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Conservation Through the Economics Lens

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Abstract Although conservation is an inherently transdisciplinary issue, there is much to be gained from examining the problem through an economics lens. Three benefits of such an approach are laid out in this paper. First, many of the drivers of environmental degradation are economic in origin, and the better we understand them, the better we can conserve ecosystems by reducing degradation. Second, economics offers us a when-to-stop rule, which is equivalent to a when-to-conserve rule. All economic production is based on the transformation of raw materials provided by nature. As the economic system grows in physical size, it necessarily displaces and degrades ecosystems. The marginal benefits of economic growth are diminishing, and the marginal costs of ecological degradation are increasing. Conceptually, we should stop economic growth and focus on conservation when the two are equal. Third, economics can help us understand how to efficiently and justly allocate resources toward conservation, and this paper lays out some basic principles for doing so. Unfortunately, the field of economics is dominated by neoclassical economics, which builds an analytical framework based on questionable assumptions and takes an excessively disciplinary and formalistic approach. Conservation is a complex problem, and analysis from individual disciplinary lenses can make important contributions to conservation only when the resulting insights are synthesized into a coherent vision of the whole. Fortunately, there are a number of emerging transdisciplines, such as ecological economics and environmental management, that are dedicated to this task.

Keywords Conservation · Ecological economics · Transdiscplinary · Ecosystem services

Introduction

We live in a world of human imposed borders—political, disciplinary, and institutional. While these borders serve various important needs, they can also serve as a serious deterrent to effective environmental management and conservation (Farley and others 2009). A logical decision-making unit for conservation and environmental management is the ecosystem. Political borders are rarely established to respect ecosystem boundaries, and even if an effort were made to do so, ecosystems are interconnected and their boundaries vague and fluid, while political boundaries are rigidly delineated. Even for ecosystems wholly contained within political borders, the services they generate (such as climate regulation, water regulation, waste absorption capacity, and habitat for migratory species) may be local, regional, or global (Sandler 1993; Daly and Farley 2004). The negative impacts of human activities on ecosystems also fail to respect political borders, as can be seen by acid rain, climate change, air and water pollution, and so on. How to conserve essential ecosystems is a serious problem. As someone once said, however, in academia there are disciplines, but in the real world, problems. Real world problems do not respect disciplinary or political borders. Effective conservation projects require insights from social sciences, natural sciences, and the humanities (Berkes and Folke 1998), and often collaboration across political borders. Conservation projects also demand solid

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scientific research, community participation, and effective governance structures, thus cutting across the institutional borders of academia, civil society, and government.

Though effective conservation must transcend such borders, this article looks at conservation through the economic lens. Economics certainly can and does make important contributions to addressing the problems of conservation, and any conservation project requiring funding is affected by economics. We often hear from politicians that they recognize the seriousness of conservation issues, but simply lack the financial resources to address them—other needs are more pressing. In addition, the driving forces behind the ecological threats we currently face are primarily economic, and economic analysis can help us understand them. But viewing these problems through an economic lens alone will not lead to solutions. In the purported words of Albert Einstein, “We can’t solve problems by using the same kind of thinking we used when we created them.” It is precisely the features of economics that are leading us into these problems that makes economic analysis alone unsuitable for solving them.

The most serious problem is that the academic discipline of economics has been increasingly narrowly defined over recent decades, to the point where it is virtually synonymous with neoclassical economics. Neoclassical economics is based on a number of highly questionable assumptions that allow the discipline to be mathematized in pursuit of objective decision-making rules for achieving optimal outcomes. Under these assumptions, optimal outcomes are the inevitable result of market forces, leading neoclassical economists to emphasize the market as the solution to almost any problem. Though many of these assumptions are contradicted by empirical evidence, economists often retain their blind faith in the market mechanism, which can present a serious threat to conservation efforts.

However, we should not let our concerns with one narrow approach to economics overcome the greater clarity this lens can bring, or let obsessive faith in markets by some blind the rest of us to their potential contributions. Rather, we should recognize the problem as one of believing that a single lens is adequate for understanding the full complexity of the conservation problem. Conservation is a wicked problem, with no optimal solution (Rittel and Webber 1973). With interacting ecological, economic, political, and social variables, conservation decisions are complex, there are many different criteria for judging outcomes, and few objective decision rules that can tell us for sure if a given conservation action is good or bad. We should extend the metaphor of a particular lens to that of a compound eye consisting of thousands of individual lenses, like that of the dragonfly. Each lens contributes something to the dragonfly’s understanding of the world around it, but if the dragonfly had to rely on any one lens alone, it would fail to survive. To solve conservation problems, we need to not only look at them through compound eyes, but we need a central processing unit to assemble the complex picture provided by a thousand lenses into a coherent whole.

The next section, Strengths of the Economic Lens, assesses the general strengths of the economic lens, which are many. Problems with the Economic Lens then focuses on the specific problems presented by the neoclassical economic lens. I make an effort to use real-life examples to illustrate both. The Conclusion discusses how the clarity provided by the economic lens can be incorporated into a more holistic understanding of the problem, and contribute to potential solutions.

Strengths of the Economic Lens

There are at least three reasons it is important to view conservation through an economic lens: it can help us understand the driving forces behind ecological loss and degradation, it can help us decide how much conservation is appropriate, and it can help us efficiently allocate resources toward conservation.

Economics as the Driver of Ecological Loss and Degradation

Efforts to conserve ecosystems and the vitally important goods and services they supply would not be necessary in the absence of threats to their health. Most of the driving forces behind these threats are economic in origin—conversion of ecosystems to agriculture, excessive deforestation, overharvesting of fish, pollution, climate change, and so on. It is an unavoidable law of physics that one cannot produce something from nothing. It is also a law of physics that energy is required to perform work. All economic production therefore relies on raw materials and energy provided by nature (Georgescu-Roegen 1971). These raw materials are necessary inputs to economic production but are also elements of ecosystem structure, the building blocks of ecosystems. As we transform ecosystem structure into economic output, we inevitably affect ecosystem function, including life support functions—humans, like all species, depend on healthy ecosystems for their survival. If too much ecosystem structure is converted to economic output, and ecosystem functions are sufficiently compromised, the biotic elements of ecosystem structure can no longer reproduce themselves. For example, studies suggest that the Amazon recycles up to 50% of the rain it receives, and if as little as 30 percent of the forest is cleared, it will no longer be able to recycle enough water to ensure its own survival (Salati and Vose 1984). Resource extraction for economic production thus directly drives ecological degradation, threatening human well-being in the process (Costanza and others 1991).

As a corollary to the law of physics mentioned above, it is impossible to create nothing from something. A related law of physics tells us that entropy always increases in an isolated system. The result is that all economic production eventually wears out, falls apart, and returns to the ecosystem as waste. Fossil fuels, the predominant source of energy sustaining our economic system, return to the system as carbon dioxide, other pollutants, and waste heat after combustion. When pollutants are released faster than ecosystems can absorb them, they further threaten ecosystem function. Global climate change, ozone depletion, acid rain, and eutrophication are all outcomes of this process (Hokikian 2002).

When the economic system was small relative to the sustaining and containing ecosystem, there was adequate ecosystem structure to maintain both economic output and ecosystem function. As our economy has steadily increased in size over recent centuries, it has driven ever greater ecological degradation, and given rise to the need for serious conservation efforts (Daly 1977). Successful conservation efforts demand that we understand the economic forces driving ecosystem destruction.

Economics and the "When to Stop" Rule

Economics can also be useful in determining how much ecosystem structure should be converted to economic output, and how much should be conserved to maintain vital ecosystem services. Economics is based on marginal analysis. It makes the highly plausible assumption that the more we have of something, the less an additional unit is worth, because we meet our most pressing needs first, and use additional units to meet decreasingly important needs. This is known as the law of diminishing marginal utility. The corollary is the law of increasing marginal costs, best illustrated with a specific example. We will look at the case of a farmer clearing a forest for crops. The farmer first clears the most accessible and fertile land, where a small amount of labor yields high returns. Once this land has been cleared, the farmer moves on to rockier, less fertile soils and steeper, less accessible land. More effort is required to clear each additional unit of forest and farm each additional unit of land, and the marginal benefits are less. Surrounding forests protect small clearings on flat land from erosion, but as clearings increase in size and move to steeper slopes, erosion results. With fewer trees to act as windbreaks, winds can dry out crops and pasture, leading to wind-induced erosion as well. Larger and larger clearings affect habitat for many species, including pollinators essential for the farmer's crops (Kremen and others 2002; Ricketts and others 2004). Ideally, the farmer should stop farming when the rising marginal costs equal the diminishing marginal benefits, at which point the farmer's "utility" (which might represent profit or quality of life) is maximized. What holds true on the scale of a farm plot holds true in principle on the scale of the planet: we should stop converting ecosystem structure to economic output when the marginal costs in terms of ecosystem services lost are equal to the marginal benefits of economic services gained (Daly and Cobb 1994).

Unfortunately, comparing marginal costs and benefits of conservation is no simple task. In complex, nonlinear ecosystems, uncertainty and ignorance of ecosystem functions are the rule rather than the exception. We may face ecological thresholds beyond which conversion of the marginal unit leads to collapse of the ecosystem and all its values, and marginal valuation becomes inappropriate. We often fail to recognize an ecosystem service until the ecosystem providing it has been destroyed, and we cannot value what we do not understand. Furthermore, conservation values include ethical elements, such as obligations to future generations, which cannot be measured in the monetary units used for market goods (Vatn and Bromley 1994; Gowdy 1997; Martinez-Alier and others 1998). Even for market goods, monetary values are determined by preferences weighted by wealth or income, ignoring the preferences of the poor. Monetary valuation of conservation benefits does the same, raising obvious ethical concerns (Farley and Gaddis 2007).

While pervasive uncertainty makes it difficult to specify exactly "when to stop," I suggest some rough guidelines. There is growing evidence that in wealthy nations increasing economic production has little to no impact on life expectancy or on measures of subjective well-being, suggesting that continued economic growth may be futile (Costanza and others 2007). There is also growing evidence that continued conversion of ecosystem structure is currently overwhelming planetary life support functions (Wackernagel and others 2002; Wilson 2002; Meadows and others 2004; Diamond 2005). Our task now should be to conserve and restore to avoid irreversible outcomes; we have time to worry later about how much restoration is necessary.

Economics and Efficient Allocation

Finally, economics can help us efficiently allocate resources toward conservation. Economics is frequently defined as the allocation of scarce resources among alternative desirable ends (Daly and Farley 2004). Using the economics lens, therefore, implies a series of three steps that must be taken in order. First, we must identify the desirable ends. Second, we must identify the scarce resources as well as their physical and institutional characteristics relevant to allocation. Only then can we undertake the third step, which is deciding how to allocate (Daly and Farley 2004). Going through these steps with respect to conservation offers important insights, and can even provide a framework for guiding conservation efforts.

Desired Ends

A high quality of life for this and future generations is a strong candidate for a desirable end toward which we should allocate our scarce resources (Costanza and others 2007). Clearly, a high quality of life demands both economic production and ecosystem services. If we care about future generations, ecological sustainability is also a desired end, which in turn requires the conservation of ecosystems and the life support functions they provide. Concern for future generations implies a concern for the just distribution of resources between generations—it makes little sense to show concern for unborn generations without showing concern for those alive today. A just distribution of resources and of the costs and benefits of conservation is presumably desirable as well. Finally, we should strive to sacrifice as little ecosystem function as possible for a given amount of economic output—efficiency is a third desirable end. Allocation strategies should, therefore, be judged by their sustainability, justice, and efficiency (Daly 1992).

Scarce Resources

Having briefly examined the desired ends, we turn our attention to scarce resources. On a finite planet, the ultimate scarce resource is the low-entropy-matter energy supplied by the solar powered planetary ecosystem that sustains us (Georgescu-Roegen 1971). It is referred to as natural capital (Jansson and others 1994). As stated above, all economic production is merely the transformation of this natural capital into forms that (ideally) satisfy human needs. Moreover, in addition to supplying raw materials for the economy, natural capital also generates services that facilitate the economic transformation process and enhance human well-being. These include life support services without which humans could not survive, such as local, regional, and global climate regulation, protection from ultraviolet radiation, nutrient cycling, waste absorption, water purification, and numerous others. Natural capital also creates the conditions necessary for its own reproduction. How does natural capital provide these services? The raw materials provided by natural capital are components of ecosystem structure—that is, they are the mineral resources, water, organic matter, and individuals and communities of plants and animals of which an ecosystem is composed. When all the structural elements of an ecosystem are in place, they create a whole that is greater than the sum of the parts, and generate ecosystem functions as emergent phenomena from the complexity of ecosystem structure (Odum 1971). An ecosystem function that has value to human beings is called an ecosystem service (Costanza and others 1997; Daily 1997). As all market goods must be produced from the structural elements of natural capital, and depletion of structure diminishes function, production of market goods in general must reduce the ability of the ecosystem to generate ecosystem services (Farley 1999).

For most of human existence, natural capital was not very scarce relative to human needs and, hence, was not very important to economic analysis—we suffered less from lack of fish than from lack of fishing boats to capture them, less from lack of timber than lack of saws to harvest it. Raw materials were often locally scarce but were not globally scarce. Relative to the human population and scale of the human economy, the global supply of raw materials seemed infinite. An abundance of healthy ecosystems meant an abundance of ecosystem services. The scarce factors were labor and capital. The planet was relatively empty (Daly 2005). Today however, human beings directly or indirectly appropriate close to 40% of net primary productivity (Vitousek and others 1986). In many cases, damage to ecosystem services through overextraction of ecosystem structure and waste emissions has led to a decrease in raw material production by natural capital. At the same time, per capita economic production of market goods has increased enormously in the past few centuries—a 9-fold increase in the last century alone (Delong 2002). Human impacts on the sustaining system are enormous. The planet is now full. This transition from a relatively empty to a relatively full planet has changed the relative scarcity of resources. Formerly, human made goods and services were scarce, and ecosystem goods and services were superabundant. Now, the opposite is true, resulting in profound implications for allocation (Daly 2005). Perversely, too many politicians and economists fail to see this. In the United States, for example, we spent enormous amounts of money on environmental management and conservation efforts during the 1970s. Since then, our economy has nearly doubled in size per capita, yet our politicians now tell us that we cannot afford to address critical environmental problems such as global warming.

Physical Characteristics of the Scarce Resources: Stock-Flow, Fund-Service, Excludability, and Rivalness

Before we can decide how to allocate resources, we must assess their physical and institutional characteristics. One useful distinction is between stock-flow and fund-flux, a second is between excludable and nonexcludable, and a third is between rival and nonrival.

All elements of ecosystem structure can be categorized as stock-flow resources (Georgescu-Roegen 1971), or, as Aristotle (1994) called them, material cause. Stock-flow resources are the raw materials physically transformed through the economic process into a desired output. They are used up by the economic process and embodied in what they produce—trees are turned into furniture. Stock-flow resources can be stockpiled or used up at the rate we choose—we can cut down all the trees in a forest today, or do so over the course of the next 50 years.

All ecosystem services, on the other hand, are fund-flux resources (Georgescu-Roegen 1971), or, in Aristotle's terms, efficient cause. A fund is a particular arrangement of stock-flow resources that generates a flux of service. For example, a car factory is a particular arrangement of metal, plastic, rubber, and so on, that generates the "service" of car production. It is the agent of transformation, converting other stocks of metal, plastic, rubber, and so on, into cars. Cars, in turn, are a fund that generates the service of transportation. If the car crashes, the stock flow resources of which it is composed remain, but the configuration has changed, and the car can no longer provide transportation services. A forest is a particular arrangement of vegetation, soil, water, minerals, and wildlife that generates a flux of ecosystem services. Fund-fluxes are not physically transformed in the production process—when a forest filters water, controls floods, recycles nutrients, or stabilizes the climate, it is not transformed into what it produces. Fund-fluxes cannot be stockpiled, and they provide services at a given rate over time. A forest can filter a certain amount of water per day, but if we refrain from using its capacity for a month, we cannot store that capacity for later use (Georgescu-Roegen 1971; Malghan 2006).

Conventional economists fail to distinguish between stock-flows and fund-fluxes, and even allow for substitution between the two (e.g., Solow 1974). If one takes a simple example of a pizzeria, it is obvious that fund-fluxes (cooks and ovens) cannot substitute for stock-flows (the ingredients for making the pizza) in the production process (Daly and Farley 2004). There is little evidence that technology can develop meaningful substitutes at all for life support functions. Most ecosystems we desire to conserve have dual functions, as stock-flows that could provide raw materials for economic production and as fund-fluxes that provide critical ecosystem services.

For markets to efficiently allocate a resource, the resource must be both excludable and rival. An excludable good is one for which exclusive ownership is possible. That is, a person or community must be able to use the good or service in question and prevent others from using it if so desired. Excludability is virtually synonymous with property rights. If a good or service is not excludable, then it will not be efficiently allocated or produced by market forces. The reason for this is obvious. Market production and allocation are driven by profits. If a good is not excludable, someone can use it whether or not any producer of the good allows it, and hence that person is unlikely to pay for it. If people are unwilling to pay for a good, there will be no profit in its production, and it will not be produced by market forces, or at least not to the extent that the marginal benefit to society of producing another unit is equal to the marginal cost of production, the criterion for efficiency.

Excludability is solely the result of institutions, though some goods and services are inherently nonexcludable. In the absence of institutions that protect ownership, no good is truly excludable unless the possessor of that good has the physical ability to prevent others from using it. Some type of institution, be it government, religion, or custom, is required to make any good excludable for someone who lacks the resources to defend her property. It is fairly easy to create institutions that provide exclusive property rights to tangible goods such as food, clothing, cars, and homes. Slightly more complex institutions are required to create exclusive property rights to intangibles such as information or waste absorption capacity. For many services, such as most of those produced by ecosystems and protected by conservation, it is virtually impossible to design institutions that would make them excludable. We cannot even conceive of a workable institution that could give someone exclusive ownership of the benefits of climate regulation, water regulation, pollination, or a host of other ecosystem services. It is often possible to establish exclusive property rights to ecosystem structure (e.g., trees in a forest) while, at the same time, impossible to establish such rights to the services that structure provides (e.g., regional climate regulation). When there is no institutional regime enforcing excludable property rights to a good or service, that good or service is nonexcludable.

A rival good or service is one for which use of a unit by one person prohibits use of the same unit at the same time by another. Rivalness may be qualitative, quantitative, or spatial in nature. A nonrival good or service then is one where use by one person has an insignificant impact on the quality and quantity of the good or service available for another person to use. All stock-flows are rival. Nonrival resources are not scarce in the conventional sense, as any number of people can use the resource without leaving less for others. Rivalness is an inherent property of the good or service in question, unrelated to prevailing institutions. Climate stability, flood control, beautiful views, and sunny days are a few of the nonrival goods produced by nature. Information, streetlights, and firework displays are some made by humans. All nonrival resources are fund-fluxes.

As discussed above, economic efficiency requires that the marginal cost to society of producing or using an additional good or service be precisely equal to the marginal benefit. However, if a good is nonrival, an additional person using the good imposes no additional cost on society. Markets allocate resources by using price as a rationing mechanism, but rationing nonrival goods creates artificial scarcity. If someone has to pay a price to use a good, he or she will only use the good until the marginal benefit is equal to the price. The price of a nonrival good is greater than zero, while the marginal cost of additional use is zero. Therefore, markets will not lead to efficient allocation of nonrival goods. Conversely, a good must be rival to be efficiently allocated by the market (Daly and Farley 2004).

There are different types of nonrival goods and services. Some nonrival services, such as climate stability, are not affected by the number of people using them. For other nonrival goods, use by too many people can seriously diminish the quality of the good or service. For example, if I lay my towel out on an empty beach, it does not diminish your ability to use the same beach. However, if thousands of people choose to use the beach at the same time, not everyone will find a place for their towel, and the crowding may diminish the utility we get from being at the beach. Such goods are nonrival but congestible (Randall 1993). These resources should be treated as nonrival for low levels of use and rival at high levels of use.

What happens when goods and services are nonrival, nonexcludable, or both? The simple answer is that market forces will not provide them and/or will not efficiently allocate them. However, we need to be far more precise than this if we are to derive policies and institutions that will lead to the efficient conservation of ecosystems. Effective policies must be tailored to the specific combination of excludability, rivalness, and congestibility that characterize a particular good or service. The possible combinations are laid out in Table 1 and described in more detail below.

Allocation

Having assessed the desired ends, the scarce resources, and the physical characteristics of those resources, we can propose some guidelines for the efficient allocation of resources toward conservation. Beginning in the upper left-hand corner of Table 1, most elements of ecosystem structure are regularly bought and sold in markets, and at first glance it would appear that market allocation is appropriate. Existing institutions make them excludable, so that markets can exist. As rival goods, there is competition for consumption. Selling such goods on the market ensures that they will go to whoever can pay the most for them. If the resources are destined to be inputs into economic processes, then the person who can pay the most for them is the one who can use them to generate the highest monetary values.

However, there are at least two serious problems with market allocation of rival and excludable resources. First, it is not at all clear that maximizing monetary value should be a desirable end. Just because an American driver of an SUV can pay more for corn-based ethanol than a poor Mexican woman can pay for corn tortillas to feed her starving children does not mean that the highest and best use of corn is conversion to ethanol. Second, these resources are the structural components of ecosystems, and their use in economic production diminishes the production of ecosystem services, which are primarily nonexcludable, nonrival, and unpriced. If the person depleting ecosystem structure is able to ignore the ecological consequences, a real cost of production, then market allocation will not lead

Table 1 The relevance of excludability, rivalness, and congestibility to resource allocation

	Excludable	Nonexcludable
Rival	*Market goods* Most elements of ecosystem structure (e.g., timber, fish, farmland, mineral and fossil fuel deposits) as well as waste absorption capacity for regulated emissions (e.g., SO_2 in the U.S.)	*Open access resources* (“tragedy of the commons”) Elements of ecosystem structure that are not protected by property rights (e.g., ocean fisheries, timber from unprotected forests) as well as waste absorption capacity for unregulated emissions (e.g., CO_2 in the U.S.)
Nonrival	*Inefficient market good* (“tragedy of the noncommons”) E.g., patented information and genetic information to which the convention on biodiversity assigns property rights	*Pure public good* Most elements of ecosystem function (e.g., climate regulation, water regulation) and services provided by waste absorption capacity (clean air, clean water, etc.)
Nonrival,	congestible	*Club or toll good* E.g., golf course
	Congestible public good E.g., public beach	

Note: Adapted from Farnsworth and others (1983) and Randall (1993) to efficient outcomes (Cornes and Sandler 1996). If the benefits of extraction go to one person while the costs are imposed on others, the outcome is also unjust. If too many resources are extracted, leading to system collapse, the result is also unsustainable and unlikely to lead to a high quality of life for this and future generations (Odum and Odum 1972).

The waste absorption capacity of healthy ecosystems is one of the few ecosystem services that is rival, and it can also be made excludable, as was done for SO_2 emissions in the United States (Daly and Farley 2004). For a market to emerge, of course, the resource needs to be scarce. This was accomplished by setting a cap on the tons of SO_2 emissions allowed. Tradable permits were then awarded to individual companies, who were free to buy and sell them on the market. SO_2 emissions continue to degrade ecosystem functions, but the extent of degradation was now limited (Burtraw and others 1998; Burtraw and Mansur 1999; Carlson and others 2000).

While the elements of both ecosystem structure and waste absorption capacity can fall into the same quadrant, there is a distinct difference in how they are allocated. For elements of ecosystem structure like timber and fish, resource owners will presumably harvest more as the price rises. As the fecundity of wild natural resources does not respond to the price mechanism, stocks will decline with a rise in price. This means that the amount of stock left intact to supply vital life support functions is determined by the market price of the good. In the case of waste absorption capacity, society determined that the level of SO_2 emissions was too high, threatening vital life support functions. Via government, society then stepped in to limit SO_2 emissions to sustainable level. The supply of vital life support functions is price determining, not price determined, thus respecting ecological sustainability (Daly 1997). In the United States, pollution permits were awarded to individual firms. As the costs of using the permits (i.e., acid rain) falls on the general public, awarding permits to the polluters hardly seems just. However, it would be possible to simply auction off the permits to the highest bidder, in which case the public sector is compensated for damages.

The second category in the matrix is open access resources—those that are nonexcludable but rival. Use of such goods commonly leads to what Garret Hardin (1968) has called “the tragedy of the commons.” The classic example Hardin used was the grazing commons once widespread in England. If everyone shares grazing land, one person adding an additional cow means that all cows get less grass. The disadvantage of thinner cows is shared with everyone, while the individual gets all the benefits of the added cow. If everyone thinks in the same manner, households will keep adding cattle to the commons until it becomes overgrazed and the productive capacity declines dramatically. Each person acting in what appears to be rational self-interest destroys the commons, and everyone is worse off than if each had stuck with one cow per person. Any unowned elements of ecosystem structure are subject to this tragedy, which helps explain why an estimated 69 percent of commercial oceanic fish species are overexploited (FAO 2000) and desperately in need of conservation. This tragedy also lurks behind global climate change.

Many economists have correctly pointed out that this problem of open access resources results from a lack of property rights. If the English commons in the first example had been divided up into 100 equally productive private lots, than the rational individual would graze only one cow in each lot, and the tragedy would be avoided. Similarly, it would be possible to assign property rights to the waste absorption capacity for CO_2, which is what the Kyoto protocol is attempting to do (IPCC 2001). Several countries have assigned tradable property rights to fish harvests as a means of conserving fisheries and the ecosystems of which they are part (Casey and others 1995; Pautzke and Oliver 1997; Batstone and Sharp 1999). Unfortunately, for many of the resources of concern to us, the ability to bestow individual property rights is more the exception than the rule. Farley and others (2009) describe a situation in which private property rights contribute to unsustainable, unjust and inefficient outcomes. It is important to recognize that property rights held in common can effectively manage nonexcludable, rival resources under the appropriate institutions (Bromley 1993; Ostrom 1990). However, some type of property right, private or common, is almost certainly superior to none.

The third category includes those resources that are excludable but nonrival. The prime example of this type of good is patented information. What does this have to do with conservation? Imagine that some corporation develops and patents a cheap and efficient way to harness solar energy and convert it to hydrogen for use in a cheap and efficient fuel cell. These inventions could virtually eliminate our dependence on fossil fuels and dramatically reduce the risk of global warming. Less fossil fuel extraction and less climate change means less ecological degradation and fewer resources that need to be devoted to conservation. The corporation knows the value of its inventions and sells the products for an extremely high price. Unfortunately, at this price, many poorer countries are unable to afford the technology and rely instead on their coal deposits, leading to unnecessarily severe global warming and potentially catastrophic impacts on global ecosystems. Conservation efforts may be futile if climatic conditions change too much.

The justification for patents is that they provide incentive for new inventions. The problem is that prices ration the use of information to those who can afford it, making it artificially scarce, even though society might benefit from greater use. The result is unsustainable and inefficient, and because most patents are owned by the wealthiest nations, arguably unjust as well. Most inventors these days work for salaries, and there is no reason to believe that they would work harder for private-sector employers than public-sector ones (Simon 1991). Private-sector firms rarely, if ever, freely share their breakthrough technologies with each other. When firms pursue common goals, they must inefficiently hire separate teams to do so, with minimal communication between them. Private ownership of nonrival resources generates a tragedy of the noncommons. A more efficient approach would be publicly financed research into activities relevant to conservation (either technologies that reduce environmental degradation, and hence the need for conservation, or knowledge that directly facilitates conservation), with the results freely available to all (Bollier 2003).

The fourth category in our matrix is nonrival, nonexcludable public goods, which include most ecosystem services. Because public goods are nonexcludable and cannot be sold, markets are unlikely to provide them. Instead, the government or some other public institution should provide them, but it is difficult to determine exactly how much should be provided. Different ecosystem services have different spatial distributions (e.g., flood control benefits those downstream, global climate stability benefits everyone in the world), but roughly speaking, everyone residing within the geographical area that benefits from a service is entitled to consume the same amount of that service. In contrast, individuals consume as much as they like (or can afford) of any given market good. An additional unit of a market good is worth producing as long as at least one individual alone is willing to pay the cost of producing it. The individual who buys it is the one who gets to use it. In contrast, a public good is worth producing as long as all individuals together are willing to pay the cost of producing another unit, whereupon all individuals are able to use it (Samuelson 1954). Once public goods are produced, however, there should be no charge for marginal use, which would inefficiently ration use to those who can afford it. Unfortunately, it is very difficult to figure out precisely how much any individual is willing to pay, since for the individual it may be better to pay nothing and free ride on the amount provided by others (Cornes and Sandler 1996). One thing that is clear, though, is that public good ecosystem services are growing more scarce and, hence, more valuable at the margin, while marketed goods are growing more abundant and hence, less valuable at the margin. We are almost certainly underinvesting in ecosystem services, and conservation is an effective way to invest in them.

To recap the discussion so far, there are resources relevant to conservation in each of the quadrants in Table 1, and how they should be allocated them depends on their physical and institutional characteristics. Governments are primarily responsible for providing public good benefits, which are the main type of benefit produced by conservation. Governments should also provide the information necessary to conserve the environment or reduce its degradation. Markets are only possible for excludable goods, and only suitable for rival ones. Rival and nonexcludable goods should be made excludable, with either private or common property rights, in which case markets are again possible. The government or other nonmarket institutions should supply nonrival goods and make them available free of charge.

At this point it is worth reiterating a complication mentioned above. Most natural capital stocks have a dual function as a stock-flow of market good raw materials and a fund-flux of public good ecosystem services. How will markets choose between the two? Take the example of someone who owns a plot of forest in the Amazon and can decide between conserving it as forest and clearing it for agriculture. Researchers have estimated the value of public good ecosystem services sustainably produced by tropical forests at roughly \$1660/ha/year (calculated by the author from Costanza and others 1997); while I have explained the problems with valuation above, I use this number simply to illustrate a point. If the landowner converts to agricultural production, he would earn an estimated \$33/ha/year (Almeida and Uhl 1995). From the perspective of society, there is no doubt that the annual flow of \$1660/year far outweighs the returns to conversion. However, from the perspective of the landowner, \$33 a year in private gains outweighs \$1660 in public goods shared with the rest of the world, and existing institutions give him the right to do as he pleases with his private property. Clearly both the landowner and society could be better off if the beneficiaries of the public goods paid the landowner \$100/ha/year to preserve them. Unfortunately, there are a number of serious obstacles preventing this exchange from happening, of which I will mention three. First, most people are ignorant of the value of ecosystem services. Second, the free rider effect means that many beneficiaries of public goods will pay little or nothing for their provision. Third, we currently lack institutions suitable for transferring resources from the beneficiaries of ecosystem services to the landowner who pays the opportunity cost of not deforesting. Thus, from the landowner's point of view, in a market economy deforestation is clearly the rational choice, and society suffers as a result. Existing markets in rival, excludable ecosystem structure undermine the provision of nonrival, nonexcludable ecosystem functions.

None of this means that markets are useless, only that markets alone will not lead to the conservation and environmental management goals of sustainability, justice, and efficient allocation. Fortunately, the economic lens provides insights into how we might achieve such goals. Historically, the economic problem was presented as how to allocate raw materials toward their highest value outputs. With the increasing scarcity of ecosystem services, however, the problem has changed: the pressing issue now is how to allocate ecosystem structure between the raw materials needed for economic production and the ecosystem services required for our survival. This is a problem that market forces cannot solve. If sustainability is a desired end, conservation of ecosystems and the services they provide is essential (Odum and Odum 1972). If justice is a desired end, it would seem that all people deserve a say not only in how we allocate resources provided freely by nature, but also in how we distribute them. Markets allocate resources according to the principle of one dollar, one vote, or plutocracy. An alternative principle for determining the desired allocation and distribution of ecosystem services is one person, one vote, or democracy. In the case of SO_2 emissions in the United States, emission limits were more or less democratically decided on, and with tradable permits it proved a cost-effective way to reduce emissions. But the distribution was grossly skewed, as all rights were awarded to existing polluters. Anyone else who wanted rights had to pay for them. Several countries have taken a similar approach to fisheries management, and the IPCC (2001) is attempting it for global CO_2 emissions. But to what extent is such an approach appropriate to conservation in general? Our allocation matrix can guide us.

When a resource is nonexcludable and rival, such as waste absorption capacity and fisheries, society (e.g., government) in some cases can make it excludable by declaring (and enforcing) common property rights, which all should agree are superior to none. Enough should be set aside to provide a desired quantity of ecosystem services. When the exact location of the conservation activity does not matter, such as limiting mobile pollutants or conserving nomadic fish species, those resource not conserved can be allocated through other mechanisms, such as tradable permits. Use of waste absorption capacity (i.e., emitting pollutants) has negative impacts on the public, and taxes or auctioned permits require those who use it to pay society (i.e., government) for the damage done. New Zealand took the interesting approach of awarding tradable permits to existing fisherman for their historical harvests, then purchasing back enough to safely conserve the resource. Stocks were conserved, but distribution issues have proven problematic (Memon and Cullen 1992). Using this approach to conserve transboundary resources such as CO_2 or fisheries outside of the economic exclusion zone for oceans would require some sort of international agreement.

When a resource is excludable but generates nonexcludable and nonrival ecosystem services, such as a privately owned forest or wetland, there are several options. One is to limit existing property rights with a total quota for excludable uses of the resource, then allow markets for uses that exceed that quota, as described above. Examples include the no net loss of wetlands policy in the United States, in which case the quota is set at existing levels but wetlands landowners are allowed to drain wetlands if they pay for restoring or building new ones elsewhere (Shabman and Scodari 2004). However, it is highly questionable whether built wetlands effectively replace natural ones. Tradable development permits cap total allowable development in an area but allow landowners to buy and sell development rates, so that the location of development is market determined (Stavins 2002). A second and increasingly popular approach is simply to pay landowners for providing ecosystem services (Landell-Mills and Porras 2002; Pagiola and others 2002).

The strength of market solutions is that they can take advantage of micro-flexibility to achieve macro-level goals, but sometimes there is no room for flexibility. Protecting an endangered species or providing a critical ecosystem services may demand that all of a remaining ecosystem is protected. Under such circumstances, nonmarket alternatives such as mandatory regulations may be more appropriate. For example, the U.S. government has decided that private property owners are not entitled to alter existing ecosystems if they contain endangered species (Czech and Krausman 2001), and the Supreme Court has ruled that it is legal to prevent property development to conserve particular natural areas (Greenhouse 2002).

While using taxes or fees to deter behaviors that undermine conservation goals or subsidies or payments for activities that promote them can work (Baumol and Oates 1989), such approaches have one potentially serious flaw. When ecosystems are nearing critical thresholds, economic incentives still make their ultimate survival contingent on economic variables. For example, we might impose a tax on deforestation high enough to ensure desirable levels of conservation at current timber prices, but if a housing boom drives up the demand for timber, builders might simply pay the tax; deforestation will then increase and conservation goals will not be met. If we believe that humans are indeed dependent on life support functions of ecosystems, and conservation is essential, then we cannot let the level of conservation depend on economic variables. Prices can respond to ecological constraints much more quickly than ecosystems can respond to economic variables, so the level of conservation should be price determining, not price determined (Daly 1997).

While market instruments can provide effective conservation tools in some cases, they do not work everywhere, and their effectiveness must be evaluated by the criteria of sustainability, justice, and efficiency.

Problems with the Economic Lens

Unfortunately, the economic lens described above is not that used by most economists. It is in fact an ecological economic approach. Ecological economics is inherently transdisciplinary and explicitly integrates ethical concerns in determining desirable ends, laws of physics and ecology in understanding scarce resources, and political, social, and market solutions to the allocation problem. Rather than a single lens, ecological economics is more like a central processing unit, similar to the brain of the dragonfly, that integrates the images from thousands of lenses into a coherent whole.

This is in distinct contrast to the dominant paradigm in economics today, neoclassical economics (NCE). NCE seeks to be a complete and monistic science—complete in that it claims to explain virtually all problems by boiling all values down to monetary ones, and monistic in that it claims to be the only lens required (Norton 2005). In its effort to be scientific, it seeks to derive objective decision-making rules based on mathematics and has made numerous simplifying assumptions to achieve this goal. I believe that this approach has made conventional economics the driving force behind ecological degradation rather than a useful tool for conservation. While the comments below certainly do not apply to all neoclassical economics, they would appear to apply to virtually all introductory textbooks in NCE.

NCE defines the desired end for allocation to be the greatest possible utility for society. Utility is difficult, if not impossible, to measure but is assumed to be determined by innate personal preferences. The individual is the unit of analysis and is assumed to be a rational maximizer of self interest. Only revealed preferences can be measured, and preferences are revealed through market purchases. Tautologically, this reveals that individuals prefer market goods. For all practical purposes, the desired end in NCE is taken to be ever greater material consumption, measured in the aggregate by economic growth. NCE claims we cannot compare utility between individuals and, therefore, should focus only on aggregate outcomes. Unfortunately, it is the blind pursuit of this goal that has led to the current need for conservation. Efforts to account for the contribution of nonmarketed ecosystem goods and services to utility by first calculating their monetary value confront their own problems, as previously discussed.

Scarce resources are whatever is required to produce market goods. However, as any single resource becomes scarce, its price increases, providing incentives to use it more efficiently and to develop substitutes. The incentive to develop substitutes is considered so powerful that we do not need to worry about absolute scarcity or worry too much about any particular scarcity (see, e.g., Simon 1981; Gilder 1989; Huber 2000). Obviously nonmarket goods have no price, so there will be no incentive for markets to develop substitutes as they become scarce, but this problem is generally ignored. In fact, most NCE production functions have only capital and labor, implying that natural resources are not scarce at all. Within the first two chapters of almost any introductory text to micro-economics, we are told that specialization and trade can lead to greater commodity outputs with no change in resource inputs, explicitly denying the first law of thermodynamics (conservation of matter-energy). The need for energy is scarcely mentioned. Waste emissions are relegated to the minor field of environmental economics, where they are considered an externality of production, not an unavoidable outcome. Economists poorly versed in ecology pay little attention to vital services essential to our survival. The net result is the implicit assumption that all scarce resources worth considering are market goods.

Given this definition of desirable ends and scarce resources, obviously the only relevant allocation mechanism is the market. Where markets do not exist, they must be created. Ecosystem services can be incorporated into markets by calculating their monetary value or by making them excludable. Beyond protecting property rights, governments just get in the way of the free functioning of markets. Admittedly, NCE has come up with some ingenious ways to create markets (see, e.g., Baumol and Oates 1989), some of which were presented above as tools for achieving conservation goals. However, the effectiveness of such tools needs to be assessed according to how well they achieve ecological sustainability, just distribution, and a high quality of life for those affected, not solely by their impact on economic growth.

Why have neoclassical economists taken such a narrow approach? It appears that in their pursuit of scientific rigor through objective decision rules, they have forgotten that science is also based on empirical observation, and, therefore, ignore the increasing empirical evidence that so many of their underlying assumptions are wrong. A second problem is that universities around the world train students in disciplines. As we write in the preface to our textbook, “The disciplinary structure of knowledge is a problem of fragmentation, a difficulty to be overcome rather than a criterion to be met” (Daly and Farley 2004, p. xvii). Each discipline has its own language, tools, methods, and journals. Faculty members are hired by disciplinary departments and, in most cases, must publish in disciplinary journals if they hope to get tenure. Grant proposals are reviewed by disciplinary peers, too often rejecting what they cannot understand. With few incentives to stray beyond the narrow confines of a given discipline, academics become comfortable with disciplinary jargon that only their colleagues can understand. This shields them from criticism, because potential critics must spend years learning the language before they are qualified to critique it, and those who believe it flawed are unlikely to invest so much.

Excessive retreat into a single discipline is comparable with autism—a disorder characterized by absorption in self-centered subjective mental activity, marked deficits in communication and social interaction, marked withdrawal from reality, and abnormal behavior, such as excessive attachment to certain objects. A jargon-filled vocabulary makes communication with other disciplines difficult. A focus on theory over practical applications too often divorces the discipline from reality, and economists are excessively attached to their simplistic methodologies, which are poorly suited for understanding complex systems (Daly and Farley 2004). At least within the natural sciences, consilience is occurring, which is to say that the sciences do not contradict each other: for example, biologists understand that their discipline depends on the rules of chemistry, which, in turn, depends on the laws of physics (Wilson 1998). The same is unfortunately not true of the social sciences: economists, sociologists, and political scientists offer theories that often fundamentally disagree with each other, and we have already pointed out how economists ignore the laws of physics and ecology.

Conclusion

The economic lens can bring important details of the conservation problem into focus and contribute to developing effective solutions. However, conservation is a complex real-life problem, and no single lens can provide a clear picture of the whole. Viewing the problem through any single lens risks obscuring more than it illuminates.

Conventional disciplinary education teaches us that only scientists should conduct research, and should apply a discipline-specific set of theories and methodologies to any problem. In multidisciplinary research, disciplinary researchers conduct separate disciplinary analyses of a given problem, with little communication among themselves, adding up the results. In interdisciplinary research, there is more communication and collaboration, but the basic approach is to divide a problem into separate components to which each disciplinary expert applies his or her disciplinary methodology, regardless of the problem. In contrast transdisciplinary research researchers assess the myriad facets of a problem, then let the problem determine which approaches, theories, and methodologies are best suited for solving it. In other words, multidisciplinary research is additive, interdisciplinary research is based on the divide and conquer strategy, and transdisciplinary research is integrative. As we all know, integration is much more difficult than addition and division (Costanza 2005).

What is needed is a transdisciplinary systems approach to conservation, a way of processing the images from multiple lenses into a coherent picture. Fortunately, there are a number of emerging transdisciplinary fields that pursue this goal. These fields include environmental management, conservation biology, restoration ecology, ecological economics, ecological engineering, and environmental justice. Together these fields will allow us to take full advantage of individual disciplinary lenses without losing sight of the larger picture.

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