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**EPOC HIGH-LEVEL SPECIAL SESSION ON THE COSTS OF INACTION**

**THE COSTS OF INACTION WITH RESPECT TO BIODIVERSITY LOSS: BACKGROUND PAPER  
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**English - Or. English**

## The Costs of Inaction with Respect to Biodiversity Loss<sup>1</sup>

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### Summary

1. Biodiversity is required for the functioning of many ecosystems and biogeochemical cycles that are essential to human well-being. Loss of biodiversity implies the loss of the services of these systems to the detriment of human welfare. Policy inaction increases the total loss of biodiversity and the services that are dependent on it. Although we know that biodiversity is important, we do not know exactly how important, nor the precise extent of the welfare costs imposed by its loss. This uncertainty, coupled with the irreversibility of biodiversity loss and the possibility of learning more about its value, implies a real option value to the conservation of biodiversity and a rationale for a precautionary approach. While the overall cost of biodiversity loss is unknown, some parts of this cost can be estimated, including the costs of lost bioprospecting leads, the costs of lost carbon storage, the costs of lost tourism business and the costs of diminished watershed protection. These very partial costs amount to many tens of billions of dollars.

### 1. Why Biodiversity Loss Matters

2. The welfare of human societies depends on the functioning of a range of diverse natural ecosystems, which provide critical and often irreplaceable ecosystem services. Many authors have discussed and documented this dependence (Daily 1997, Ecological Society of America 1997, Millennium Ecosystem Assessment.) Natural ecosystems are responsible for services as diverse as climate stabilization, crop pollination, soil fertility, waste disposal, water purification, flood control, pest control, recreational services, and many others.

3. Biodiversity is a critical ingredient of most natural ecosystems: while the exact nature of the relationship between biodiversity and ecosystem function is still a research topic (Grime 1997, Hooper and Vitousek 1997, McGrady-Steed 1997, Naeem and Li 1997), there is general agreement that loss of biodiversity weakens ecosystems, making them less resilient and less productive, and reduces their capacity to provide the services needed by humans. Tilman's (1997) study showed that the average amount of biomass grown per year on a plot of a given size increased with the diversity of functional groups represented. The increase leveled off after a certain point, above which more diversity adds little to the community's performance. 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 weather fluctuations. It appears from this work that both functional diversity and species diversity are important in maintaining productivity and resilience.

4. There are several different ways of measuring biodiversity (see Armsworth *et al.*, 2004 and Nunes *et al.*, 2001 for details and for comments on how the measurement of biodiversity relates to economic valuation) but the differences are not significant for the discussions in this paper. We can take biodiversity to be some measure of the total number of species, which may be a global measure or a local one. Locally the loss of biodiversity in a specific ecosystem may weaken that system and make it less productive, so that localized losses of biodiversity may lead to a loss of human welfare even if not a part of a global biodiversity loss. A global loss will certainly mean that some ecosystems are weakened and their services reduced. There is also general agreement that the current rate of loss of biodiversity is

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<sup>1</sup> The views expressed in this paper are those of the author, and do not necessarily represent the views of the OECD or its member countries.

unprecedentedly high, both for populations (i.e. locally) and for species (i.e. globally) (Hughes *et al.*, 1997). An implication of this is that biodiversity loss threatens human welfare through the reduction of the ecosystem services upon which we depend.

5. There are other mechanisms through which biodiversity loss threatens human welfare. Biodiversity has made, and indeed continues to make, a vast contribution to agricultural productivity. It is no exaggeration to say that the green revolution of the second half of the twentieth century allowed us to feed a doubled human population because of clever use of biodiversity, and with the prospect of at least four billion more sharing the Earth's bounty within decades there is clearly a need for continued use of biodiversity in this way. Plant breeders find use for genetic diversity within a species by developing varieties resistant to disease, drawing on the fact that different varieties of the same species have different degrees of susceptibility to any particular disease. If one were to plant a single variety and a disease to which it is susceptible were to strike, the entire planting would be destroyed. If instead one plants different varieties, which typically differ in their susceptibility to a disease, then there is some insurance against complete crop loss (for a discussion of whether agricultural biodiversity is adequately used for this purpose see Heal *et al.*, 2004). The Irish potato famine of the nineteenth century is an example of the extreme hardship caused by growing a single variety of potato, *Solanum tuberosum*. So genetic variation at the species level is economically valuable and has historically been the source of almost all agricultural progress.

6. A dramatic example of the direct importance of diversity to humans comes from the recent history of rice production. The prosperity and comfort of literally billions of people depends on rice harvests. In the 1970s, the grassy stunt virus, a new virus carried by the brown plant hopper, threatened the Asian rice crop. The virus appeared capable of destroying a large fraction of the crop: in some years it 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 about 80,000 different varieties of rice and the near-relatives of rice. In this case the IRRI located a single strain of wild rice that was not used commercially and 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 the genes from a strain 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 by the new virus. The strain 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 situation occurred later in the 1970s, and similar stories have occurred with other food crops, in particular corn in the United States (Myers 1997).

7. Biodiversity also contributes to the development of human knowledge and understanding, especially in the medical arena. Biodiversity's store of genetic material is a priceless source of knowledge. A good example is provided by the polymerase chain reaction (PCR), a reaction central to the amplification of DNA specimens for analysis, as in forensic tests used in criminal investigations and many processes central to the biotechnology industry. Culturing – the process of taking a minute sample of DNA and multiplying it manifold – requires an enzyme that is resistant to high temperatures. Enzymes with the right degree of temperature resistance were found in organisms in the hot springs in Yellowstone National Park and used to develop an enzyme for culturing DNA specimens. This enzyme is now central to the rapidly growing biotechnology industry and the pharmaceuticals that it is producing. Other widely-cited illustrations of the use of biodiversity in producing pharmaceuticals are the extraction of taxol, a treatment for breast cancer, from willow bark, and the extraction of vincristine and vinblastine, treatments for childhood leukemia, from the rosy periwinkle.

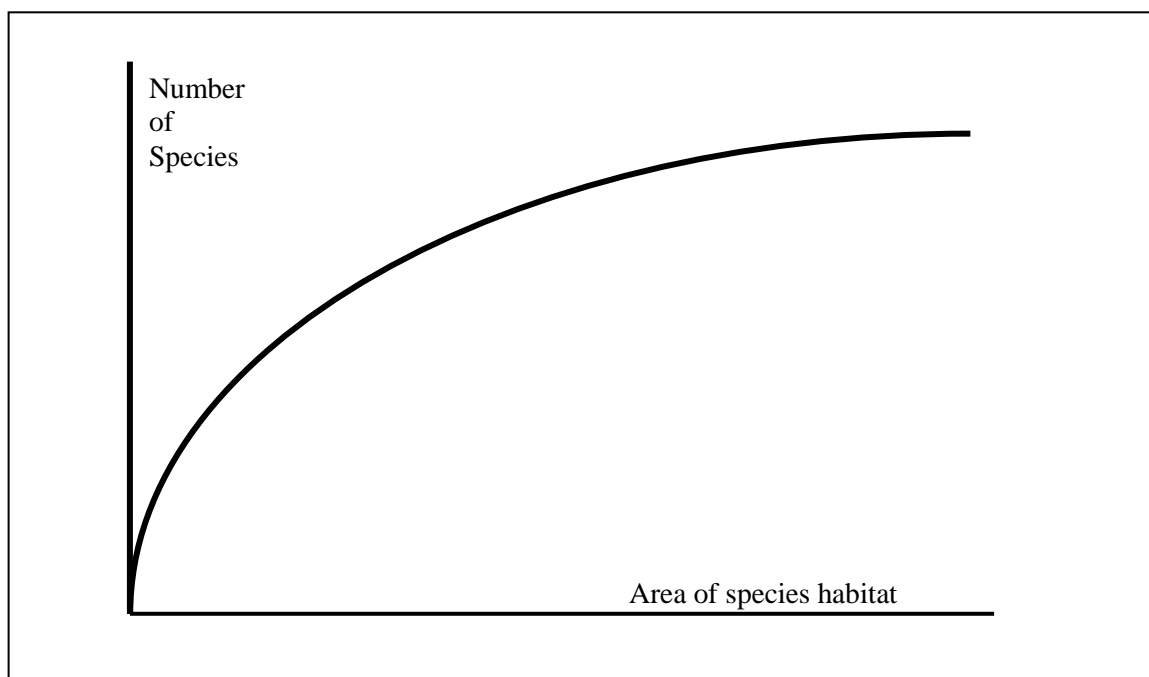
8. These examples clearly show that human welfare is threatened by the loss of biodiversity. As biodiversity loss is a continuing process, a part of the cost of policy inaction is that the longer we wait to stem this loss, the greater the final total cost to human societies. And it is important to note that biodiversity loss is in general irreversible – extinction of a species is a collective death of that species and a collective transit to “that undiscovered bourne from which no traveler has yet returned.” So the longer we wait to act, the greater the costs we will ultimately pay.

## 2. Uncertainties Concerning Biodiversity Loss

9. However, the problem is in fact far more complex than this analysis suggests. Biodiversity loss (conceived for the moment as extinction of species and extinction of populations) is not always easily measured, nor is it easy to say how human actions – which are the predominant cause of biodiversity loss – enter into this process. Biodiversity loss usually follows human actions with a long and unpredictable lag. And of course some elements of biodiversity matter more to us than others. All of these issues make assessment of the costs of policy inaction considerably more complex than they might appear at first sight.

10. There is much uncertainty about the rate of biodiversity loss, even though all parties to the debate agree that the rate of loss is high, higher than at any time in the last several thousand years. Uncertainty comes in part from the fact that we do not really know how many species there are, which introduces the possibility that we may be losing species of whose existence we are unaware. It also comes from the fact that we have only limited information about the populations of many species, and so are not well-placed to estimate the threats to their continued existence.

11. But perhaps more important than this statistical uncertainty about populations and their rates of change is a lack of knowledge of how human activities impact a species’ ability to continue. The main causes of species loss are deforestation and the clearing of land for agriculture – some of which is included in deforestation. Climate change will probably join them within the next decades. Many ecosystems respond in a very nonlinear fashion to stress: they can cope with outside stress with little or no damage up to a point, but are damaged substantially if the stress passes a critical level. A possible illustration of this is the species-area relationship, which finds that the number of species  $S$  on an area of land  $A$  increases with a fractional power of the area:  $S = kA^c$  where  $k$  and  $c$  are constants,  $k > 0$  and  $0 < c < 1$  (Ehrlich and Roughgarden 1987). Plotting the number of species vertically against area horizontally therefore gives a curve that is steep near the origin and flatter further out. So cutting back the area available for species from a large level, we see that initially a given reduction in area leads to only a small loss in the number of species, whereas once the area has been reduced substantially the same reduction in area leads to a far larger drop in species and in biodiversity. There are other more dramatic examples of ecosystems responding nonlinearly to human stresses, perhaps the best of which are the classic studies of eutrophication of freshwater lakes by Carpenter *et al.* (1999). Here a very small change in the phosphorus loading of a lake can cause it to flip from a pure and productive to a eutrophic state, with little or no warning and serious economic consequences to lake users.

**Figure 1: Relationship between Species Habitat Area and Number of Species**

12. Time lags in responses add a further element of uncertainty here. Biologists have a concept of the minimum viable population, the smallest population of a species that has a high probability of continuing in existence (Ehrlich and Roughgarden 1987). Once the population is below this level the species is effectively extinct, in the sense that it will eventually die out. But if the life of members of the species is long, it might be decades before actual extinction occurs and there is agreement that this has happened. For example, macaws live for sixty years or more: the populations of several species are thought to be below the minimum viable level today (Beissinger and Snyder 1991), but as there are breeding young adults alive, these species will still be visible, albeit on a reduced scale, for perhaps as long as the next century. Biologists refer to such species rather graphically as the “walking dead.”

13. These uncertainties and nonlinearities complicate greatly the assessment of the costs of policy inaction. In the simplest of all worlds, where everything is known, calculating the cost of delaying intervention in the process of biodiversity loss would also be simple. We would know that a specific measure, such as incentives for the conservation of tropical forests, would cut the rate of species loss from  $X$  per year to  $Y < X$  per year. Delaying introducing the measure for  $T$  years would therefore cause the loss of  $T(X-Y)$  extra species. To go further we would have to know the welfare losses associated with species loss: suppose for the moment that the loss of a species imposes a welfare loss whose present value is  $\$L$ . Then the cost of  $T$  years of policy inaction is  $\$LT(X-Y)$ .

14. In practice the only number we know in this expression is  $T$ , the time for which we are delaying the policy. We do not know the current rate of biodiversity loss  $X$ , nor the rate to which this could be reduced by an intervention such as cutting deforestation,  $Y$ . And we do not know the value of a species either, although I will review below some estimates.

### 3. The Timing of Interventions

15. A common response to such extensive uncertainty is to postpone a decision, in the hope that we will learn more about some of the currently-unknown parameters – the Xs, Ys and Ls above. Then on the basis of better scientific evidence we will be able to proceed with a more rational and defensible choice, always attractive to decision makers. But we have to recognize that there is a cost to waiting for more information, the cost of the biodiversity that is lost in the meantime, a cost that is unknown. In fact there are some important and far-from-obvious analytical issues raised by postponing decisions in order to wait for better information, which are captured under the title of “real option values.” (For a detailed discussion, see Dasgupta and Heal 1979.)

16. The point associated with option values is as follows. If you have the option of destroying something irreplaceable now, or postponing the destruction in the hope of learning more about how important it is and what the consequences of loss would be, then in comparing the two options the choice to postpone destruction and conserve has to be credited with an “option value,” a value which arises because if you conserve the item then the decision about whether to destroy can be revisited again later in the light of additional and better information. So by postponing destruction you may be able to make better decisions later on, and the expected gain from this constitutes the option value. It is the value of retaining an option for the choice to go either way, an option that is foreclosed if an irreplaceable object is destroyed. Roughly it is the value of taking a flexible position that keeps options open. From this it follows that conserving biodiversity has to be credited with an option value, in addition to any direct benefits expected to be associated with the conservation. Very few cost-benefit analyses of biodiversity conservation have taken this into consideration. (There are estimates of option values associated with conservation of forests in North America, where the values of the forest are largely a function of its timber and recreational values, and there is the possibility of developing the land - see Conrad 2000 and Buttle and Rondeau 2004). If policy intervention is postponed and more biodiversity is lost, then this option value is also lost.

17. A natural extension of the observation that better decisions can be made if one waits for additional information is the use of adaptive management, which is a relatively new paradigm for confronting the uncertainty amongst management policy alternatives for large complex ecosystems or ecosystems where functional relationships are poorly known (Walters 1986, Holling 1973). A key component of adaptive management is active learning by introducing new management policies to learn more about the system’s behavior and so reduce uncertainty. Typically, there may be an effort to implement environmental management actions as “experiments” in order to “learn by doing,” with the experiments designed to reduce the critical uncertainties about the ecosystem’s behavior. Adaptive management thus provides for a mechanism for learning systematically about the links between human societies and ecosystems. In contrast, the learning that occurs in economic models with option values is purely passive—information about the value of an environmental system is acquired with the passage of time. Adaptive management is a natural step from the passive concept of an option value associated with gaining information to the concept of managing the ecosystem to learn and so reduce uncertainty. When an adaptive management approach is possible, the option value associated with conservation is likely to be increased because of the enhanced rate of information acquisition.

### 4. Risk Aversion

18. Given all the uncertainties associated with the value of biodiversity conservation, one may be tempted to invoke the precautionary principle. Notably, the 1992 Rio Declaration (Article 15) (see Gollier *et al.*, 2000) stated: “where there are threats of serious and irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.” Though the precautionary principle has been attacked as being a vague concept lacking a

precise definition, the essence of the precautionary principle is clear<sup>2</sup> and is that the burden of proof should be to demonstrate that changes do not cause irreversible environmental damage, rather than proving a change is dangerous. Biodiversity loss is clearly a serious form of irreversible damage.

19. Most economists, if asked to think of a justification for the precautionary principle in decision-making, would probably couch it in terms of learning, irreversibilities, and option values. The option value linked to conserving an ecosystem whose change is irreversible is in effect a reward for cautious behavior, although it certainly does not imply that conservation is always appropriate. Gollier *et al.* (2000) note that the precautionary principle can also be given a formal justification in environmental decision making without invoking irreversibilities, just assuming that there is cumulative damage from human actions and possible learning over time about the consequences of the damage.

20. The unpredictability of the outcome of an environmental policy under uncertainty means that while the outcome could be excellent, it also has a chance of being poor. In general, faced with the choice between policies that generate the same expected value but with different ranges of outcomes, most people would choose the policy with the lowest variability. Risk aversion is a measure of what a person is willing to pay to avoid a risk and replace it by a certain outcome. If people are very risk-averse, then an environmental policy that delivers a modest outcome with some certainty might be preferred to one that may deliver a truly outstanding outcome but may also deliver a very poor result. In such situations, a policy maker has to decide whether to build some measure of risk aversion into the analysis, and if so how much. There are studies of the degree of risk-aversion displayed by individuals in financial markets (see Chetty 2003 and the references therein), but as risk aversion for a given person may vary with the magnitude of the risk and as it varies across people, these are not necessarily the appropriate values to use in environmental studies.

21. If society is extremely risk averse, then the objective of maximizing the expected value of society's welfare can be replaced by an objective known as "maximin." The intent in such cases is to focus on the worst possible outcome, the minimum, and then seek the policy intervention that maximises the welfare gains in the event that this outcome arises (hence the name: for a discussion see Arrow and Hurwicz 1972 and Maskin 1979). This policy will be different from that which would have been adopted on the basis of certainty equivalence. By way of illustration, consider an aquatic ecosystem that amongst others provides flood control services to a residential area. It is possible that decision-makers believe that the loss of human life through floods is the worst possible outcome and must be prevented at all costs. Such a belief would be appropriately represented by maximin preferences which would lead the analyst to select as best the project that minimizes the loss of life from flooding. Focusing exclusively on the worst possible outcome is only justified if there are good reasons to suppose that society is really risk averse and is willing to sacrifice considerable upside potential of a policy to avoid any chance of a bad outcome. Technically, the maximin objective can be seen as a limiting case of the expected welfare objective as the degree of risk aversion increases without limit. There are also arguments that suggest that the maximin may be an appropriate choice of objective in some cases of ambiguity, that is, cases in which there are no objective or subjective probabilities (Arrow and Hurwicz 1972 and Maskin 1979). Intuitively there is some connection between the precautionary principle and the maximin approach: both emphasize the worst possible outcome and seek to avoid it. Both would suggest placing great priority on stemming the loss of biodiversity because of the possibility of very costly losses that cannot currently be anticipated.

## 5. The Costs of Biodiversity Loss

22. We have seen that there are many complications in making rational decisions about the conservation of biodiversity. We do not know exactly how much we have nor how much we are losing.

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<sup>2</sup> Which is not to say that it is correct – for a discussion see National Academy of Sciences (2000).

Nor do we know exactly how the rate of loss depends on our actions; although we do know the general qualitative properties of this relationship – we know which of our actions are driving biodiversity loss and how to reduce that loss. Are there any solid economic grounds on which we can base our analysis? At the root of our difficulties in valuing biodiversity is the fact that many of the services that it provides are public goods – for example, climate stabilization and genetic knowledge – so that in many cases there is no market for them and so no market price. When there is a market for biodiversity-based services, as with ecotourism based on charismatic megafauna (see section 5.4 below) then the market captures only a part of society's willingness to pay for the service (Heal 2003); so that the market undervalues biodiversity even when it does value it. Furthermore we can rarely value biodiversity directly: we value the services of the ecosystems of which biodiversity is an integral and essential component. In other words, biodiversity leads to services which produce value: we work back to attribute some value to the biodiversity. Without the underlying biodiversity there would be no services and so no value. This does not necessarily imply that all the biodiversity in the underlying ecosystems is needed to produce the services, but it is the general opinion of systems ecologists that few if any components of an ecosystem are redundant (see Chapin *et al.* 2000). In this case it is reasonable to attribute the end value to the underlying biodiversity.

23. There are some estimates of the values of some of the ecosystem services provided by systems that depend on biodiversity and which are destroyed in the process of biodiversity loss. These are estimates of the values of biodiversity as a source of genetic information for use in pharmaceutical research, the value of forests in carbon sequestration, the value of biodiversity in watersheds as water purification systems and the value of charismatic fauna as tourist destinations.<sup>3</sup> All of these have been reasonably well-established. Unfortunately they cover only a small set of the values of services of biodiversity in total and so can only be taken as a lower bound on the overall value. Nevertheless they are high enough to give a sense of the economic importance of biodiversity loss. (For an earlier review of some of these values, and an excellent overview of the issues raised by biodiversity valuation, see Pearce 2001.)

### **5.1 Biodiversity and Bioprospecting**

24. Bioprospecting refers to the use of naturally-occurring substances as potential sources of pharmacologically active and valuable compounds, as what the pharmaceutical industry call “leads.” Over one-third by value of prescription drugs originated as naturally-occurring compounds, so bioprospecting has been an important source of biochemical leads in drug development. Several drug companies have signed agreements with tropical countries under which they will systematically investigate the potential of compounds derived from plants or insects, and sometimes from vertebrates such as snakes, as pharmacological leads (Heal 2000). Typically such agreements involve an up-front payment by the company and then royalties on the drugs developed. This has led to a number of studies of the value that might be assigned to biodiversity in this process, the most recent of which is Rausser and Small (2000) (see also Simpson, Sedjo and Reid 1996, and for a review of the economic characteristics of biodiversity in the context of genetic resources see OECD 2001). Rausser and Small look at the value of biodiversity in known biodiversity “hot spots” from the perspective of drug development, and conclude that this could be worth as much as USD 9000 per hectare. It bears emphasizing that this is an upper limit and applies only to the areas in which biodiversity is most concentrated. And if two different areas contain similar biodiversity, we cannot sum their values as this would involve some double-counting.

25. We can use this to put a dollar value on the loss of some of the tropical rainforests, losses that could be halted by policy interventions that are now available. Many millions of hectares of tropical forest are lost each year. Not all of this is in biodiversity “hot spots,” however: a guess is that one million

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<sup>3</sup> There are also estimates of the value of wetlands as water purification systems. I have neglected these as the total extent of wetlands playing this role is small and the values are very context-dependent. These are discussed briefly in Pearce (2001).



hectares of biodiversity-rich forests are lost each year. And not all of these contain unique biodiversity. Nevertheless, it is possible that the annual loss of biodiversity due to deforestation is costing humanity billions of dollars annually solely from the perspective of new drug development, that is, each year we are losing new drug leads that could be worth billions of dollars.

## **5.2 Biodiversity and Carbon Sequestration**

26. Biodiversity is an integral part of ecosystems, often of complex ecosystems. Nowhere is this more true than with tropical forests, ecosystems whose components are a vast range of species that constitute a significant fraction of Earth's biodiversity. These systems draw carbon from the atmosphere and store it above and below ground. The Kyoto Protocol establishes emissions markets which put a price on carbon emissions and on carbon sequestration. Estimates of what this might be if the Kyoto Protocol were fully implemented run in the range of USD 20 to USD 50 per ton of CO<sub>2</sub>. More concretely, the European Union's current emissions trading scheme has that price at about EUR 10 per ton of CO<sub>2</sub>. Forests may sequester carbon: in fact the terrestrial biosphere is thought to sequester about 30% of the CO<sub>2</sub> emitted by the combustion of fossil fuels. Forests sequester primarily when they are growing: growing moist tropical forests may sequester as much as 20 tons of CO<sub>2</sub> per hectare per year, an ecosystem service worth EUR 200 per hectare per year at current European Union Emissions Trading Scheme (ETS) prices and considerably more at the prices associated with full implementation of the Kyoto Protocol. The capitalized value of such a flow of services is several thousand Euros per hectare, which is additional to any value that the forest may have for bioprospecting.

27. Climax forests, forests that are in an equilibrium age distribution of trees, sequester much less. These are the forests which are extensively logged and of which a significant percentage is cut each year. The cutting of these forests releases carbon dioxide back into the atmosphere – the last IPCC reports estimate that between 20% and 25% of all CO<sub>2</sub> released into the atmosphere in the 1990s came from deforestation. This makes deforestation as important a source of heat-trapping gases as the use of fossil fuels in the U.S.. Tropical forests cover about 2.7 billion hectares, and about 15% are cut down each year. That makes an annual loss of tropical forests of about 200 million hectares. If each hectare of deforestation releases Q tons of CO<sub>2</sub> and we take the current EU ETS price for CO<sub>2</sub>, then the total value of this CO<sub>2</sub> release from deforestation is 10x200,000,000xQ. As the number Q could be about 10, this is a value that is again in the tens of billions. So the conservation of even climax forests, which are not large carbon sinks but are large stocks of carbon, could be providing carbon storage services worth tens of billions. Climax tropical forests constitute much of the world's biodiversity. Again, this is additional to any bioprospecting value that this may have.<sup>4</sup>

## **5.3 Biodiversity and Watersheds**

28. Watersheds are some of the most valuable of all ecosystems, as they fulfill two crucial functions – the stabilization of stream flows and the purification of the water that flows through (National Academy of Sciences 2000). As water is a critical human need and an increasingly scarce commodity, these functions are of signal importance. Their economic significance is well illustrated by the choice that New

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<sup>4</sup> Some have argued that the carbon sequestration and storage roles of tropical forests could be replaced by plantation forests, with much less biodiversity, suggesting that biodiversity is not needed to sequester and store carbon. That the carbon storage role of tropical rainforests could be played by monocultures of for example eucalypts is untrue: the subsoil communities of the tropical rainforests store more carbon than other ecosystems. The life of the trees is also more limited. It is also untrue that the carbon sequestration roles of tropical rainforests could be replaced by plantations, as the soil of tropical rainforests will generally not support plantation agriculture. Tropical rainforests have surprisingly little soil and what they have is rapidly lost on deforestation.

York City made in 1997 to invest USD 1.5 billion in the restoration of its Catskill watershed, as a way of avoiding the need to introduce water filtration plants.

29. Watersheds are a specific type of ecosystem, and it is the biodiversity in them that allows them to purify water and control stream flow. Specifically, as rain falls into a watershed and percolates through the soil, microorganisms in the soil remove impurities from the water, and the slow flow through the soil facilitates sedimentation of additional impurities. In New York's case, development in the neighbourhood of the watershed had overloaded its capacity to process impurities, and consequently the City's response was to invest in upgrading sewage systems, buying undeveloped land to prevent further development, and pay farmers in the region to maintain riparian buffer zones and to adopt organic agriculture. (For details see National Academy of Sciences 2000.) Similar measures have now been adopted in many other watersheds – for example, the owners of the Perrier brand pay local farmers to adopt organic farming methods to avoid compromising the watershed. So the biodiversity in the various watersheds around the world is worth many billions of dollars.

#### ***5.4 Biodiversity and Tourism***

30. When the general public thinks of biodiversity, it generally thinks of what conservation biologists term charismatic megafauna, exemplified by lions and tigers and elephants and giraffes and the great herds of ungulates on the African plains. That these have economic value is shown by people's revealed willingness to pay substantial amounts to view them and spend time in their presence. For many African countries (including Botswana, Namibia, South Africa, Zambia and Kenya), ecotourism based on their endowments of charismatic megafauna is one of the major contributors to national income, and the support of this aspect of biodiversity often is the highest value use of land. In addition to providing income, ecotourism has the attractive feature that it generates income and employment in remote rural areas and so contributes to rural development and the stabilization of the rural population, an important issue in many developing countries (see Heal 2004). In general in Southern Africa the alternative land use is cattle ranching, and tourism provides more and better-paid employment than ranching. The value of biodiversity in this role worldwide is hard to estimate, but must be in the hundreds of millions of dollars and possibly in the billions.

#### ***5.5 The Costs of Biodiversity Loss - Summary***

31. In sum, biodiversity has great economic value although many aspects of this are hard to value. Its pharmacological value could be in the tens of billions of dollars. Intuitively, this order of magnitude makes sense: a successful pharmacological product can be worth USD 5 to USD 10 billion per year in revenues net of production costs, with a present value over its life of perhaps USD 50 to USD 100 billion. If there is the potential for several more blockbuster drugs in the biodiversity that remains, then this justifies the range of values that emerge from the Rausser-Small paper. That biodiversity's carbon storage value should be in the tens of billions of dollars also makes intuitive sense: forests are an integral part of biodiversity and store a large fraction of the planet's released carbon, a service for which there is now a market price on the European carbon markets. With carbon permits at roughly EUR 10 per ton, this service has immense value. If the world combats climate change effectively, this price will rise. The services of biodiversity in watersheds and in charismatic megafauna are harder to estimate in total, but again clearly run to billions of dollars.

32. In total therefore the loss of biodiversity could cost us certainly tens of billions of dollars, and possibly hundreds of billions, in the loss of the ecosystem services discussed above. It is important to recall that these are only some of the services provided by, and some of the sources of value of, biodiversity. By way of example, the entire value of biodiversity as an input to agricultural progress is omitted, omitting its value in the production of hybrid corns amongst others. And the insurance value of biodiversity, clearly

great from the example in section 1, is also omitted. These numbers are thus underestimates of the true value, perhaps serious underestimates. They are still high enough to make one take notice.

## 6. Conclusions

33. Ecosystems provide valuable services to humans. Biodiversity is an integral and essential part of most ecosystems and therefore of the provision of those services. There have been attempts at valuing some of the services provided by natural ecosystems, and these estimates provide some insight into the value of what we lose as we lose biodiversity, as we are doing. The estimates we have are underestimates, and in addition they neglect the option value calculations outlined in section 3. The true value of what we are losing is probably significantly larger, and as much of it will be gone before we decide to take action, we will never know the value of much of what we have lost.

34. We are uncertain about the value of biodiversity loss, although we know it is big enough to be serious. In the policy context, what matters is not so much the cost of policy inaction as a comparison of the costs of policies to stop biodiversity loss with the gains from such policies. So the operational question is: Could biodiversity conservation policies cost more than the value of the biodiversity that is being lost? Could it cost more than some hundreds of billions of dollars? There are almost certainly policies that would reduce biodiversity loss at a cost greatly below the value of the biodiversity thus conserved. As an example, consider the possibility of opening the European Union's Greenhouse Gas Emissions Trading Scheme to avoided deforestation carbon offsets, as has recently been discussed by the Union itself and a number of advisory bodies (Trines *undated*, Commission of the European Communities 2005). As some of these references indicate, this could lead to the conservation of significantly more tropical forests and a mitigation of biodiversity loss on a large scale. There are as yet no systematic studies of the precise scale of forest conservation that would result from this, but it is generally thought to be large, and the cost to the EU would be negligible. So there clearly are policy options currently available that will conserve biodiversity at costs considerably less than the benefits from conservation.

35. A final observation about the value of biodiversity loss: there is considerable uncertainty about this value, not about the fact that it is large, but about exactly how large it is. If we as a society are risk-averse, then the possibility that we may be losing something even more valuable than we currently think is one that should concern us, particularly given the irreversible nature of the loss and the prospect of learning more about the values at stake in the future. Risk aversion, irreversibility and learning can justify a precautionary element to our behavior which should tilt the balance in favor of conservation more than the numbers presented above do.

## REFERENCES

- Armstrong, P.R., B.E. Kendall and F.W. Davis. "An Introduction to Biodiversity Concepts for Environmental Economists." *Resource and Energy Economics* Volume 26 issue 2 June 2004 pp 115-136.
- Arrow K.J. and L. Hurwicz. "An Optimality Criterion for Decision-Making Under Ignorance." In *Uncertainty and Expectations in Economics*, Carter C.F. and J.L. Ford (eds) Basil Blackwell, Oxford, U.K. 1972.
- Beissinger S.R. and N. F.R. Snyder. *New World Parrots in Crisis: Solutions from Conservation Biology*. Smithsonian Institution Press, 1991.
- Buttle Jonathan and Daniel Rondeau. "An Incremental Analysis of the Value of Expanding a Wilderness Area." *Canadian Journal of Economics*, Vol. 37, No. 1, pp. 189-198, February 2004
- Carpenter S.R., D. Ludwig and W.A. Brock. "Management and Eutrophication for Lakes Subject to Potentially Irreversible Change." *Ecological Applications* 1999, 9:751-771.
- Chapin FS 3rd, *et al.* 'Consequences of Changing Biodiversity' *Nature*. 2000 May 11; 405(6783):234-42.
- Commission of the European Communities. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: *Winning the Battle against Global Climate Change*. SEC (2005) xxx
- Conrad J.M. (2000). "Wilderness: options to preserve, extract, or develop". *Resource and Energy Economics*, 22.
- Chetty R. 2003. "A New Method of Estimating Risk Aversion." NBER Working Paper 9988 available at [www.nber.org/papers/w9988](http://www.nber.org/papers/w9988) Accessed June 15 2004.
- Daily, G. (Editor) *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press 1997.
- Dasgupta P.S. and G.M. Heal. *Economic Theory and Exhaustible Resources*. Cambridge University Press 1979.
- Ecological Society of America. "Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems" *Issues in Ecology*, Number 2 Spring 1997.
- Ehrlich P. and J. Roughgarden 1987. *The Science of Ecology*. Macmillan, New York.
- Gollier C. *et al.* "Scientific Progress and Irreversibility: An Economic Interpretation of the Precautionary Principle." *Journal of Public Economics* 75:229-253, 2000.

- Grime J.P. "Biodiversity and Ecosystem Function: the Debate Deepens." *Science* 277:1260 1997.
- Heal G.M. *Nature and the Marketplace*. Island Press 2000.
- Heal G.M. 2003 "Bundling Biodiversity" *Journal of the European Economic Association* April-May 2002 1(2-3): 553-560.
- Heal G.M., B. Walker, S. Levin, K. Arrow, P. Dasgupta, G. Daily, P. Ehrlich, K-G. Maler, N. Kautsky, J. Lubchenco, S. Schneider and D.Starrett. "Genetic Diversity and Interdependent Crop Choice in Agriculture." *Resource and Energy Economics* 26 (2004): 175-184.
- Holling, C.S. "Resilience and Stability of Ecological Systems." *Annual Review of Ecological Systems* 4:1-23 1973.
- Hooper D.U and P.M. Vitousek. "The Effect of Plant Composition and Diversity on Ecosystem Processes." *Science* 277: 1302-5. 1997.
- Hughes J. *et al.* "Population Diversity: Its Extent and Extinction." *Science* 278:689-92. 1997.
- Maskin, E. "Decision Making under Ignorance with Implications for Social Choice Theory." *Theory and Decision* 11:319-37 1979.
- McGrady-Steed J. *et al.* "Biodiversity Regulates Ecosystem Predictability." *Nature* 390:162-5. 1997
- Millennium Ecosystem Assessment. "Ecosystems and Human Wellbeing." Available at <http://www.millenniumassessment.org/en/index.aspx>
- Myers N. "Biodiversity's Genetic Library" in Daily G. (Editor) *Nature's Services*, Island Press 1997
- Naeem G.P. and S. Li. "Biodiversity Enhances Ecosystem Reliability." *Nature* 390:505-9. 1997
- National Academy of Sciences. *Watershed Management for Potable Water Supply: Assessing the New York City Strategy*. National Academies Press Washington D.C. 2000.
- Nunes, P.A.L.D., J.C.J.M. van den Bergh and P. Nijkamp. "Integration of Economic and Ecological Indicators of Biodiversity." In *Valuation of Biodiversity Studies*, OECD, Paris 2001.
- OECD. "Economic Issues in Access and Benefit Sharing of Genetic Resources: a Framework for Analysis." Organization for Economic Cooperation and Development, November 2003, ENV/EPOC/GSP/BIO(2001)2/FIANL/
- Pearce D. "Valuing Biological Diversity: Issues and Overview." In *Valuation of Biodiversity Studies*, OECD, Paris 2001.
- Rausser G.C. and A.A. Small. "Valuing Research Leads: Bioprospecting and the Conservation of Genetic Resources." *Journal of Political Economy* February 2000.
- Simpson, R.D., R.A. Sedjo and R. Reid. "Valuing Biodiversity for Use in Pharmaceutical Research," *Quarterly Journal of Economics* 1996 104 No.1:163-185.
- Tilman D. *et al.* "Biodiversity and Ecosystem Properties." *Science* 278:1866-7. 1997.

Trines E. 'Possible role of Land Use, Land-Use Change and Forestry in future climate regimes: An inventory of some options, Report on the informal EU workshop on the future treatment of LULUCF.' Study commissioned by the Netherlands Ministry of Agriculture, Nature and Food Quality from Eveline Trines, Marconistraat 27 2562 JB, Den Haag, the Netherlands.

Walters C.J. Adaptive Management of Renewable Resources. McGraw Hill New York 1986.