ESTIMATING ANCILLARY IMPACTS, BENEFITS AND COSTS ON ECOSYSTEMS FROM PROPOSED GHG MITIGATION POLICIES

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Preface

The primary question to be addressed in this paper is what are the ancillary impacts, both positive and negative, on ecosystems from proposed GHG mitigation policies. Several secondary questions follow from this, including what are the best ways to estimate these impacts, can we attach values to these impacts, and how might the information about these impacts best be used to assist policy-making.

It is important to preface what follows with a brief discussion of several caveats on what I propose to do in this paper. Adopting an approach similar to that in the EPA's retrospective (US Environmental Protection Agency 1997) and prospective (US Environmental Protection Agency 1999) studies of the Clean Air Act and its amendments, I will address *changes* in impacts on ecosystems from *changes* in policies. This is a "marginal" approach, in that I do not attempt to draw conclusions about the total value of ecosystems or the total impact that human actions may be having on them.

Secondly, in the context of valuation, this paper is inherently anthropocentric. As noted by Pearce (1992, p.7), "What {economic} valuation does is to measure *human preferences* for or against changes in the state of the environments. It does not 'value the environment'. Indeed, it is not clear exactly what 'valuing the environment' would mean" (author's italics, my brackets). This is not to argue that other forms of value independent of humans, e.g. intrinsic value, do not exist. However, I believe, by their very definition, that neither I nor any other person is privy to truly understanding and putting words to these values.[1]

Thirdly, I will focus, at times, on economic and specifically monetary valuation, but not to the exclusion of other concepts of value and valuation. Policy-making is and should be heavily and appropriately influenced by economic considerations, but not to the exclusion of other concerns (Vatn and Bromley 1995; Toman 1999). Too often, however, an overemphasis on monetary valuations has placed a straitjacket on analysts and limited the information used, at least implicitly, in making policy (Porter 1995).

[1] Toman (1999) discusses this same issue in somewhat more depth in laying out a general value typology, where he describes four separate forms of value: anthropocentric instrumental, anthropocentric intrinsic, non-anthropocentric instrumental, and non-anthropocentric intrinsic.

Guided by these principles, I hope to contribute positively to the evaluation of proposed GHG mitigation policies, while avoiding certain pitfalls that lurk in linking economic and ecological analysis. By limiting myself to, primarily, marginal changes, I remain within the purview in which economic analysis is most appropriate (Toman 1998; Heal 2000). By not being bound by the specific requirements of monetary valuation, I do not limit myself to a small number of impacts to the exclusion of the vast majority (Rothman 2000).[2]

Abstract

Many of the policies being proposed to address the issues of greenhouse gas emissions and atmospheric concentrations strongly resemble, if not duplicate, policies that have been proposed and/or implemented to address other environmental issues. At the same time, other policies involve direct changes to ecosystems. Thus, it is reasonable to expect that GHG mitigation strategies will have direct and indirect impacts on ecosystems. This paper presents a framework for understanding and assessing these impacts. It is concluded that although much is not known, the impacts are likely to be wide ranging, resulting in both positive and negative effects.

1. Introduction

In its Second Assessment Report (SAR), the Intergovernmental Panel on Climate Change very briefly raised the issue of secondary or ancillary effects of climate change policies (Pearce, Cline *et al.* 1996, p.215). In 1997, the Intergovernmental Panel on Climatic Change released two technical papers addressing the implications of stabilizing atmospheric greenhouse gases and of proposed CO_2 emissions limitations (Houghton, Filho *et al.* 1997; Wigley, Jain *et al.* 1997). Unfortunately, no mention of ancillary impacts was made in either of these papers. In preparing its Third Assessment Report (TAR), however, the issue of ancillary impacts and the linkages between climate change policy and sustainable development, more generally, have received greater attention (Markandya and Halsnæs 1999; Munasinghe 2000).

In this paper, I focus specifically on the ancillary impacts, both positive and negative, on ecosystems from proposed GHG mitigation policies. Other papers and/or sessions in this workshop volume address issues more directly related to public health, transportation, agriculture, and land use. There will certainly be some overlap in these categories.

The concern about impacts of human actions on ecosystems preceded discussions of greenhouse gases and potential global climate change and has intensified in recent years for reasons that go well beyond this issue. Furthermore, most of the policies being proposed to address greenhouse gas emissions and atmospheric concentrations strongly resemble, if not duplicate, policies that have been proposed and/or implemented to address other issues, several of which have had ecosystem impacts as one of their principle concerns. Thus, it is reasonable to expect that climate change policies will have impacts on ecosystems.

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[2] Note, for example the recent EPA (1999) prospective study on the Clean Air Act Amendments of 1990. Based upon self-imposed criteria, including the ability to monetize flows of ecosystem services, the authors were able to identify only 5 endpoints for quantitative analysis, of which the monetary values for only 2 were included in their numeric results.

The framework I will use in addressing this issue draws from recent work in integrated environmental assessment and is shown in Figure 1 (blue or lightly shaded boxes). The GHG policies considered are examined for the *changes* they exert on the pressures ecosystems face. These lead to changes in the state of ecosystems, which result in both ecosystem and socio-economic impacts. Variations on this framework can be found in the literature, alternatively referred to as the Damage Function approach (Rowe, Smolinsky *et al.* 1995), the Impact Pathway approach (Holland, Berry *et al.* 1999), or the Pressure-State-Impact-Response approach (Rotmans, de Vries *et al.* 1997).

Figure 1 also shows the outline for this paper. Before addressing proposed GHG mitigation strategies and their potential impacts on ecosystems, it is necessary to provide some background on ecosystems – what they are, why they are of interest, and what are the principle causes of change in these systems. Finally, after addressing the potential impacts of GHG policies on ecosystems, I summarize the major findings of this study and its implications for climate change policy-making.

This procedure differs slightly from other studies, which have first defined major ecosystem types and then applied a similar approach to examine each of these (Watson, Zinyowera *et al.* 1996; Costanza, d'Arge *et al.* 1997; Watson, Zinyowera *et al.* 1998; US Environmental Protection Agency 1999). Given the nature and purpose of this paper, I have chosen not to do this, but rather to focus on the framework itself, citing particular examples without attempting to provide an exhaustive list of effects. It is hoped that the careful development and discussion of the framework will help to illuminate examples deserving of further exploration.

2. Background on Ecosystem Functioning, Goods, & Services – What are they and why are they of interest?

There has been much discussion recently about ecosystem functioning, goods and services, and their value (de Groot 1992; 1994; 1997; Costanza, d'Arge *et al.* 1997; Daily 1997; 2000 #664; Pimental, Wilson *et al.* 1997; Heal 1999; 2000; Norberg 1999; Turner 1999; US Environmental Protection Agency 1999; de Groot, Van der Perk *et al.* 2000).[3] The terminology can be confusing. In this section, I discuss briefly one way to think about ecosystem functioning vis-à-vis goods and services and the values we can derive from these. For further detail on any of these topics, the reader is recommended to look at the referenced literature.

In their general functioning, ecosystems generate goods and services, from which humans derive value. Alternatively, we can state that, in the process of satisfying specific desires (values), humans draw upon goods and services that have been generated as a result of ecosystem functioning. Please note that, in general, there is not necessarily a one-to-one-to-one relationship between specific functions, goods and services, and values; specific values can be derived from a number of goods and services, which may rely on a number of functions.

[3] Chapter 5 of the IPCC TAR Working Group II report, on Ecosystems and Their Services, is also addressing these issues.

Table 1 presents one classification of ecosystem functioning, goods, and services, developed by Gretchen Daily and colleagues as part of the "Ecosystem Services Framework" (Daily 1999). Table 2 translates these into values derived by humans from these goods and services.[4] I defer the important discussion of monetary/economic valuation until later in this paper, focusing here on simply cataloguing types of value. The categories in these tables represent just one way of slicing reality; other categorizations have been suggested (see references from first paragraph in this section). The specifics are less important that the following general points:

- Many, if not all, human needs and wants are met by ecosystem goods and services, directly or indirectly;
- Many of these goods and services cannot be substituted for, or, if so, not at reasonable costs;
- Functioning ecosystems are necessary for the continued provision of goods and services; and
- Human activities that impinge upon the ability of ecosystems to function will necessarily affect human welfare.

3. Background on Causes of Ecosystem Change

That human activities impact upon ecosystems in a myriad of ways should be of no surprise. Like all other species, we exist within the biophysical environment. What is relatively new, and of some concern, is that there exist very few remaining ecosystems that can be considered not dominated by humans (Vitousek, Mooney *et al.* 1997). Unfortunately, this domination is not always recognized, especially since much of our impact is unintentional. Furthermore, even where our impact is intentional, we rarely understand the full implications of our actions.

Table 3 presents a standard categorization of human pressures on landscapes and ecosystems, as specified by Rapport, *et al.* (1998). These are: harvesting, waste residuals, physical restructuring, magnified extreme events, and exotic species introductions. Harvesting represents the systematic removal of particular species from the ecosystem. It is of most concern when it occurs at high rates or affects keystone species. Waste residuals include both direct and indirect changes in the chemical environment. These can be in the form of air, water, or soil pollutants. Physical restructuring, or land transformation, can occur at small or large scales, and includes fragmentation of landscapes. It is considered the leading cause of the loss of biodiversity and other ecosystem goods and services worldwide (Vitousek, Mooney *et al.* 1997). Magnified extreme events are less well defined, but include such events as the large fires in the last decade, partially due to a century of no-burn policies that allowed fuel stocks to increase in forest ecosystems. Finally, exotic species introductions, whether intended or not, have the ability to reshape entire ecosystems.

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4 Note that I have specifically excluded intrinsic value, which I define as an inherent value of an organism or ecosystem independent of human existence. As expressed in the preface, I view this, by its very nature, to be inaccessible to valuation by humans. This is not to be confused with existence value, which is the value that human's receive from knowing of an organism's or ecosystem's existence and is very much within the scope of valuation by humans. See Toman (1999) for a similar argument.

At this point, I am ready to address the specific question at hand. Referring back to Figure 1, the next section begins with a consideration of the policies being proposed to address the issue of atmospheric concentrations of GHGs, with an eye toward specifying the *pressures* they will generate. This will be followed by a discussion of the changes in *state* expected to result from these pressures. In particular, these will be examined in the context of the causes of ecosystem change outlined above. The next two sections will focus on the potential *impacts* of these changes, first considering the biophysical changes and then their socio-economic implications. The rubric of ecosystem functioning, goods and services, and value will structure these discussions.

4. GHG Policies Considered (Pressures)

From the perspective of reducing atmospheric concentrations of GHGs, there are two general options – reduce what is being added or increase what is being taken out. Of course, there are many alternatives for achieving these goals. In November of 1996, the IPCC released its first Technical Paper, which dealt with Technologies, Policies and Measures for Mitigating Climate Change (Watson, C. *et al.* 1996). For the TAR, the contribution of WGIII is to explore the issue of mitigation of climate change. Two chapters will specifically address the technological and economic potential of various mitigation options. Chapter 3 will focus on reducing emissions; Chapter 4 will focus on enhancing, maintaining and managing biological carbon reservoirs and geo-engineering. Finally, the Special Report on Land Use, Land-Use Change, and Forestry also addresses some of these issues (Watson, Noble *et al.* 2000).

Table 4 summarizes the principle alternatives being considered. These are divided between those that focus on the use of fossil fuels for energy production, those that focus on land-use practices, and those that fall out of either of these categories. The reason for this division will become clearer in the next section, where I indicate how these activities relate to the principle causes of ecosystem change discussed in the previous section. The last two alternatives have potentially large impacts on ecosystems, but they generally receive much less attention in the discussions of GHG mitigation, especially in the short-term. Population control is a much more fundamental and contentious issue; geo-engineering remains speculative and controversial. Thus, although these options are worth acknowledging, they are not dealt with further in this paper.

5. Potential Non-Climatic Effects on Ecosystems (Changes in State)

Is it possible to map GHG policies to causes of ecosystem change and, furthermore, to changes in the provision of goods and services? Ideally, this would be done for very specific cases, where the chains of causality could be identified in detail. This would require information not only on the options chosen, but also the areas of impact. This form of analysis has been attempted in several recent studies that examined the impacts of air pollutants (see, for example, Rowe, Chestnut *et al.* 1995; US Environmental Protection Agency 1997; Holland, Berry *et al.* 1999; US Environmental Protection Agency 1999). Here, I am more interested in providing a general framework, which may stimulate more detailed analysis.

Table 5 maps, in a general fashion, the linkages between the GHG policies considered and the principle causes of ecosystem change. Some specific examples are suggested in Table 6. Of course, even these need to be explored in the context of specific landscapes. Still, a number of general points can be highlighted:

- There is a wide range of potential effects;
- The greatest effects will likely be in the areas of waste residuals and physical restructuring;
- Changes in waste residuals will primarily result from changes in energy production and use; and
- Changes in physical structuring will primarily result from changes related to enhancing, maintaining and managing biological carbon reservoirs.

6. Ecosystem Changes (Impacts - Biophysical)

Table 7 specifies a number of general changes to ecosystems and their provision of goods and services that can be expected from the above effects of GHG mitigation policies. This is a speculative list that would benefit from additional input. It does, however, give an indication of some of the key areas of concern for assessing the ancillary impacts of proposed policies on ecosystems. Furthermore, it indicates the importance of considering second and higher-order impacts and the fact that the impacts can be both positive and negative.

As pointed out earlier, a number of studies have organized the potential impacts by major ecosystem type (Watson, Zinyowera *et al.* 1996; Costanza, d'Arge *et al.* 1997; Watson, Zinyowera *et al.* 1998; US Environmental Protection Agency 1999). Others have been careful to note that the impacts must be considered at a number of biological/ecological scales, ranging from the molecular and cellular to global cycles (Norberg 1999; US Environmental Protection Agency 1999). A careful consideration from each of these perspectives would certainly help to illuminate further impacts.

Before moving on to the issue of the socio-economic implications of these changes, it is important to recognize how little we know about the actual physical nature of these changes. A number of recent compilations have attempted to shed light on these and related processes (see for example Daily (1997); Watson (1996); Watson (1998), US Environmental Protection Agency (1999), Levin (1999), and the special issue of *Ecological Economics* 29(2), 1999). However, most of the studies represented in these present only very general descriptions or are limited to very specific locales. It will require further advances in the underlying disciplines and their integration to truly understand these changes.

7. Socio-Economic Effects of Ecosystem Changes (Impacts – Socioeconomic)

The next step in our analytical framework is to translate the biophysical impacts noted above into socio-economic impacts. An attempt to do so is shown in Table 8. Once again, this is a speculative list that would benefit greatly from further input. In particular, this list emphasizes the use value of ecosystem resources over their non-use values. Furthermore, our understanding of all impacts suffers from the uncertainties surrounding the functioning of ecosystems. However, the table does show that the potential impacts are wide ranging. It is also clear that there are both positive and negative effects that need to be considered.

When discussing socio-economic impacts, it is important to go beyond simply delineating the more or less tangible changes and link these to human values (see Table 2). Several of these – importance to human health, amenity value, productive use value, and consumptive use value – clearly fall out of the list of impacts in Table 8. The other values, albeit more subtle, cannot be ignored. The preservation and restoration of forest ecosystems certainly provides option value. The preservation of species most assuredly carries with it existence value.

The translation of these values into something meaningful for policy-making can perhaps be considered the 'final' step in our analytical framework. To do so, requires an introduction to the details of valuation in the context of ecosystems. This introduction will necessarily be brief. For further details on the general topic, the reader is referred to the many works in the literature on this topic (e.g. O'Connor and Spash (1999) Pearce (1993), Freeman (1993), Toman (1999), Costanza (1997), and Costanza (2000)).

Table 9, taken from Munasinghe (2000), lists a number of techniques that have been developed by economists to value ecosystem goods and services and the impacts of changes in their availability. DeGroot (1997) has, furthermore, tried to link the techniques to the values being considered to show which tools may theoretically be used to estimate different value. This is shown in Table 10.

Those methods that do not reflect actual behavior in conventional markets, i.e. those not listed in the upper left corner of Table 9, have been developed because, for the most part, ecosystem goods and services, among others, are not directly traded in conventional markets. The techniques have been applied in numerous studies and can be utilized to value the effects described in this paper. However, there remains large debate about the validity of these methods, particularly the contingent valuation method (CVM) (Arrow, Solow *et al.* 1993; Bateman and Willis 1999). As shown in Table 10, though, this presents a problem, as CVM is the only method that can be used to estimate a number of the values of interest.

In general, the limitations of these techniques have severely restricted the range of impacts that are included in analyses of human impacts on ecosystems (Rothman 2000). For example, based upon self-imposed criteria, including the ability to monetize flows of ecosystem services, the authors of the recent EPA (1999) prospective study on the Clean Air Act Amendments of 1990 were able to identify only 5 endpoints for quantitative analysis, of which the monetary values for only 2 were included in their numeric results.

Beyond the issue of not being able to capture many of the values of interest, a few other points need to be made concerning the valuation described above:

- These techniques focus almost exclusively on economic values, where the goal is economic efficiency. Other values, based upon concerns of fairness or sustainability are not well represented (Costanza and Folke 1997; Costanza 2000);

- The conceptual foundation for these forms of valuation is the value of scarce resources to *individuals*. For a number of ecosystem services, however, the values derived are better seen as community values (Toman 1999);

- These techniques are most appropriate for estimating the value of marginal changes in ecosystem services (Toman 1998; Heal 2000). As complex, adaptive systems, ecosystems may exhibit non-marginal effects from even marginal changes in pressures (see, for example Levin (1999));

- Many of these techniques are most appropriately applied to very specific locations/situations. There remain large problems with transferring these estimates to other situations and aggregating these (see, for example, Rothman (2000) and the special issue of *Water Resources Research* 23(3), 1992); and

- These techniques can be very time and cost intensive.

The criticisms leveled against these forms of economic valuation and the responses by their defendants has stimulated lengthy debates, but, in the eyes of many, little progress. There is recognition of the problems and inadequacies with these techniques, both in theory and practice. It remains a question, however, whether there exist any better tools.

There have been attempts to get beyond this impasse, however (see, for example, O'Connor (1998)). Here I wish to present examples of just two quantitative approaches that extend or complement economic valuation. Neither, to my knowledge, has been widely used.

The first was proposed by Bawa and Gadhgil (1997) and is illustrated in Table 11. Their focus was on an assessment of the contribution of ecosystem services to subsistence economies, but the schema could be adapted for more general use. The second, proposed by Schneider, *et al.* (forthcoming), is referred to as the "five numeraires" (see Table 12).

Both of these build upon the strengths of economic valuation, but complement it with other approaches, where it is less appropriate.[5] The five numeraires approach, in particular, explicitly separates out the issue of loss of life from monetary valuation. If the amount of effort expended on applying and defending a dollar figure for the value of a (statistical) life were applied to other areas, it is likely that we would have a much better handle on the impacts of GHG policies and other areas of concern.

8. Summary

In this paper, I have laid out a framework to address the question of ancillary impacts on ecosystems from proposed GHG measures. The current state of knowledge does not permit a simple answer as to whether these are, on balance, positive or negative. It is apparent, though, that the impacts may be far ranging and significant.

It is my hope that further development and discussion of this framework will help to illuminate more examples of ancillary impacts deserving of further exploration. This, and advances in our understanding of ecosystems and their interactions with human systems are necessary to adequately answer the questions posed.

At the same time, I recognize that policy-makers cannot wait for definitive evidence to make decisions. By following the framework as defined, however, I feel that a better and more complete accounting of what we do know can be provided.

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5 Inappropriate use of economic valuation has been at the core of the criticisms of two major efforts in the last decade –the impacts of climate change (Pearce, Cline *et al.* 1996) and the value of the world's ecosystem services and natural capital (Costanza, d'Arge *et al.* 1997).

Table 1. **Ecosystem functioning, goods, and services**

Production of Goods
Food: terrestrial animal and plant products, forage, seafood, spice
Pharmaceuticals: medicinal products, precursors to synthetic pharmaceuticals
Durable materials: natural fiber, timber
Energy: biomass fuels, low-sediment water for hydropower
Industrial products: waxes, oils, fragrances, dyes, latex, rubber, precursors to many synthetic products
Genetic resources: intermediate goods that enhance the production of other goods
Life-Support Processes
Regeneration Processes
Cycling and filtration processes: detoxification and decomposition of wastes, generation and renewal of soil fertility, purification of air, purification of water
Translocation processes: dispersal of seeds necessary for revegetation, pollination of crops and natural vegetation
Stabilizing Processes
coastal and river channel stability
compensation of one species for another under varying conditions
control of the majority of potential pest species
carbon sequestration / partial stabilization of climate
regulation of hydrological cycle (mitigation of floods and droughts)
moderation of weather extremes (such as of temperature and wind)
Life-Fulfilling Conditions
aesthetic beauty
cultural, intellectual, and spiritual inspiration
existence value
scientific discovery
serenity
Preservation of Options
maintenance of the ecological components and systems needed for future supply of these goods and services and others awaiting discovery

Source: Daily 1999.

Table 2. **Values derived from ecosystem goods & services**

Socio-Cultural Criteria	Short Description
Importance To Human Health	These are derived from the maintenance of clean air, water, and soil, the development of new medicines, and the maintenance of mental health through the provision of opportunities for recreation and cognitive development.
Amenity Value	The direct enjoyment people derive from recreational activities in natural surroundings.
Heritage Value	The importance people attach to their cultural heritage, e.g., historic trees or specific landscape elements.
Bequest Value	The responsibility people feel towards future generations to conserve and enhance the evolution of natural ecosystems and biological diversity.
Existence Value*	The well-being ascribed to natural ecosystems and the wildlife they contain, as reflected in ethical and religious attitudes toward nature.
Option Value	The importance people place on a safe future (i.e., the future availability of a given amenity, good, or service) either within their own lifetime or for future generations.
Consumptive Use Value	The direct dependence of a community on natural ecosystems for resources (e.g., food), but also direct enjoyment of amenities (e.g., natural scenery)
Productive Use Value	The contribution of natural goods and services to economic production

*I changed this from intrinsic value in the original, in keeping with my use of the terms existence and intrinsic value.

Source: modified from de Groot, 2000.

Table 3. **Human pressures on ecosystems and landscapes**

Harvesting
Waste Residuals
Physical Restructuring
Magnified Extreme Events
Exotic Species Introductions

Source: Modified from Rapport, Costanza *et al.* 1998.

Table 4. **GHG policies considered**

Focused on Use of Fossil Fuels for Energy Production
Curtailment of Energy Use Changes in Energy Extraction and Production Methods Improvements in Energy Efficiency Fuel Switching (including increased use of hydropower) GHG Capture
Focused on Land-Use
Increase or Maintain the Area of Land in Forests Manage Forests to Store More Carbon Manage Non-Forested Lands to Store More Carbon Reduce Dependence on Fossil Fuels through Product Substitution
Other
Geo-Engineering Population Control

Table 5. **Linking policies and pressures**

	Pressure on Ecosystems				
GHG Policy	Harvesting	Waste residuals	Physical restructuring	Magnified Extreme Events	Exotic Species Introductions
Curtailment of Energy Use		+			
Changes in Energy Extraction and Production Methods		+	++		
Improvements in Energy Efficiency		++			
Fuel Switching (including increased use of hydropower)	+	++	++		
GHG Capture		+	+		
Increase or Maintain the Area of Land in Forests		+	++		+
Manage Forests to Store More Carbon	+	+	++	+	+
Manage Non-Forested Lands to Store More Carbon	+	+	++	+	+
Reduce Dependence on Fossil Fuels through Product Substitution	+		+		
+: potentially small effects; ++: potentially large effects					

Source: author's interpretation.

Table 6. **Some specific non-climate effects on ecosystems**

Flooding of Landscapes for Hydropower Production
Conversion of Landscapes for Carbon Sequestration
Reduced Soil Erosion from Land Management Changes Reduced Air Pollutants (Primary and Secondary) from Fossil Fuel Combustion Reduced Air, Water and Toxics Pollution from Large-Scale Energy/Materials Extraction, Production, and Transport Changes in Catastrophic Fire/Pest/Disease Potential in Heavily Managed Ecosystems

Table 7. **Some specific impacts on ecosystems (impacts - ecosystems)**

Impacts on Biodiversity from Physical Restructuring
Losses in Areas Flooded for Hydropower
Increases in Preserved and Restored Forested Areas
Losses in Areas Heavily Managed for Carbon Sequestration
Other Impacts from Physical Restructuring
Improvements in Net Primary Productivity from Reduced Erosion
Improvements in Water Quality from Reduced Erosion
Reduction in Flood Damage from Increased Water Retention and Reduced Erosion
Potential for Increased Pest/Disease/Fire Outbreaks
Impacts on Local and Regional Ecosystems from Air Pollutants
Reduced Eutrophication of Estuaries Associated with Airborne Nitrogen Deposition
Reduced Acidification of Freshwater Bodies Associated with Airborne Nitrogen and Sulfur Deposition
Improvements Tree Growth Associated with Damage from Ozone Exposure
Reduced Accumulation of Toxics in Freshwater Fisheries Associated with Airborne Toxics Exposure
Reduced Aesthetic Degradation of Forests Associated with Ozone and Airborne Toxics Deposition
Impacts on Local Ecosystems from Large-Scale Energy/Materials Extraction, Production, and Transport
Reductions in Damage from Oil Spills
Reductions in Damage from Strip and Underground Mining for Coal
Increased Bird Losses from Increased Wind Generation

Source: U.S. EPA 1999 and author's interpretation.

Table 8. **Some specific socio-economic effects (impacts - socio-economic)**

Changes in Opportunities for Recreation
Changed Opportunities in Flooded Areas
Changed Opportunities in Forest and Other Ecosystems
Improved Opportunities on Freshwater Bodies
Provision of Consumables
Changes in Availability of Timber and Non-Timber Products from Forests
Increases in Availability of Products from Freshwater Fisheries
Provision of Productive Inputs
Increases in Productivity of Forest Systems
Increases in Productivity of Freshwater and Marine Systems
Reductions in Expenses for Water Quality Treatment
Changes in Availability of Biological/Genetic Resources
Other
Reduction in Damage to Health and Property from Flooding
Potential for Increase in Damage to Health and Property from Pest/Disease/Fire Outbreaks

Sources: U.S. EPA (1999) and author's interpretation.

Table 9. **Techniques for economic valuation of ecosystem goods & services and environmental impacts**

	Type of Market		
Type of Behavior	Conventional	Implicit	Constructed
Actual	Direct Purchases Effect on Production Effect on Health Defensive or Preventative Costs	Travel Cost Hedonic – wage, property value Proxy Marketed Goods	Artificial Market
Intended	Replacement Cost Shadow Project		Contingent Valuation

Source: Modified from Munasinghe (2000).

Table 10. **Techniques vis à vis values**

	Value							
Technique	Human Health	Amenity	Heritage	Bequest	Existence	Option	Consumptive Use	Productive use
Direct Purchase	x						x	x
Effect on Production								x
Effect on Health	x							
Defensive or Preventative Costs	x							x
Replacement Costs								x
Shadow Project						x		
Travel Cost		x					x	x
Hedonic – Wage, Property Value		x					x	x
Proxy Marketed Goods		x						
Artificial Market		x						
Contingent Valuation	x	x	x	x	x	x	x	x

Source: Modified from de Groot (1997).

Table 11. **Quantification of ecosystem services as proposed by Bawa and Gadhgil**

	Pressure on Ecosystems				
Parameter	Direct Measure of Importance to Ecosystem People	Easy to Estimate	Estimates Non-Use Values	Incorporates Marginal Costs of Extraction and Benefits of Biodiversity	Importance to Policy Makers
Number of Persons Dependent on Ecosystem Services for Livelihood	x	x			
Value of Specific Products	x	x			x
Contribution to Cash Income	x	x			
Proportion of Households Dependent on Ecosystem Services for Livelihood		x			
Contribution to GDP			x		x
Value per Hectare			x		x

Source: Bawa and Gadghil (1997).

Table 12. **The five 'numeraires' as proposed by Schneider, et al.**

Monetary Loss
Loss of Life
Quality of Life (Including Coercion to Migrate, Conflict Over Resources, Cultural Diversity, Loss of Cultural Heritage Sites, etc.)
Species or Biodiversity Loss
Distribution/Equity

Source: Schneider, *et al.* (forthcoming).

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