BIODIVERSITY AS A COMMODITY

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Abstract: What is the nature of biodiversity as an economic commodity and why does it matter? How would its conservation contribute economically to our well being? I consider three issues:

- Why is biodiversity important from an economic perspective?
- What kind of commodity is it?
- Does our usual economic mechanism, the market system, have the capacity to appreciate the economic value of biodiversity?

I first characterize biodiversity from an economic perspective, and then consider the capacity of our main economic institutions to realize the value of biodiversity and ensure that it is treated in a way commensurate with its importance.

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Many distinguished scientists have argued strenuously for the conservation of biodiversity as a significant human priority (Ehrlich, Raven and Williams, Wilson). As economic activity is the main driver of biodiversity loss, such conservation would undoubtedly have important economic implications. It would require economic changes and would certainly be associated with economic costs, though of course these could be more than offset by the gains. The proposal implicit in these arguments is in effect that we – society – should "buy" biodiversity by changing our economic modus operandi and incurring conservation costs.

What are we buying if we make such a deal? What is the nature of biodiversity as an economic commodity and why does it matter? How would its conservation contribute economically to our well being? These are the themes I want to address in this entry. I want to consider three issues:

- What are the economic functions of biodiversity?
- What kind of commodity is biodiversity?
- Does our usual economic mechanism, the market system, have the capacity to appreciate the economic value of biodiversity?

In other words, I want first to characterize biodiversity from an economic perspective, and then to consider the capacity of our main economic institutions to realize the value of biodiversity and ensure that it is treated in a way commensurate with its importance. In the first of these tasks, assessing why biodiversity is important economically, I have to draw extensively on recent literature in ecology, which I do with some trepidation, as this is not my field of expertise.[2] However, this in unavoidable: a serious analysis of the economic contributions of biodiversity has to draw on scientific understanding of how diversity contributes to the functioning of the natural environments that provide crucial infrastructure to human societies.

I begin with an attempt to understand what biodiversity contributes, in economic terms, to human societies. Why is biodiversity important? I think we can classify the reasons under the following headings. Biodiversity provides or enhances

- Ecosystem productivity
- Insurance
- Knowledge
- Ecosystem services.

There is some overlap between these concepts, but nevertheless they are helpful as a guide to thinking through the issues. All of them are economically important categories.

Biodiversity and Productivity

How does biodiversity contribute to productivity? There is experimental evidence that plant systems with more biodiversity are on average more productive than those with less. A good illustration of this is work done by David Tilman at the University of Minnesota (Tilman and Downing, Tilman Wedin and Knops, Tilman et al.). He took a number of similar plots of land and planted each of them with a variety of grassland plants, some with a large number of species,

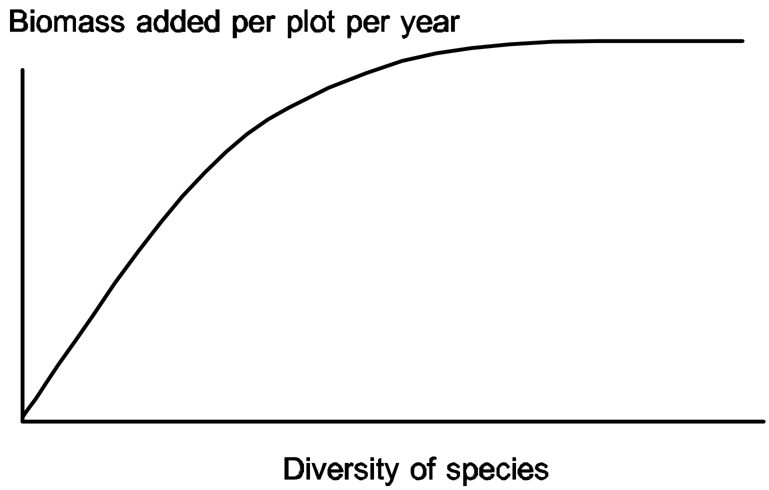
[2] My understanding of the relevant issues has benefited from conversations with Gretchen Daily, Paul Ehrlich, David Tilman and Peter Vitousek.

some with a much smaller number. Each plot was planted with the same mix year after year, and several indicators of plot performance were recorded. These included the amount of biomass grown and the proportion of the nutrients available that were taken up by the plants. Biomass refers to the total dry body weight of the plants: it is a measure of the amount of carbon from the atmosphere that is photosynthesized into carbohydrate. Tilman and others performing similar studies have found that on average over a period of about twenty years plots with a more diverse collection of species performed better than those with a less diverse collection.

What does more or less diverse mean here? There are two dimensions to diversity: diversity of functional groups, or of plant types, and diversity of plant species within a functional group. Plants are classified into functional groups on the basis of their intrinsic physiological and morphological characteristics, such as whether they fix nitrogen, have three carbon or four carbon photosynthetic pathways, or are woody (Tilman et al.). These characteristics influence resource requirements, seasonality, and life history. One key aspect of diversity is measured by the number of different functional groups represented by the plants on the plot. This is called, not surprisingly, functional diversity. Species diversity refers to the number of different species within each functional group, or to the total number of species present. This latter measure is sometimes called diversity per se. Clearly there is a correlation between diversity per se, the total number of different species present, and functional diversity, as one cannot add more species without eventually adding more functional groups as well. Another related determinant of productivity is the composition of the functional groups present: productivity may depend not just on the number of such groups represented but also on their identities, as some groups may be more important than others in contributing to productivity or resilience.

The average amount of biomass grown per year on a plot of a given size increased with the diversity of functional groups represented, as shown in the figure. The increase leveled off after a certain point. Tilman and co-workers also found more nutrient uptake and better soil quality on plots with a more diverse collection of plant species. Furthermore, the plots that were more diverse in this sense were also more robust in the face of climatic fluctuations. It appears from this work that both functional diversity and species diversity are important in maintaining productivity and resilience. Having functionally similar plants that respond differently to environmental fluctuations contributes to resilience. It ensures that whatever the environmental conditions there will be plants of a given functional type that thrive under those conditions. The functional composition of the community will therefore not be changed by environmental fluctuations. In contrast, if the members of different functional groups respond differently to environmental fluctuations, then these fluctuations will alter the functional composition of the community and so its ecological characteristics, and it will be less resilient in the face of such fluctuations (Chapin et al.). These authors argue that

> “genetic and species diversity per se are important to long-term maintenance of community and ecosystem structure and processes. This argues that no two species are ecologically redundant, even if they appear similar in their ecosystem effects under one particular set of environmental conditions.”



What is the mechanism behind these results? There is still some dispute about this. One possibility is that each plant type has a range of climatic conditions to which it is best suited. Climate varies from year to year in terms of temperature, rainfall, and in many other ways, and if a plot contains only one plant type then in many years it will not have any plants well adapted to the climates of those years. If however a plot carries many types, then in most years there will be some that are well adapted to the climate of that year and on average its productivity will be greater. It is another illustration of the old proverb "Don't put all your eggs in one basket." Analytically, it illustrates the same point as the economic argument for holding a diversified portfolio of stocks. The more diversified the portfolio, the less vulnerable you are to conditions that are bad for particular stocks or stocks in a particular sector of the economy. A robust portfolio should have stocks that do well in times of growth, stocks that do well in times of high interest rates, stocks that do relatively well in times of recession. It should have different types of stocks. Diverse plots will also be more resilient to climatic variation, as a part of the same phenomenon. This is related to the insurance role of biological diversity, here manifested as higher average productivity. An alternative explanation for the greater productivity of mixed plant communities has been suggested, based on the interactions between the fungal communities associated with the roots of the plants and the diversity of the fungi in the soil, which affects the effectiveness of nutrient uptake. (van der Heijden, Read)

Similar studies have been conducted for microbial communities, and have found similar results. Again they show that more diverse communities are on average more stable and robust in the face of environmental fluctuations. (For reviews of this area, see McGrady-Steed et al, Grime, Hooper and Vitousek, Naeem and Li.)

There are other arguments about why diversity raises productivity, mostly specific to particular biological communities. Trees in forests provide a good example. Some trees are tolerant of shade and others of bright light. A forest of a uniform tree species will consist entirely of trees of one of these types. Consider in contrast a forest with tall shade-intolerant trees forming the upper canopy. These need bright light and in the upper canopy this is what falls on their leaves. Below them are shorter trees that are more shade-tolerant, and perhaps below them another layer of even more shade-tolerant trees or shrubs. With such an arrangement of diverse species, bright light falls on those that most need it, and the light that passes through their canopy and is of lesser intensity then falls on plants well suited to it. Total photosynthesis, that is conversion of carbon dioxide in the air to carbohydrates with the aid of light energy, will be greater under such a regime than in a single-species forest. (Aber and Melillo)

These arguments show that diversity is important in ensuring the productivity and robustness of natural plant communities, and therefore of the ecosystems that are based on them. Diversity also helps natural ecosystems to make the best adjustments to conditions that vary over time or over space. Without the appropriate level of diversity, natural ecosystems cannot adjust to natural variations in the environment.

Through its role as the raw material in plant breeding, biodiversity also contributes very substantially to the productivity of agricultural systems. New and higher-yielding plant and animal varieties are generated from the natural variation in plants and animals. The great increases in grain yields of the “green revolution” of the 1960s and 1970s, which were responsible for keeping food output growing in parallel with population in developing countries, were largely achieved by use of genetic diversity in the plant populations. There are estimates suggesting that as much as $1 billion has been added to the value of the US agricultural output each year for the last half century as a result of plant breeders’ use of genetic diversity. Specifically, in the last half century we have seen a doubling in yields of rice, barley, soybeans, wheat, cotton, and sugarcane, a threefold increase in tomato yields, and a quadrupling in yields of maize, sorghum and potato (US Congress Office of Technology Assessment). All of this has been based on and derived from genetic variability in the underlying plant populations. In economic terms, this variability is an asset, and one that has yielded a great return at little cost. Diversity also contributes to productivity in agriculture through the practice of crop rotation. Changing from one crop to another from one year to the next can enhance soil productivity by increasing the nutrients in the soil. For example, rotating a crop such as wheat with a legume that fixes nitrogen can prevent long-term nitrogen loss and reduce the need for nitrogen fertilizers. This type of crop rotation was characteristic of traditional agricultural practices in medieval Europe.

It is important to note that while biodiversity contributes to the productivity of both natural ecosystems and agricultural systems, it does so through different mechanisms. Natural systems benefit directly from a diverse mix of species: agricultural systems benefit from the existence of a pool of genetic variability on which breeders can draw. Agricultural systems are usually monocultures, consisting of a single species grown intensively over a large area. Its growth is supported by applications of water, fertilizers, pesticides and weedkillers. The farmers manage cropland so as to ensure that crop growth is not limited by lack of water of nutrients, and that the main food crop does not have to compete with other species or with pests in its growth. Farmers create and maintain an artificial environment and then plant a crop that is optimally adjusted to this environment, an approach that is radically different from the natural growth process.

Biodiversity and Insurance

A dramatic illustration of the insurance role of biodiversity comes from the recent history of rice production. The prosperity and comfort of literally billions of people depend on the rice harvest. In the 1970s, a new virus, the grassy stunt virus, carried by the brown plant hopper, threatened the Asian rice crop. This appeared capable of destroying a large fraction of the crop and in some years destroyed as much as one quarter. Developing a form of rice resistant to this virus became of critical importance. Rice breeders succeeded in this task with the help of the International Rice Research Institute (IRRI) in the Philippines. The IRRI conducts research on rice production, and holds a large seed bank of seeds of different varieties of rice and the near-relatives of rice. In this case the IRRI located a variety of wild rice that was not used commercially but which was resistant to the grassy stunt virus. The gene conveying resistance was transferred to commercial rice varieties, yielding commercial rice resistant to the threatening virus. This would not have been possible without genes from a variety of rice that was apparently of no commercial value. Without this variety, the world's rice crop, one of its most important food crops, would have been seriously damaged. An interesting additional detail of this story is that the variety of wild rice that was resistant to the virus was found in only one location, a valley that was flooded by a hydroelectric dam shortly after the IRRI found and took into its collection the critical rice variety. The same story was repeated later in the 1970s, and similar stories have occurred with other food crops, in particular corn in the United States. (Myers) We have every reason to expect that events like these will recur regularly: planting large areas with genetically identical plants greatly increases the chances that once a disease starts it will spread with dangerous speed through the entire area and crop. A recent report by the Committee for Agriculture, Science and Technology emphasized this point:

> "Because of the increasingly high densities and large areas over which they are now grown, both livestock and crop plants are continually acquiring new diseases and pests, and existing diseases and pests are continually evolving new strains that overcome the defenses of particular breeds or strains. This is exacerbated by the accidental transport of diseases around the world. These diseases and pests destabilize agricultural systems. For instance, areas of western Minnesota and eastern North and South Dakota no longer can produce viable wheat and barley crops because of new strains of scab and vomit toxin for which no crop varieties have sufficient genetic resistance. Indeed, catastrophic attacks of disease, invasions of insects, and climatic extremes have caused wholesale crop destruction and ensuing famines whenever crops had insufficient diversity to provide at least some plants with the ability to withstand the assaults. Outbreaks of avian flu in the Chesapeake Bay area regularly result in rigorous quarantines of poultry houses due to the extremely high density of poultry farms in this region.
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> Disease problems, as old as agriculture, are recorded in myth and in written history, and still exist. Red rust on wheat in Roman times, mass poisoning from ergot-tainted rye during the middle ages, the Irish potato famine of the 19th century, and the Southern corn leaf blight in 1970 all were due to insufficient biodiversity in the affected crops. The severity of the 1998 Hong Kong chicken epidemic was likely exacerbated by the lack of diversity in disease resistance as well as by the high chicken densities in the production facilities.
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> The continual accrual of new diseases can be countered only if breeders can find sufficient genetic diversity within a crop or its relatives. Even the full complement of natural genetic variation, though, may not be sufficient to stop some diseases. Consider, for instance, the impacts of chestnut blight, an introduced disease that devastated what was once the dominant tree of the Eastern United States, but which now occurs only as rare stump sprouts. Despite the vast geographic expanse and genetic diversity of the native North American Chestnut, there is no known genetic resistance to its pathogen. Similarly, in vast areas of west and central Africa, livestock genetic resistance to the debilitating effects of trypanosomiasis is found only in a few

> unproductive local breeds. Despite massive efforts, the genetic mechanisms governing this resistance are not yet well understood.
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> A lethal disease of corn, or wheat or rice, were it to appear, would devastate agriculture and human society. The only insurance that society has against such a catastrophe is biodiversity. Genetic diversity within a crop plant or animal species and its relatives might allow resistant strains to be discovered and used. Similarly, a diversity of potential food plants might allow another species to become an effective substitute for a major crop species that was lost to disease."

These cases illustrate clearly the insurance role of biodiversity. It is an important defense against disaster in the form of new diseases. The pathogens that cause disease are evolving continually, in an attempt to outwit our defenses against them. A clear example of this phenomenon is the evolution of antibiotic resistance amongst bacteria. The bacteria that cause several once common diseases in humans are now showing resistance to their principal controls, to the great concern of public health authorities. The same is happening with the pathogens that cause disease in crops and in commercial animals. Without reserves of genetic variability we may not be able to develop varieties of our agricultural crops and animals that can resist these new disease varieties. Indeed, it is precisely genetic variability in the pathogens that allows them to develop resistance. Genetic variability means that some of the disease-causing pathogens are naturally relatively unaffected by our defenses against them, which may be in the form of weedkillers, insecticides or vaccinations for livestock. These more resistant specimens are the ones that survive and from which new subsequent generations are bred. So pathogens use against us just the mechanisms that we would use against them if we preserve and use genetic diversity. Without this diversity, we have disarmed unilaterally in the war against our most threatening enemies.

There is another important role for the insurance provided by biodiversity. This is to provide variability that could be critical in responding to the environmental changes wrought by humans. Human activity is changing the climate and the sea level, and is making many more local changes in the environment. A hotter climate may require different crop varieties. A rise in sea level may lead to increased salinity in ground water, and so to a need for crop varieties that are salt-tolerant. A good example of the value of diversity in the context of a changed environment is the evolution of plants that have grown on mine wastes in the United Kingdom. These wastes are rich in heavy metals, and are poisonous to most plant species (Antonovics and Bradshaw). The existence of a pool of genetic diversity allows us to find plants that could tolerate these poisons and even help to remove them from the soil. We are making changes to the global environment on an unprecedented scale, and biodiversity might be critical in allowing us to respond to the consequences of these changes. Population growth and environmental change mean that we now need the insurance provided by biodiversity more than ever before.

Biodiversity and Genetic Knowledge

The third reason I gave above for the importance of biodiversity is that it is a source of knowledge. We can learn from natural organisms how to make chemicals that have important and valuable properties. A good example is provided by the polymerase chain reaction (PCR). This reaction is central to culturing DNA specimens for analysis – as in forensic tests used in trials such as the O.J. Simpson trial, and in many processes central to the biotechnology industry. Culturing requires an enzyme that is resistant to high temperatures. Enzymes with the right degree of temperature resistance were found in hot springs in Yellowstone National Park, and the heat resistance of these was then used to create an enzyme that could be used to culture DNA specimens. This enzyme is now central to the rapidly growing biotechnology industry. There are many more less complex examples. In fact 37% by value of the pharmaceuticals sold in the United States are or were originally derived from plants or other living organisms.[3] Asprin comes from the bark of willow trees. The bark of Yew trees has been used to derive a drug that is effective against ovarian cancer.[4] A derivative of the Rosy Periwinkle flower is being used to cure childhood leukemia. The key point is that certain plants and animals are known to produce substances that are highly active pharmacologically. Plants that live in insect-infested areas produce substances that are poisonous to insects, and these have been used as the basis for insecticides. Some snakes produce venom that paralyses parts of the nervous system, and others produce venom that reduces blood pressure. Other insects produce anti-coagulants. All of these have been adapted for medical use. There is little that is new in these observations: they for the basis for many traditional medicines, which rely heavily on plants. Shakespeare refers to this in Romeo and Juliet (II:iii):

> O! mickle is the powerful grace that lies
> In herbs, plants, stones and their true qualities:
> For nought so vile that on earth doth live
> But to the earth some special good doth give,
> Within the infant rind of this weak flower
> Poison hath its residence and medicine power.

Biodiversity and Ecosystem Services

I have mentioned the role of genetic diversity in providing raw material for selective breeding, the traditional way of developing new crop or animal varieties that are more productive, more disease resistant, hardier, or more desirable in some other way. I have also mentioned its role in ensuring the productivity of ecosystems, and in insuring their robustness against diseases and pathogens. There are other more complex ways in which biodiversity is essential to the proper functioning of ecosystems and to the delivery of the ecosystem services upon which human beings are so dependent.

There are cases in which the full diversity of organisms in an ecosystem is required for that system to function and to provide services to human societies, and the removal or addition of even a single type of organism can have extraordinarily far-reaching consequences. “Keystone species” provide a convincing illustration. Ecologists use the term “keystone species” to describe a species whose removal will cause an entire ecosystem to change substantially. A widely cited example is that of sea otters on the California coast. The removal of sea otters by hunting them for their pelts led to far-reaching and undesirable changes in the California coastal ecosystems. Sea otters eat sea urchins, which in turn graze on kelp plants. Without control of the urchin population by otters, the urchins will destroy the kelp beds, completely changing the marine coastal environment. Removal of otters led to a greatly impoverished coastal environment, which was restored in part to its original state with a ban on otter hunting. Another example of the role and impact of a keystone species is provided by the removal of kangaroo rats from an area of the Chihuahuan desert, which led to a threefold increase in the yields of grasses and to far-reaching

[3] BK Carte.

[4] See Stierle, et al. .

changes in the desert ecosystem. In this case the rats had played a key role through eating seeds and disturbing the soil, and their removal consequently changed the plant balance.[5]

Not only can the removal of a species led to big changes in an ecosystem: the introduction of a new species (a so-called exotic species) can also lead to a profound transformation of the system. A dramatic example is the introduction of the rinderpest virus into East Africa in 1890. This initially attacked domestic and wild cattle, and then spread. By 1892, 95% of the wildebeest in the Serengeti region had died, together with most of the domestic cattle. Wildebeest are one of the main grazers and also the main food sources for carnivorous predators (lions, leopards, hyenas) in the Serengeti, so that their virtual elimination led to profound changes in the system. In the 1930s the introduction of a vaccination against rinderpest reestablished the original system. (Aber and Melillo) The point of these examples is that we cannot easily tell a priori what species are essential and what are not. There is often a risk that an apparently small change in a set of species will have effects far beyond those initially anticipated. The degree of interdependence between different species is great, so that human beings may depend on many more species than we would expect from a first analysis of the situation. There is a nice quotation from Abelard (an eleventh century French theologian) that suggests that any organism has a role to play and a reason for existing: "Whatever is generated is generated by some necessary cause, for nothing comes into being except there be some due cause for it." (Cited in National Research Council) I am also reminded of the words of John Donne, an English metaphysical poet of the seventeenth century, who wrote that

> "No man is an island, entire of itself; every man is a piece of the continent, a part of the maine; if a clod be washed away by the sea, Europe is the less, as well as if a promontory were, as well as if a manor of thy friends or thine own were; Any man's death diminishes me, because I am involved in mankind; And therefore never send to know for whom the bell tolls: It tolls for thee."[6]

There is an ecological equivalent to this: no species is an island, entire of itself, not even Homo Sapiens. Any species' extinction may diminish us, because we depend on many species. To repeat: the loss of even apparently unimportant species can have immensely costly consequences because of the complex patterns of interdependence between species. In the end the loss of an apparently small and unimportant group of species could threaten the provision of ecosystem services that are essential to humanity. The distinguished biologist E.O. Wilson once said of microbes that "We need them but they don't need us." This is why many scientists see a serious risk in the current rate of species extinction: they cannot be precise about the dangers involved but nonetheless believe that there is a real risk of costly consequences. To give this point some substance, let me mention a possible relationship between the extinction of passenger pigeons and the introduction of Lyme disease into American society. When Europeans first arrived in the United States, the passenger pigeon was probably the most abundant bird in the country. Its population was estimated in billions. It traveled around in flocks of hundreds of thousands, flocks so big that their passing darkened the sky for many minutes at a time. By 1914 they were extinct, annihilated by a combination of hunting and destruction of the habitat that they needed for survival. It seemed unbelievable that an animal so abundant could be reduced to extinction so

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[5] See Power M.E., D. Tilman, J.A. Estes, B.A. Menge, W.J. Bond, L.S. Mills, G.C. Daily, J.C. Castilla, J. Lubchenco, R.T. Paine.

[6] Cited in Ernest Hemmingway, "For Whom the Bell Tolls."

fast. A possible connection between this extinction and the emergence of Lyme disease events has recently been proposed. A letter to Science in 1998 made the following suggestion.

> There is another possible twist to the complicated ecological chain of events presented by Clive G. Jones et al. (Reports, 13 Feb., p. 1023) whereby the incidence of Lyme disease might increase following population increases of mice allowed by a big mast year of acorns. A major competitor of deer and mice for these bumper crops has been absent from the eastern deciduous forests for a century. The extinct passenger pigeon (*Ectopistes migratorius*) was a nomadic wanderer that specialized on a diet of the superabundant, but unpredictable, crops of mast. With a population estimated at 2 to 5 billion, concentrated in enormous flocks, passenger pigeons congregated wherever there were huge crops of mast. The birds were so efficient at denuding the woods of nuts that many observers noted that native wildlife and feral hogs could not find sufficient food after a pigeon flock had passed through. Is it possible that, in the presence of passenger pigeons, the population explosions of mice in mast years, reported by Jones et al., would have been less likely. Could the outbreaks of Lyme disease in the late 20th century have been a delayed consequence of the extinction of the passenger pigeon? [7]

The point here is that passenger pigeons ate acorns and beechnuts, both of which were abundant in the forests of the North East of the United States. The demise of the pigeons led to an increase in the food available for other animals that ate these, including mice. Mice are the main breeding ground and hosts of the parasites that cause Lyme disease, and it is reasonable that the explosion of food for mice led to a jump in their population and thus in the population of Lyme disease vectors. (Abundant acorn crops always lead to increases in the population of mice.) The disease vectors transfer from mice to deer, which browse in the same forests and on the same foods, and then move across territory likely to be used by humans, grazing on grass on lawns and fields. So the extinction of passenger pigeons could have been instrumental in causing the spread of Lyme disease to humans. This illustrates well the extraordinary complexity of the web of life, of the connections between different species, and between species and human welfare. No one could reasonably have anticipated this connection between passenger pigeons and Lyme disease. No analysis of the consequences of the loss of this bird could have anticipated such an outcome. Indeed, the bird was so abundant that it must have been difficult to anticipate that human activity could drive it extinct.

The message of these examples is that it is hard to foresee the consequences of a change in the biodiversity of an ecosystem. Even an apparently small change can lead to dramatic alterations in the system's ability to function and to provide the services on which human beings are dependent. There is another aspect of this phenomenon. A particular role in an ecosystem may be played at different times or under different circumstances by quite different plants or animals. The type of tree that stabilizes soil on a north-facing slope at a certain latitude may not grow on a south-facing slope at that latitude, so that a different species is needed there to maintain the physical stability of the system. As a consequence the set of species required for a certain type of ecosystem to function may vary greatly from region to region. In fact, we know of no single subset of species that on their own would serve to operate all ecosystems and provide all ecosystem services in all regions of the planet. So diversity in a given location may increase productivity and ecosystem functions in that location, while diversity at the regional or global

[7] See Blockstein D. I am grateful to Paul Ehrlich for this reference.

level is actually necessary for the operation of important ecosystems in all geographic regions. While individual species may possibly be redundant in some locations, it is possible that at the global scale few if any are really redundant. (For more on the role of biodiversity in maintaining the supply of ecosystem services, see the entry by G.C. Daily and S. Dasgupta.) A clear statement on this is given by Chapin et al.:

> "the abundance of species with similar ecological effects should give stability (resistance and resilience) to ecosystems in the face of increasingly rapid human-induced environmental change. Loss of a keystone species or of all species in a major functional group will, by definition, have large ecosystem effects. Efforts to identify and protect such species and groups often yield demonstrable near-term benefits. Of increasing concern is the loss of species that have similar ecosystem effects but differ in their environmental responses. Loss of such species may reduce ecosystem resilience and the capacity to adjust to ever-increasing rates of environmental change. This latter role of diversity is not adequately represented in current international conventions, but it may be one of the most important mechanisms by which we sustain the long-term functioning of ecosystems and the services they provide to society."

Biodiversity and Markets

To return to the economic questions, to what extent can we hope to commercialize these contributions of biodiversity? Obviously they are economically important, but can the market capture them? Can the economic contributions of biodiversity be used to generate incomes to the owners of biodiversity that will provide them with incentives to conserve it? Can they make conserving tropical forests more attractive than clearing them? This is a critical question: forest owners do not conserve forest because they are important to humanity: they conserve them, if they do, because they can profit from so doing. So we need to know whether the important services provided by biodiversity can be the basis for profits from forest conservation or for conservation of sources of biodiversity more generally. In this context, I look again at the categories under which I classified the contributions of biodiversity:

- increasing productivity,
- providing insurance
- providing knowledge
- maintaining ecosystem services.

One of the most fundamental insights into the operation of a competitive market economy is that under certain conditions it will align individual and social interests and provide incentives that lead to an efficient outcome. In the famous words of Adam Smith in his *An Enquiry into the Nature and Causes of the Wealth of Nations,*

> "Every individual .. neither intends to promote the public interest, nor knows how much he is promoting it. He intends only his own security, his own gain. And he is in this led by an invisible hand to promote an end which was no part of his intention. By pursuing his own interest he frequently promotes that of society more effectively than when he really intends to promote it." (Smith 1977)

This is a beautiful metaphor: market forces are an invisible hand, steering us to act in the interests of society as a whole when in fact we only seek to promote our own interests. More recently this insight was formalized and made more precise via some important propositions from economic theory. These include what is called the First Theorem of Welfare Economics. These propositions state that:

> If all goods are private goods [i.e. there are no public goods] and the private and social costs of all activities are equal, then a competitive market economy is Pareto efficient, i.e. operates so as to leave unexploited no possibilities for mutual gain.

This is a remarkable result and provides the basis for economists' belief in the efficacy of market systems and the desirability of market-based approaches to economic organization. However, in the context of biodiversity the restriction that all goods be private is critical.

What is the public-private good distinction? A public good in one that has two properties: my consumption does not interfere with yours, and the provider cannot prevent non-payers from benefiting from the good. Such goods are said to be non-rival and non-excludable, in contrast with private goods, which are both rival and excludable. A seat at the opera is a private good: if I sit in it you cannot, and the management can certainly exclude non-payers from seeing the performance. Law and order, in contrast, is a public good: it benefits everyone in the region in which it is enforced and the benefits cannot be restricted to those who have contributed to its costs.

Markets are not good at providing public goods: their non-excludability makes it difficult for the provider to earn a good return on the costs of providing them. Knowledge is an interesting and relevant example: it is naturally a public good as it can be passed costlessly from one person to another and enjoyed by all of them, even though none of them, or perhaps only the first, paid for it. Hence the existence of intellectual property rights, instituted as a means of ensuring some return on the generation of knowledge. Because of the difficulty in appropriating the returns on their provision, markets tend to under provide public goods relative to an economist's concept what is efficient for society. Consequently they have traditionally been provided by the public sector, which is where their name comes from. Some of the services provided by biodiversity are public goods, although biodiversity does not fit the traditional mold for public goods completely. The extent of biodiversity is not something that can be determined by the public sector, because it is the result of literally billions of land-use choices all around the world. It is also strongly influenced by issues such as climate change, which are again driven by billions of heating and transportation choices. In fact biodiversity is what has been called a privately produced public good. For the remainder of our argument, the key point is that the First Theorem fails in the context of public goods, and indeed it has long been recognized that markets will under-provide public goods relative to the level that would be required for efficiency.

One further basic economic point is needed, a familiarity with the diamond-water paradox and the limitations of market prices as indicators of "importance" to society. Discussion of this paradox helps us to be clear that the price of a good does not reflect its importance in any overall social or philosophical sense. Very unimportant goods can be valued more highly by the market than – have higher prices than – very important goods. The classic illustration of this is the diamonds and water paradox, which perplexed economists through the eighteenth and nineteenth centuries until its resolution by Alfred Marshall. The point here is that water is clearly more important to human society than diamonds, yet diamonds trade in the market at prices far in excess of those fetched by water. Why? Marshall's answer was simple and is by now part of common knowledge: price is set by supply and demand. The market price is the price at which the amount supplied is also the amount demanded. In the case of water, the supply (at least in Marshall's time) was so large as to exceed the amount that could possibly be demanded at any price. Consequently the price was zero: water was free. Now, of course, the demand for water has increased greatly from population growth and rising prosperity, while the supply has remained roughly constant, so that water is no longer free. For diamonds, being naturally scarce, the desire for ownership always exceeded that which could be accommodated naturally. The market price was high as a result of competition between rich people for the few diamonds available.

What are the implications for biodiversity? Simply that even if it is of great importance to society, and is not a public good, it will not necessarily be possible to convert this importance into value in the market place. The balance of supply and demand has will be critical here, as we shall see in the context of the commercialization of the genetic knowledge inherent in biodiversity.

Productivity

To the extent that diversity increases productivity in agricultural systems, we would expect that farmers would be willing to pay for it. Arable farmers achieve some of the benefits of diversity by crop rotation, i.e. rotating between a series of different crops in successive years. The different crop types make different demands on the soil and contribute different nutrients to it. However the range of crops used for this purpose is quite limited and does not contribute in any substantial way to the conservation of biodiversity. The other mechanism through which diversity contributes to productivity in agriculture is via its contribution to the breeding of new plant species that are better adapted to emerging conditions or more resistant to new diseases. At this point the productivity and knowledge roles of biodiversity merge, and I will comment on the possibility of commercializing the knowledge role below. These comments on biodiversity's contribution to knowledge will also apply to the contribution that biodiversity makes to human societies via the breeding of new varieties.

There appears to be some appreciation of the benefits of diversity in tropical agriculture, where there is a tendency to grow several crops together, or to grow crops in a way that conserves the original forest. Traditionally coffee was grown as an understory plant beneath high tropical forest trees: this benefits the coffee, which is a shade-tolerant plant, takes full advantage of the light available in the region, and avoids the need to destroy the main forest trees to make land available for coffee growing. This practice also allowed other commercial crops to be grown with the coffee, such as citrus fruits and avocados, thus allowing farmers to diversify their risks. In cases such as this there is a contribution to the preservation of diversity because of the conservation of the forest. Studies have shown that forests converted for production of shade-grown coffee retain a very large proportion of their original biodiversity, and that growing in this way is less expensive per pound produced than plantation growing. This cost difference reflects in part the greater productivity of diverse ecosystems and the more effective cycling of nutrients in these plant communities. (The total yield of coffee per hectare is however less.)[8] In this case it seems that there can be some conditions under which the productivity enhancements of diverse systems can be realized commercially, with attendant benefits for biodiversity conservation.

Insurance

Insurance is clearly something for which there is a demand. Most of us insure our homes, our cars, and carry health insurance. So perhaps the insurance role of biodiversity is one for which people will pay? The difficulty here is that until recently this insurance has been provided as a public good, indeed as a global public good. Consider in the light of the public-private good distinction the conservation of rice varieties by the IRRI mentioned above and in particular the use of one of these to provide a defense against the grassy stunt virus. In cases such as this, the insurance was provided as a public good. It was available to all for the cost of buying the new variety of rice incorporating resistance to the grassy stunt virus. You did not have to pay an insurance premium to benefit from the insurance. The developers of the new variety could not exclude from using it those who did not contribute to its development by paying insurance premiums.

At this point I again need a brief digression into economics. Risk, such as the risk of the destruction of a part of a crop, is managed in a market system by what we call contingent contracts. A contingent contract is a contract that pays a specified amount if and only if a specified contingency occurs. Buying the contract reduces the risk to you associated with the specified event. If it occurs and has negative consequences, then you are to some degree compensated by the payment made to you under the contract. An insurance contract is a classic example of a contingent contract: you buy it by paying a premium and it entitles you to a payment if and only if a specified event – the insured peril – occurs. It is crucial for the efficient management of risks that the payment for a contingent contract should not be contingent. You pay the insurance premium whether you use the insurance or not: the only uncertainty or contingency is whether you can make a claim under the policy.

It follows from this that the problem of the public good nature of the insurance provided by the existence of new varieties could not be overcome by charging premium prices for them. This price would only be paid after the product had been developed and needed. If the new variety were never needed, then this price premium would never be paid. No contingent contract is being sold in this framework.

There is a possibility that the public good nature of the insurance will change. Public goods can become private goods, through either institutional or technical change. A good example is television broadcasting. Until about ten years ago this was a public good par excellence: a broadcaster could not exclude from viewing a program anyone in the reception area, so that the non-excludability property of public goods held, and of course there is no rivalry in consumption. My viewing a TV broadcast in no way interferes with yours. The development of scramblers changed this. A TV broadcast can now be scrambled so that it can only be viewed by those who have purchased a descrambler. Broadcasters can now exclude those who have not paid from viewing their programs, which are therefore no longer public goods. A public good has been privatized.

[8] See Perfecto I., RA Rice, R Greenberg, ME van der Voort.

Developments in the area of intellectual property rights for agricultural biotechnology could change the situation in a similar way for the insurance value of biodiversity. These may lead to the privatization of a hitherto public good. Crop developers are increasingly patenting genes developed to enhance the properties of crops, including such properties as their taste, productivity and insect resistance. Most agricultural biotechnology companies have a large and growing portfolio of patents on genes and on genetically modified plant varieties. They are also aggressively defending these patents, to the extent of developing and introducing "terminator genes" that will ensure that the properties conveyed by patented genes will not be transferred to offspring of the plant. Consequently users cannot breed from seed that they have bought but must go back to the supplier and purchase more. It is possible that plant breeders with such a tight hold on their intellectual property will be able to extract from users a great enough return to justify substantial investment in biodiversity conservation. The aggressive enforcement of intellectual property rights might act here like scramblers did with TV broadcasts, effectively privatizing a previously public good. Were it to happen, this would increase substantially the incentives for biodiversity conservation, but possibly at the cost of restricting access to the latest agricultural technology to those with the ability to pay a premium.

There is already a good illustration of the possible side effects of privatization of genetic knowledge. The bacteria *Baccilus thuringiensis* (*Bt*) produces a toxin that kills many crop pests and is itself biodegradable. For this reason organic farmers use it as a pesticide: being biodegradable it leaves no dangerous residues on the crops on which it is used. Monsanto and Novartis recently incorporated genes from *Bt* into transgenic crops. The presence of these genes in the plants means that the plant itself benefits from the defense provided by the *Bt* bacteria, which is the production of proteins that are toxic to the main pests of cotton and corn. Because the *Bt* genetic defense against pesticides is now being used widely, it is possible that pests will develop resistance to it. Resistance develops faster, the more widely a defense is used. So within a few years we may have generations of crop pests that are immune to this way of defending crops, i.e., immune to the *Bt* toxin. Monsanto and Novartis will seek to develop variants on the *Bt* genes, and with their scientific and financial resources may succeed. If so, they will sell a new generation of transgenic plants with defenses against the new generation of pests. However, these will be their proprietary products, covered by their patents. Because of the development of resistance to the *Bt* toxin, organic farmers will no longer be able to use *Bt* as a harmless pesticide. They will be forced to buy proprietary defenses against pests. This is a clear illustration of the two factors mentioned above: development of intellectual property rights in genetic knowledge leading to both stronger incentives to conserve and to develop further, and also leading to a restriction of access. In the case of transgenic crops including the *Bt* defenses, Monsanto recently announced that all growers of *Bt* corn will be required to grow plots of non-engineered corn that are at least 20% of the size of the engineered crops. The aim here is to provide sufficient non-engineered corn that the development of resistant pests will be delayed or possibly even prevented. (Nature 1999)

Knowledge

Next we turn to the role of biodiversity as a source of knowledge. There are two different areas of application here: the development of medical products by the pharmaceutical industry, and the development of new or better crops by the agricultural biotechnology industry.

In applications of biodiversity to the development of pharmaceuticals there has already been some progress towards commercialization. Recognition of the likelihood that tropical plants contain chemicals that could be forerunners of pharmaceuticals has led most major drug companies to pursue bioprospecting as a way of finding new pharmacologically active substances to serve as a basis for drug development. Typically they have sought these compounds in the tropics, in areas where there is extensive inter-species competition, or in other extreme areas. They have been willing to pay quite substantial sums for access to these regions, and have made deals with host countries that involve giving them a royalty on the products that might eventually be based on this prospecting. Such royalties could be large relative to the incomes of the countries concerned. Merck Inc., one of the largest pharmaceutical companies in the US, has an agreement with a Costa Rican agency called InBio (Institute Nacional de La Biodiversidad) for bioprospecting rights in Costa Rica. The terms of the agreement are that Merck paid InBio a fixed sum, $1.35 million, to be used for forest conservation, in exchange for the right to receive samples collected by InBio and to use these as the basis for new product development. Should any of them prove commercially successful, Merck will pay InBio a royalty on the revenues generated. Similar agreements are in place between other US pharmaceutical companies and regions of Central and South America.

The discovery of the PCR enzyme and the agreement between Merck and InBio and several other drug discoveries based on plants from developing countries led to a wave of optimism, some perhaps excessive, about the potential commercial value of in situ biodiversity in developing countries. What in fact is the commercial potential here? There is no question that pharmaceutical and agricultural products of great human and commercial value have been and will in future be developed from the biodiversity in tropical countries. The key question is how much of this will be returned as a reward for the conservation of the originating biodiversity. In answering this question, we have to take note of several points.

The first point takes us back to the discussion of the diamond-water paradox above: not everything that is important will have value in the market place, because there is nothing associated with being important that rules out the possibility that the supply may exceed the demand. Some commentators have seen this as a critical issue in the market for biodiversity-based genetic information. There are literally millions of organisms in the world that might provide genetic information, and if we do not know which will provide valuable information and which not, then the supply of potential genetic leads is huge, possibly greater than pharmaceutical companies can process. In such a situation the market price for such leads would be close to zero. However, recent calculations have suggested that in a small number of the world's biodiversity hotspots, bioprospecting rights may be worth as much as $9000 per hectare. This is small in relation to the amount that might ultimately be derived from drug sales, but still large relative to other uses of the land. In fact it is about a century of ranching income.[9] The key insight in these calculations is that prior knowledge of the nature of the ecosystems in a location can improve estimates of the probability of finding commercially interesting compounds there, and can suggest where search would be profitable and where success is unlikely. In this case not all organisms or all leads are equivalent: some have much greater chances of success than others. Prior scientific information can change the odds of success from one in ten thousand to something an order of magnitude better. In practical terms this means that developing countries can clarify the commercial attractions of their biodiversity by research on the ecosystems of which it is a part. This is rather like a country with potential oil reserves engaging in basic geological prospecting before seeking to negotiate leases for oil development. The results may

[9] See G.C. Rausser and A.A. Small.

be positive or negative, but either way they will give it a better view of its prospects. In those cases in which the research is positive, the impact on the value of prospecting rights could be large.

Another important point is that an immense amount of human skill and expertise is needed to go from a plant specimen to a commercial drug. Typically there will be a minimum of ten or more years of work by hundreds of skilled people working with millions of dollars of sophisticated equipment. And unfortunately very few plant extracts actually produce drug leads, i.e., contain pharmacologically active compounds with no obvious ill effects, probably less than one in ten thousand. And of these few, very few become commercial drugs, again less than one in one hundred. On average perhaps one in 250,000 samples collected leads to a commercial drug. (Nature 1998)

The picture that emerges, then, is that the chance of any individual bioprospecting operation leading to a commercially valuable drug is very small indeed. And even if it does produce a drug, tens or even hundreds of millions of dollars will have to be invested, with significant chances of failure right to the end. Developments in biotechnology are currently altering this picture. They are reducing the time needed for testing and development, and giving greater insights into the kinds of chemicals likely to be successful. By reducing the costs of drug development based on bioprospecting, they are making bioprospecting more attractive. To give some precision to this effect, the cost of screening 10,000 samples for pharmaceutical potential ten years ago would have been $6 million: today it is $150,000 (Reid et al.). At the same time, advances in knowledge are also making more effective alternative methods of drug development, based on understanding of the cellular and genetic mechanisms of disease. In total, the picture that emerges here is one of heavily guarded optimism. Bioprospecting does have economic value, and technological developments may be increasing that value. However, in the short term we cannot expect great sums of money to flow to the conservation of biological diversity because of bioprospecting possibilities.

There is a further problem to be overcome in establishing an income flow from bioprospecting, a problem in intellectual property rights. The same plant may occur in several different regions, and the same or similar chemicals may occur in different plants. So the same or similar drugs may be derived by different routes from different plants or different geographic regions. Research towards a commercial product has to be well under way before it is patentable, so that there is always a risk of being blocked by a prior patent.

There is also a risk, as far as the conservation of biodiversity is concerned, that biodiversity is valuable but leads to no direct commercial application. A recent article on the value of marine bioprospecting put this point very clearly:

> "Although many of these products are not likely to become therapeutics, the information gained from studying them is likely to lead to the development and understanding of novel molecular targets, which may in turn lead to the development of new therapeutic agents".[10]

This is a classic statement of the importance of basic knowledge. Basic knowledge is a public good: its importance is great but it is not patentable and not something that can be appropriated by a typical bioprospecting contract with an element of royalty payment or revenue sharing. The

[10] From BK Carte.

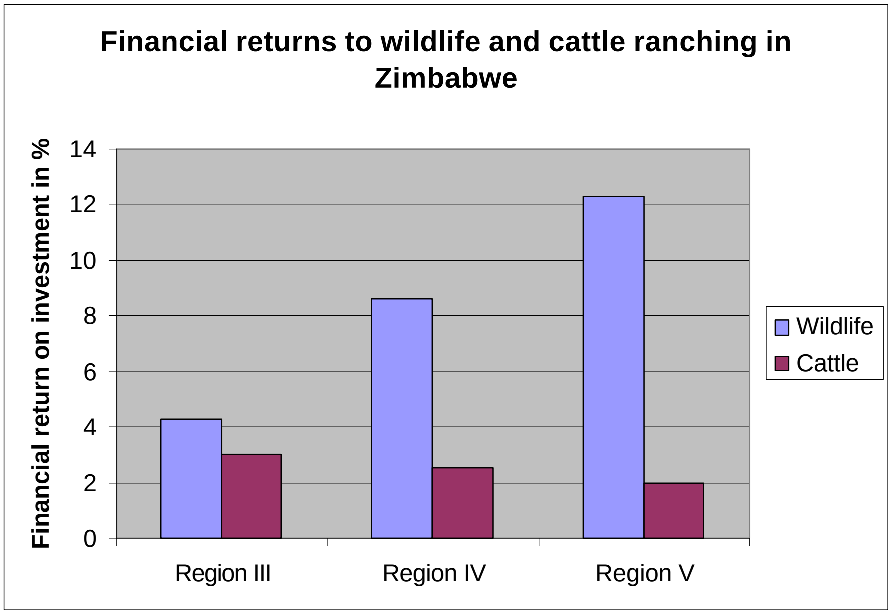
development of basic knowledge is typically publicly funded precisely because its economic benefits, while potentially immense, are hard to appropriate. We need more constructive thinking about how to realize the undoubted importance of bioprospecting in terms of income for conservation. A further illustration of this point is provided by the example of taxol mentioned earlier. Taxol is a promising anti-tumor agent in breast and ovarian cancers that can be extracted from a fungus that lives in the phloem (inner bark) of the Pacific Yew tree. Taxol was first isolated from the tree itself, but the tree is relatively rare and slow-growing, and produces little taxol, so a search for other sources was initiated.[11] Ultimately little in the way of economic returns may flow to the regions in which taxol was discovered.

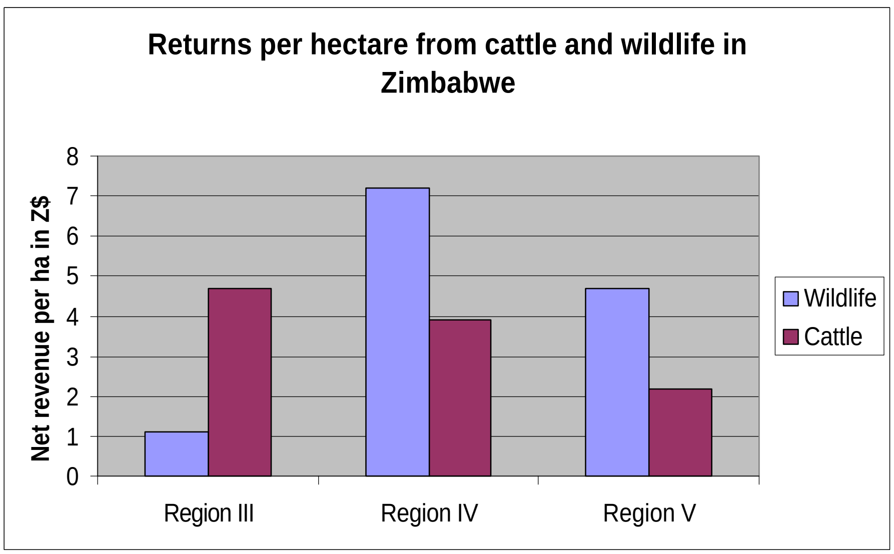
Biodiversity can also be applied to the development of new or better crops: to date this has probably been the most important application commercially of biodiversity. As I have noted several times, the existence of a pool of genetic variation provides plant and animal breeders with the raw materials for developing new varieties and more productive or resilient variants of existing varieties. The existing varieties of a commercially important crop are by now usually the property of a commercial firm or of a research facility and are protected by patents. As an example, the University of California owns the patents of many varieties of strawberries: these cover varieties that are best suited to different soil types, different weather conditions, that are least prone to spoiling during transport and storage, and so on. For most other commercial crops, the varieties are owned by seed companies, whose main asset is often the intellectual property represented by their ownership of patents to widely used varieties. In this context, the market can certainly recognize the value of biodiversity, provided that it is of the type that seems likely to contribute to the development and refinement of commercially important crops. Unusual variants of commercial crops, such as early variants of wheat or corn or soybeans, would qualify: so possibly would their near genetic relatives. But biodiversity more broadly would probably not derive a value through this process, even though genes from unrelated plants might enhance the commercial potential of existing crops.

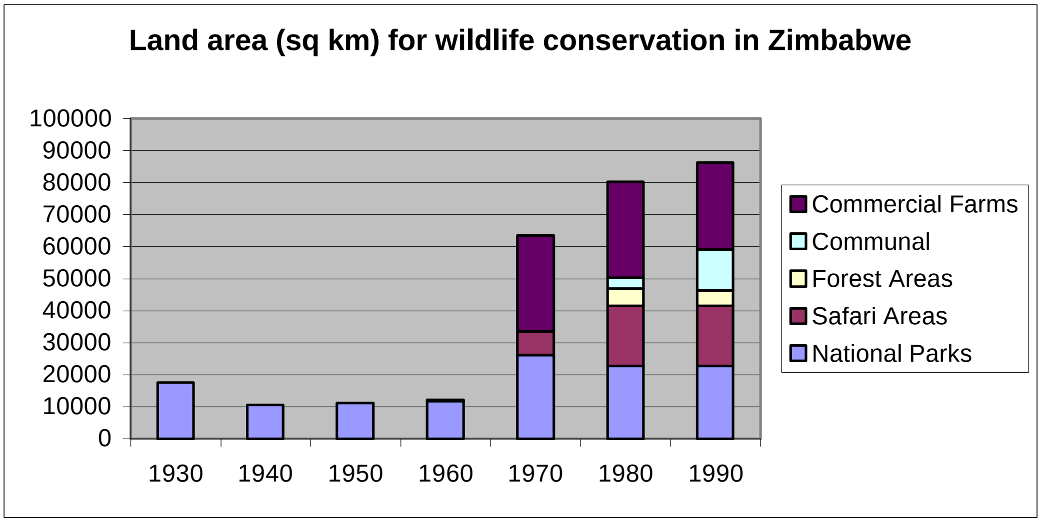
Ecosystem Services

Perhaps the most promising approach is to think of selling the services of natural ecosystems and using the revenue from this to provide incentives for conserving the biodiversity that supports them. Selling services provided by natural ecosystems can potentially provide incentives for the conservation of these systems and thus indirectly of biodiversity. For example, watersheds provide economically valuable services for which there is a market and indeed recognition of this has already led to the conservation of significant forest areas (Chichilnisky and Heal). Some commentators (Reid) have suggested that as much as fifteen percent of the earth’s land area serves as watersheds for large cities and so could legitimately be conserved on the basis of the watershed services that it supplies. Many of these watersheds are areas of considerable biological uniqueness and their conservation alone would be a major advance for the conservation of biodiversity. Their functioning as watersheds probably depends substantially on the continuation of something approaching their present levels of biodiversity.

[11] See Stierle, et al.


Financial returns to wildlife and cattle ranching in Zimbabwe
Financial return on investment in %
14
12
10
8
6
4
2
0
Region III
Region IV
Region V
Wildlife
Cattle


Returns per hectare from cattle and wildlife in Zimbabwe
Net revenue per ha in Z$
8
7
6
5
4
3
2
1
0
Region III
Region IV
Region V
Wildlife
Cattle



Ecotourism is based on the preservation of intact ecosystems and the more appealing elements of biodiversity to be found in some of these, and revenues from this are providing powerful incentives for the conservation of several important ecosystems. (Chichilnisky and Heal, Heal) In so far as ecotourism conserves tropical ecosystems, it contributes to the conservation of biodiversity. In certain regions, southern Africa in particular, ecotourism is making a major contribution to the conservation of biodiversity. In the countries of Angola, Botswana, Kenya, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe, about eighteen percent of the total land area is now devoted to the support of wildlife. This both a significant amount in total and a massive increase relative to fifteen or twenty years back (Bond, Cumming a and b, Cumming and Bond). This has lead to an increase in the populations of several previously endangered species and to more robust breeding populations of many important birds and mammals. All of this has been driven by the fact that in many parts of this region land devoted to ecotourism and sport hunting can earn a higher return than land devoted to more conventional agriculture. The tables illustrate these phenomena: they show for Zimbabwe both the growth in land whose primary use is the support of wildlife and the favorable economic returns to wildlife conservation relative to agriculture in parts of the region. (Regions III, IV and V are either arid regions or wetlands.) While the growth of ecotourism as an economically important activity has progressed furthest in southern Africa, this region is not unique in being able to generate conservation incentives by tourism. Central and South America, and parts of Asia, are now benefiting from ecotourism, which is providing significant returns to the conservation of certain endangered species in these regions (Heal, Freese, Honey).

Finally, there is a real prospect of commercializing some of the carbon sequestration services of forests under the terms of the Kyoto Protocol, which provides for compensation for some carbon sequestration activities via its provisions for joint implementation and through its clean development mechanism. I have estimated elsewhere (Heal) that this could generate an income as high as $50-$100 pre hectare per year, quite high enough to change radically the incentives for forest conservation and hence biodiversity conservation.

There are also other economic mechanisms through which the gods and services provided by tropical forests and their associated diversity might be marketed, though it is not clear how general they are. One is the sale of what are called “non timber forest products.” These are commercially valuable forest products that are not produced by tree cutting. They are therefore not timber and their harvest and sale is compatible with conservation of the forest. They include various tropical fruits, vines that can be used as ropes, rattan (which grows amongst the trees), resins such as latex, and plants used as medicine by local populations. This last use is important: about four billion people have no access to Western-style medicine and depend for treatment in times of sickness on plant extracts, known as ayurvedic medicine. This is a market that is important in human terms: the amounts of money involved are small by comparison with those in Western medicine but could still be enough to provide a significant incentive. Recent estimates suggest that in some tropical forests the collection and sale of non-timber forest products could yield as much as $60 to $140 per hectare per year, although many other studies have suggested significantly lower numbers. (Grimes et al, Houghton and Mendelsohn, Peters Gentry and Mendelsohn). These are significant numbers. Given that they are sustainable, i.e., can be earned year after year, they are probably sufficient to justify conservation of forests even in the face of pressure for logging. However, at the moment we have a limited number of studies of this form of forest use, so that it is not clear how general are these numbers not whether the implied levels of harvesting are truly sustainable.

These different mechanisms for generating income from natural ecosystems and the biodiversity that powers them are not mutually exclusive: the same land area could earn income by all mechanisms. A forest could obtain returns from carbon sequestration, bioprospecting, non-timber products, managing a watershed and ecotourism. In fact, the region of the Mata Atlantica (Brazilian coastal rainforest) inland from Rio de Janeiro is in a position to do exactly this. It manages the watershed for Rio in much the way that the Catskills region does for New York. It also manages the streamflow of the river Rio Paraibo do Sul, which provides most of the electric power for Rio via hydropower. These two services make it truly a major utility for Rio, with great economic value. Additionally it supports a wide range of endemic species, sequesters carbon and acts as a magnet for tourists. Currently the region obtains a financial return only on one of these activities, ecotourism. In a case such as this, it is clear that the economic incentives for conservation could be immense, if we were only to do effectively what we already know how to do.[12]

Conclusions

What can we conclude about biodiversity, its economic importance and the prospects for generating income based on this? Clearly its importance is great, in the sense that it has been and remains a key contributor to human well being. We understand enough of this contribution for its magnitude to be clear, although there are probably many aspects that are still invisible to us. Economically, a key questions is: Can this importance be reflected in a commensurate income yielded by the conservation and use of biodiversity and of goods and services based on it?

In essence much of what biodiversity contributes is, or has traditionally been, a public good. Its contribution to the functioning of natural ecosystems is non-excludable and non-rival, as is its

[12] All of these measures are consistent with the United Nations Convention on Biological Diversity, to which many nations (though not at the time if writing the United States) have subscribed. This states in article 11 that “Each Contracting Party shall, as far as possible and appropriate, adopt economically sound measures that act as incentives for the conservation and sustainable use of biological diversity.”

insurance value. And knowledge is the quintessential public good. In spite of the overwhelming publicness of much that biodiversity offers us, there is some prospect of commercializing a limited part. Some of the services provided by natural ecosystems can be privatized and sold, generating a return to the conservation of the biodiversity that supports them. In the case of knowledge, the prospect of commercialization rests on the ability to establish intellectual property rights that will effectively privatize some of the public good aspects of its insurance and knowledge functions. Probably the most fundamental of these functions, like basic scientific research and development, will never be privatized and will thrive only with financial support via other mechanisms.

In summary, biodiversity is important economically. There are some market-based approaches to obtaining returns from biodiversity that can provide incentives for its conservation. If fully implemented they would have a profound and positive impact. But they would not solve the problem of biodiversity conservation. They would need to be supplemented by non-market measures such as the Endangered Species Act, the Convention on International Trade in Endangered Species, the Marine Mammals Protection Act, the Fishery Conservation and Management Act, and others. I am not suggesting that these are good examples of non-market policies: indeed in several cases they are not. The point is that they illustrate the type of option that we have as an alternative to the market. Of course, except for CITES, the measures listed are all domestic US measures. To be really effective, we would need global equivalents – a Global Endangered Species Act, for example. Given the political complexity of the domestic ESA, this prospect should illustrate clearly the desirability of market-based policies whenever possible.

It is important to note that even regulatory approaches such as the Endangered Species Act can give rise to market-based incentives if coupled with provisions for measures such as mitigation banking. In the case of the ESA, several states have modified this in a way that has proven highly effective and has introduced economic incentives where none existed in the initial formulation of the act. A good illustration is an agreement reached between the International Paper Corporation and the United States Fish and Wildlife Service concerning the red cockaded woodpecker. This bird is endangered and nests in forests owned by International Paper. The US Fish and Wildlife Service and International Paper reached the following arrangement. A target number of breeding woodpecker pairs has been agreed, and provided that this number is attained or exceeded then International Paper will be regarded as complying with the ESA, whatever modifications it might make in the habitat under its control. Further, the agreement also provided that any surplus of breeding pairs over this number could be "banked." This means that it could be used by the company to offset ESA requirements with respect to red cockaded woodpeckers elsewhere, or title to the surplus could be sold to other landowners and used by them to gain some measure of exemption (Jorling, and for a general discussion of the ESA see Noss O'Connell and Murphy). The important point here is that the costs of compliance with the ESA have been reduced by this agreement, without reducing its effectiveness. Indeed, the benefits go beyond this: as the production of nesting pairs over a target level is saleable, International Paper now actually has an economic incentive to encourage the endangered species, something they never had with a strict interpretation of the ESA. Recent press reports suggest that International Paper has been able to sell banked breeding pairs for as much as $200,000 per pair (personal communication, W. Coleman). Similar mitigation banking systems have been put in place for wetlands, which have to be conserved under the Clean Water Act and which also provide important habitat for endangered or threatened species.

In the case of the red cockaded woodpecker, and the case of wetlands, regulation has produced a market. The market arises as a result of moves to meet the regulations at minimum costs and has the positive effect of providing stronger incentives than the original regulation for the conservation of the endangered species or habitat. In principle we do not need to go through the process of regulation to set up a market. The most obvious move from an economic perspective is instead to create a market where this seems needed by using the state as a buyer. In other words, in the case of the red cockaded woodpecker, the government could just pay landowners on whose land the woodpeckers breed. This immediately establishes an incentive for conservation without the political and other costs of regulation. Systems of this type are currently being used on a trial basis in parts of the United Kingdom. In regions where hill farming is economically marginal, and has been subsidized by the European Community's Common Agricultural Policy, the farming subsidies have been replaced by subsidies for preserving the ecological integrity of the countryside.[13] Specifically, farmers are paid to grow and maintain hedgerows, ponds, wetlands, wildflowers and coppices that provide habitat for birds and mammals. The Financial Times, the European equivalent of the Wall Street Journal, recently commented in an editorial that in many cases it would make more economic sense to pay farmers to provide "ecological sustenance" rather than to grow food that is clearly surplus to the region's needs and cannot compete on world markets.[14] This solution is less attractive than establishing a market where consumers buy directly, as in the cases of ecotourism or watersheds, because the money spent by the government has to be raised as tax revenue from individuals or corporations. This can produce a loss of economic efficiency elsewhere in the economy. However, if the services provided by biodiversity are public goods, then there may be little alternative to having the public sector act as a buyer on behalf of society as a whole.

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