of Unequal Exchange: Articulating World Systems Theory and Ecological Economics*, 25 *Ecological Econ.* 127, 127 (1998).

production and consumption.<sup>48</sup>

Using this ecological footprint approach, Japan, the U.S., every non-Scandinavian member of the EU, and some densely populated developing nations such as India and Bangladesh are ecological deficit nations; natural resource exporting Australia and Brazil are examples of ecological surplus nations. Andersson and Lindroth coin the phrase "rich country illusion effect"<sup>49</sup> where the apparent improvement in environmental quality that Kuznets Curves show accompanies rising affluence often comes through *geographic displacement* through either importation of goods derived from the natural capital of other regions, or through the generation of wastes that are absorbed through the ecological sink capacities of other regions. Core status in the global economic system sometimes allows a region to have its ecosystem service cake and eat its natural resource consumption too.

Global warming is an intriguing example where the benefits of fossil fuel use, concentrated in the industrial regions of North America, Europe, Russia, and China, largely coincide with the geography of emissions of greenhouse gases to the global atmospheric sink. While global warming is affecting hydrologic, agricultural, and ecological systems across the globe, the most severe consequences are distributed very differently from the emissions, with polar regions, coastlines and island nations, populous river floodplains and deltas, drought-prone agricultural areas, and impoverished regions of the tropics, especially in Africa, bearing the greatest burden of changes and reductions in ecosystem services brought about by global warming.<sup>50</sup> Global warming thus illustrates a variant of ecologically unequal exchange where the global atmospheric carbon sink is the mechanism through which ecosystem service benefits are redistributed geographically.

As natural capital shifts from a long-term, and therefore somewhat hypothetical, limiting factor of socioeconomic development to a short-term real limiting factor, positional competition occurs through shifting environmental costs among nations and regions, possibly leading to an increase in conflict.<sup>51</sup> An additional effect of this competition is that as developing countries increasingly specialize in natural capital-intensive industries,<sup>52</sup> they forgo the development of human, social, and intellectual capital that accompanies growth in advanced manufacturing and services industries.<sup>53</sup>

Every locality thus, has a natural capital history that reflects both its physical geography and its changing role in local, regional, and global economies. Globalization intensifies this dynamism by making the natural capital of each locality accessible to global markets, bringing to bear a global search for low-cost raw materials and energy supplies, frequently abandoning small-scale locally-oriented production, and replacing

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48. Jan Otto Andersson & Mattias Lindroth, *Ecologically Unsustainable Trade*, 37 *Ecological Econ.* 113, 117-18, 121 (2001).

49. *Id.* at 114.

50. See generally *Climate Change 2007: Impacts, Adaptation, and Vulnerability* (Martin Parry, Osvaldo Canziani, Jean Palutikof, Paul van der Linden & Clair Hanson eds., Cambridge U. Press 2007).

51. See Michael T. Klare, *Resource Wars: The New Landscape of Global Conflict* (Metro. Bks. 2001).

52. Examples would be mining and processing of ores, petroleum production and refining, paper products, or input-intensive agriculture.

53. See Roldan Muradian & Joan Martinez-Alier, *Trade and the Environment: From a 'Southern' Perspective*, 36 *Ecological Econ.* 281 (2001).

traditional economies that rely heavily upon local mechanisms of social reproduction and ecosystem service provision with commodity trade at the periphery of the world economy. Often, as is well illustrated by Piers Blaikie,<sup>54</sup> the result is rapid depreciation of local natural capital. The critical processes to consider in an analysis of the dynamism of natural capital are therefore the spatial unevenness of economic development and geographic displacement of ecological costs.

### C. *Current Approaches to the Geography of Ecosystem Services*

Natural capital is the fund that provides ecosystem services, but these services are often an emergent property of several ecological characteristics and functions that vary over space and time. Empirical ecological economic studies, to the extent that they incorporate space at all, often utilize a *benefit transfer* approach that (1) finds the ecosystem service value per hectare of various land use or ecological categories from pre-existing literature, (2) employs remote sensing to measure the area of these land uses or ecological types, (3) multiplies the former by the latter, and (4) adds them up.<sup>55</sup> Let us explore the limitations of this approach. For example, Aneilski and Wilson estimated the annual value of ecosystem services of the Mackenzie River basin, encompassing 1.7 million km<sup>2</sup> of northwestern Canada, at 448.3 billion dollars. Consider, however, their approach to space:

For several assets, including carbon and water values, we considered them to be of global strategic importance, and felt they warranted values that reflected their global significance. . . . If we could not find a suitable Canadian value for an ecosystem service function we deferred to estimates made by Costanza in *The Value of the World's Ecosystem Services and Natural Capital*.<sup>56</sup> With a value per hectare land-cover approach, our analysis was much simpler since we could map land cover by type across the watershed. This approach made it ideal to estimating ecosystem service values for each land-cover type.<sup>57</sup>

For carbon, this approach is reasonable because carbon stored or sequestered from the atmosphere anywhere lowers the concentration of greenhouse gases everywhere. However, water supply or flood control benefits can only accrue to people utilizing Mackenzie basin waters or its floodplain. In fact, the authors note that, if the value of watershed protection in the New York City Catskills water supply system is applied to the Mackenzie, the ecosystem service values of water supply and filtration exceed one trillion dollars. Yet with the Mackenzie's sparse population and constant water surplus, these services have very little value at the margin to local residents, even if the same services generate billions in value to New York City's nine million residents. Thus, ecological economic studies generally fail to consider the spatial and temporal relationships that govern delivery of ecosystem services from natural capital sources to human beneficiaries. Compare this to a case study in the U.K. concerning water quality

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54. Piers Blaikie, *The Political Economy of Soil Erosion in Developing Countries* (Longman Publ. Co. 1985).

55. See e.g. Costanza, *supra* n. 20.

56. *Id.*

57. Mark Anielski & Sara Wilson, *The Real Wealth of the Mackenzie Region: Assessing the Natural Capital Values of a Northern Boreal Ecosystem* 9–10 (Canadian Boreal Initiative 2007).

improvements in the badly polluted River Tame.<sup>58</sup> Willingness-to-pay (WTP) for small, medium, and large improvements declined to zero at distances of 28, 24, and 20 km from the river, respectively, demonstrating a very finite ecosystem service provision zone or field. Their argument for a spatially sensitive valuation function is well taken; little is known for sure about the most important factor governing the economic valuation of ecosystem services—defining the geographic area and the people within it that receive the benefits.

#### D. *An Improved Geographical Ecological Economics*

Tracing ecosystem services from natural capital sources to human beneficiaries is a geographical exercise, see *Figure 3*. For example, a floodplain forest upstream of a riverside city provides the ecosystem service of flood control intermittently to that specific city during times of high runoff. A different town near the wetland, but not on the floodplain down stream of it, may benefit from the improved water quality the town withdraws from the affected river and the aesthetic and recreational opportunities the wetland provides during particular seasons or under specific weather conditions. In implementing this approach, one key concept is distance decay. With location of stated preference respondents indicated on contingent valuation surveys, the distance decay function would be derived by regressing WTP bids on distance from the ecosystem service source. One clear implication is that the economic value of ecosystem functions is higher in densely populated areas.

This more geographical approach is required if ecological economics is to take an important step down the ladder of abstraction into the empirical world of specific landscape components that deliver specific ecosystem services to specific individuals at specific times at specific locations. Conversely, these techniques can identify an ecosystem services package that accrues variously over time to any geographical location. These are key factors if rights to ecosystem services are to gain legal status.<sup>59</sup> If ecosystem services constitute a substantial portion of human welfare, as nearly every ecological-economic study finds, and their provision is extremely variable over space, then much of environmental politics is a geographically-constituted political struggle over (often diminishing) ecosystem service benefits.

Spatial ecological economics is also pertinent in the nuts and bolts of environmental policy design. The 1990 Clean Air Act Amendments, for example, initiated a successful tradable pollution permit system for sulfur dioxide, one of the major causes of acid rain that, in the 1970s and 1980s was damaging forest and lake ecosystems in the northeastern U.S. and adjacent areas of Canada due to emissions from coal-fired power plants in the Midwest and Ohio Valley.<sup>60</sup> Subsequent efforts to apply tradable permit systems to water pollution in the form of nutrients, however, have so far been largely unsuccessful.<sup>61</sup> A primary reason for these divergent results is that the

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58. Ian J. Bateman et al., *The Aggregation of Environmental Benefit Values: Welfare Measures, Distance Decay and Total WTP*, 60 *Ecological Econ.* 450 (2006).

59. See Ruhl, Kraft & Lant, *supra* n. 38, at 36–56.

60. See generally T. H. Tietenberg, *Emissions Trading: Principles and Practice* (2d ed., RFF Press 2006).

61. See Felix Kumah Godwin Anebo, *The Adoption of Environmental Policy Innovation: Water Pollution Permit Trading in the United States* (Ph.D. dissertation, S. Ill. U., 2005) (on file with the Dept. Political Sci., S.

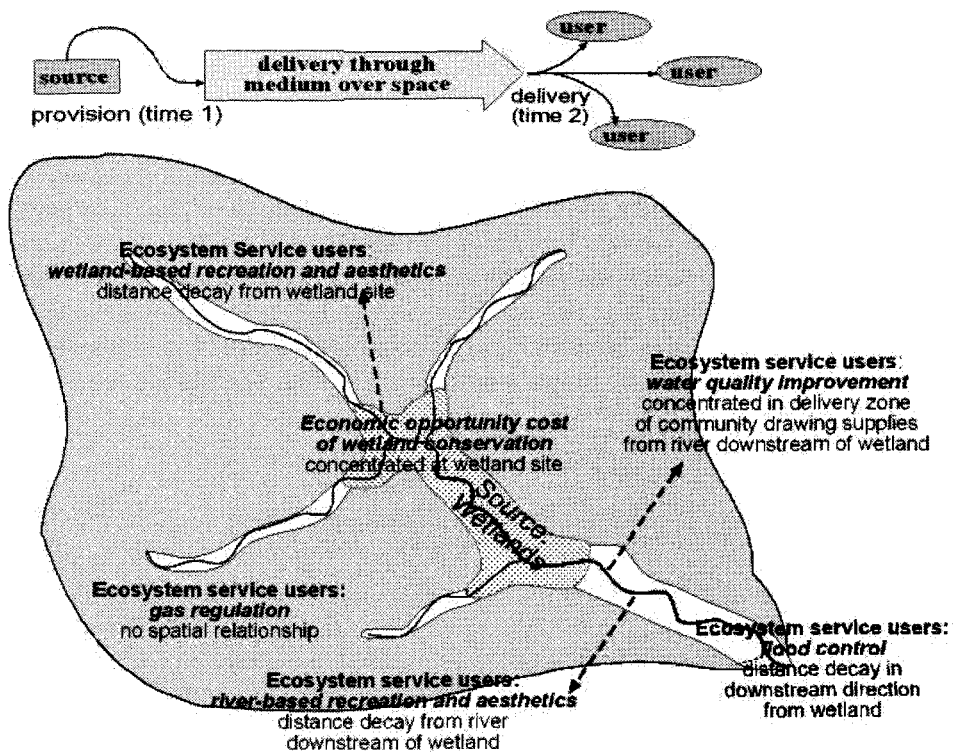
airshed for sulfur emissions is the 48 contiguous states while the watershed for nutrient emissions is usually so small that an insufficient number of potential traders are available to constitute a market. Of course, it would be possible to enlarge the trading zone to encompass basins as large as the Mississippi, but the resulting wholesale redistribution of nutrient pollution could threaten many communities with contamination of municipal water supplies rendering the system politically unviable. This issue of spatially redistributing ecosystem service benefits is further reflected by a study of wetland mitigation banking in Florida that found that wetland drainage occurred mainly in urban areas where land values are high and ecosystem service beneficiaries are numerous. In contrast, wetland restoration occurred mainly in rural areas where land values are low, but so also are the number of people who benefit from the services provided by the restored wetlands.<sup>62</sup>

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Ill. U.); Dennis M. King & Peter J. Kuch, *Will Nutrient Credit Trading Ever Work? An Assessment of Supply and Demand Problems and Institutional Obstacles*, 33 *Envtl. L. Rptr.* 10352 (2003).

62. J.B. Ruhl & James Salzman, *The Effects of Wetland Mitigation Banking on People*, 28 *Natl. Wetlands Newsletter* 1, 9–14 (Mar.–Apr. 2006).





**Figure 3.** Tracing ecosystem services from source to user: the example of wetlands.

#### IV. CONCLUSION

By focusing attention on natural capital and its capacity to provide valuable ecosystem services, ecological economics provides a rigorous framework through which to consider and operationalize natural resource and environmental sustainability. It is now time to take the next necessary step in transforming ecosystem services from an essential concept to a flow of value, a form of natural income, upon which specific individuals and communities depend and in which they may have rights. To do this, a geographical approach to ecological economics is required.