Guidance Manual for the Valuation of Regulating Services

UNEP

UNITED NATIONS ENVIRONMENT PROGRAMME

DISCLAIMER

Guidance Manual For the Valuation of Regulating Services
ISBN: 978-92-807-3131-6
Job Number: DEP/1338/NA

Printing: Publishing Services Section, UNON, Nairobi-Kenya, ISO 14001:2004 certified

UNEP promotes
environmentally sound practices
globally and in its own activities.
This publication is printed on 100 per cent
chlorine free paper from sustainably managed
forests. Our distribution policy aims to reduce
UNEP's carbon footprint.

Guidance Manual for the Valuation of Regulating Services

Pushpam Kumar, Ecosystem Services Economics Unit, Division of Environmental Policy Implementation, United Nations Environment Programme
Madhu Verma, Indian Institute of Forest Management
Michael D Wood, School of Environmental Sciences, University of Liverpool
Dhaval Negandhi, Indian Institute of Forest Management

December, 2010

UNEP

UNIVERSITY OF LIVERPOOL

iifm

Contents

Glossary

Benefits: Positive change in well-being from the fulfilment of needs and wants.

Benefits transfer approach: Economic valuation approach in which estimates obtained (by whatever method) in one context are used to estimate values in a different context (Millennium Ecosystem Assessment MA, 2005).

Biodiversity (a contraction of biological diversity): The variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part. Biodiversity includes diversity within species, between species, and between ecosystems.

Biosphere: The sum of all ecosystems of the world. It is the component of the zone of the Earth that supports life.

Consumer surplus: The benefits enjoyed by consumers as a result of being able to purchase a product for a price that is less than the most that they would be willing to pay.

Contingent valuation: Stated preference-based economic valuation technique based on a survey of how much respondents would be willing to pay for specified benefits.

Cost-benefit analysis: A technique designed to determine the feasibility of a project or plan by quantifying its costs and benefits.

Cultural services: The nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g., knowledge systems, social relations, and aesthetic values.

Decision-maker: A person whose decisions, and the actions that follow from them, can influence a condition, process, or issue under consideration.

Direct use value (of ecosystems): The benefits derived from the services provided by an ecosystem that are used directly by an economic agent. These include consumptive uses (e.g., harvesting goods) and nonconsumptive uses (e.g., enjoyment of scenic beauty). Agents are often physically present in an ecosystem to receive direct use value.

Double counting of services: Erroneously including the same service more than once in an analysis.

Economic valuation: The process of expressing a value for a particular good or service in a certain context (e.g., of decision-making) in monetary terms.

Ecosystem accounting: The process of constructing formal accounts for ecosystems.

Ecosystem function: See Ecosystem process

Ecosystem management: See Management (of ecosystems)

Ecosystem process: An intrinsic ecosystem characteristic whereby an ecosystem maintains its integrity. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy.

Ecosystem services: The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth. The concept "ecosystem goods and services" is synonymous with ecosystem services (MA 2005). This MA typology provides one definition and classification scheme but, for the purposes of economic analysis, ecosystem services may also be defined as the direct and indirect contributions of ecosystems to human well-being.

Elasticity: A measure of responsiveness of one variable to a change in another, usually defined in terms of percentage change. For example, own-price elasticity of demand is the percentage change in the quantity demanded of a good for a 1 percentage change in the price of that good. Other common elasticity measures include supply and income elasticity.

Equity: Fairness of rights, distribution, and access. Depending on context, this can refer to resources, services, or power.

Final services: Ecosystem services with direct effects on human well-being.

Functional groups: Groups of organisms that respond to the environment or affect ecosystem processes in a similar way. Examples of plant functional types include nitrogen- fixer versus non-fixer, stress-tolerant versus ruderal versus competitor, resprouter versus seeder, deciduous versus evergreen. Examples of animal functional types include granivorous versus fleshy-fruit eater, nocturnal versus diurnal predator, browser versus grazer.

Indirect use value: The benefits derived from the goods and services provided by an ecosystem that are used indirectly by an economic agent. For example, an agent at some distance from an ecosystem may derive benefits from drinking water that has been purified as it passed through the ecosystem.

Intermediate services: Ecosystem services which contribute to the delivery of final services but do not affect human well-being directly.

Management (of ecosystems): An approach to maintaining or restoring the composition, structure, function, and delivery of services of natural and modified ecosystems for the goal of achieving sustainability. It is based on an adaptive, collaboratively developed vision of desired future conditions that integrates ecological, socioeconomic, and institutional perspectives, applied within a geographic framework, and defined primarily by natural ecological boundaries.

Non-linearity: A relationship or process in which a small change in the value of a driver (i.e., an independent variable) produces an disproportionate change in the outcome (i.e., the dependent variable). Relationships where there is a sudden discontinuity or change in rate are sometimes referred to as abrupt and often form the basis of thresholds. In loose terms, they may lead to unexpected outcomes or "surprises".

Opportunity cost: The benefits forgone by undertaking one activity instead of another.

Option value: The value of preserving the option to use services in the future either by oneself (option value) or by others or heirs (bequest value). Quasi-option value represents the value of avoiding irreversible decisions until new information reveals whether certain ecosystem services have values society is not currently aware of.

Producer surplus: The benefits enjoyed by producers as a result of being able to sell a product for a price that is higher than the least that they would be willing to sell for.

Productivity: Rate of biomass produced by an ecosystem, generally expressed as biomass produced per unit of time per unit of surface or volume. Net primary productivity is defined as the energy fixed by plants minus their respiration.

Provisioning services: The products obtained from ecosystems, including, for example, genetic resources, food and fiber, and fresh water.

Regulating services: The benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases.

Resilience: The level of disturbance that an ecosystem can undergo without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics as well as the organizational and institutional capacity to understand, manage, and respond to these dynamics.

Revealed preference: Consumer preferences can be understood through observations of consumer behavior.

Scale: The measurable dimensions of phenomena or observations expressed in physical units, such as meters, years, population size, or quantities moved or exchanged. In observation, scale determines the relative fineness and coarseness of different detail and the selectivity among patterns these data may form.

Stakeholder: A person, group or organization that has a stake in the outcome of a particular activity.

Stated preference: Consumer preference understood through questions regarding willingness to pay or willingness to accept.

Supporting services: Ecosystem services that are necessary for the production of all other ecosystem services. Some examples include biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat.

Sustainability: A characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs.

Sustainable flow (of ecosystem services): The availability of ecosystem services to yield a continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations.

Sustainable use (of ecosystems): Using ecosystems in a way that benefits present generations while maintaining the potential to meet the needs and aspirations of future generations.

Trade-offs: Management choices that intentionally or otherwise change the type, magnitude, and relative mix of services provided by ecosystems.

Utility: In economics, the measure of the degree of satisfaction or happiness of a person.

Valuation: The process of expressing a value for a particular good or service in a certain context (e.g., of decision-making) usually in terms of something that can be counted, often money, but also through methods and measures from other disciplines (sociology, ecology, and so on).

Value: The contribution of an action or object to user-specified goals, objectives, or conditions.

Well-being: A context- and situation-dependent state, comprising basic material for a good life, freedom and choice, health and bodily well-being, good social relations, security, peace of mind, and spiritual experience (MA 2005).

Willingness to accept: The minimum amount that a person is willing to receive to give up a good in their possession.

Willingness to pay: The maximum amount that a person is willing to pay for a good they do not have.

FOREWORD

Services derived from ecosystems contribute to individual and societal well-being. They fall into categories such as provisioning services like food and timber; regulating services like climate regulation and waste minimization; cultural services from education to aesthetics and supporting services such as soil formation and nutrient cycling.

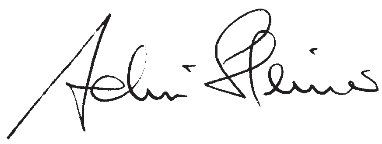
In recent years, economic valuation of ecosystem services has increasingly been seen by decision makers and development practitioners, as a tool to resolve conflicting choices and trade-offs, involving limited and competing resources.

Most of the provisioning and cultural services of ecosystem such as timber, fish and recreation are easily captured by economists through well-known market and non market methods.

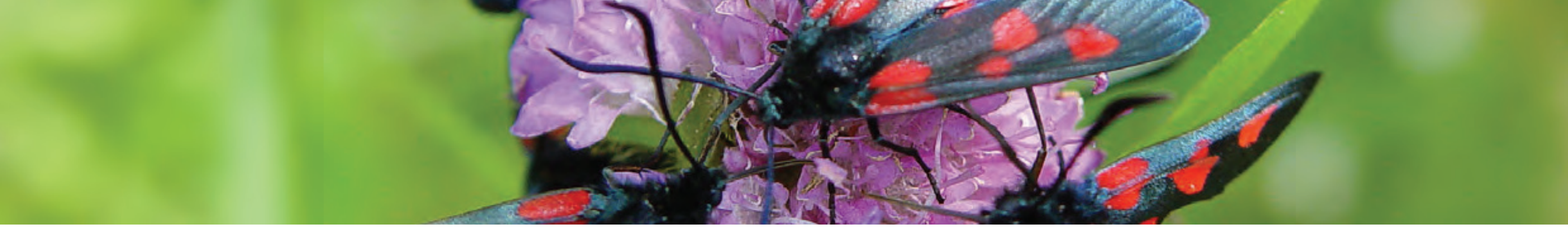
Nevertheless, valuation of regulating services such as regulation of climate, water and some human diseases and supporting services such as bioremediation by wetlands or carbon storage by forest are more difficult to estimate and thus pose serious challenges to planners and practitioners.

Valuation of regulating services has special significance in the context of ecosystem accounting at the level of national income to make it more sustainable and comprehensive. Several developing countries like Brazil and India are now attempting to undertake such accounting as part of initiative to translate the global work of The Economics of Ecosystems and Biodiversity (TEEB) into national settings. Valuing regulating services also help in establishing the credibility of innovative response policies such as Payment for Ecosystem Services (PES). PES has potential to provide cost effective management options for ecosystems including bringing clarity to issues like Access and Benefit Sharing (ABS) of genetic resources for biodiversity conservation.

This manual explores methods and necessary tools for valuing regulating ecosystem services. It explains the concept and methodology involved. The clarity in methodological steps, combined with rich illustrations, should prove an asset for practitioners and end users alike.



Mr. Achim Steiner,
United Nations Under-Secretary General and Executive Director,
United Nations Environment Programme



1. Introduction

1.1 Regulating services of ecosystems

Natural ecosystems deliver a range of benefits for people. These benefits are known as ecosystem services. The Millennium Ecosystem Assessment (MA) typology of ecosystem services identified four main categories:

Provisioning services – The products obtained from ecosystems, including genetic resources, food and fiber, and fresh water.

Regulating services – The benefits obtained from the regulation of ecosystem processes, including the regulation of climate, water, and some human diseases.

Cultural services – The nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, knowledge systems, social relations, and aesthetic values.

Supporting services – Ecosystem services that are necessary for the production of all other ecosystem services. Examples include biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat.

Supporting services and many regulating services underpin the delivery of the other service categories. Regulating services provide many direct and indirect benefits to humans, including clean air and water, pollination, climate regulation and disease control (Table 1). The maintenance of the Earth's biosphere in an otherwise hostile cosmic environment depends on a delicate balance between these regulating services (de Groot et al. 2002). Sustainable ecosystem service delivery depends on the health, integrity and resilience of the ecosystem.

For economic valuation, the services flowing from ecosystems must be amenable to economic analysis in that they should serve the consumptive or productive purposes of humans. Most of the provisioning and cultural services like timber, fish and recreation are services that the economics profession has long been adept at estimating the economic value of. However, regulating services present much greater challenges (Kumar and Wood 2010).

One area of confusion in the valuation of regulating services has been the difficulties faced in deciding on what should be valued – the ecosystem processes or the service. Actually, benefits are the end element of an ecosystem process-service-benefit chain and only these benefits enter into the domain of well-being that is likely to be analyzed for policy and decision-making discourse (Fisher and Turner 2008). Regulating services of ecosystems can be both final and intermediate services. Economic science uses the taxonomy of final and intermediate good, stock and flow for accounting and valuation purposes. Adopting the final and intermediate classification of regulating services enables a more direct aligning and application of classical valuation methodologies to estimating the value of regulating services.

Table 1. Examples of regulating services (MA 2005)

Service	Definition	Examples
Air quality regulation	Influence ecosystems have on air quality by emitting chemicals to the atmosphere (i.e., serving as a "source") or extracting chemicals from the atmosphere (i.e., serving as a "sink")	• Lakes serve as a sink for industrial emissions of sulphur compounds • Vegetation fires emit particulates, ground-level ozone, and volatile organic compounds
Climate regulation	Global: Influence ecosystems have on global climate by emitting greenhouse gases or aerosols to the atmosphere or by absorbing greenhouse gases or aerosols from the atmosphere	• Forests capture and store carbon dioxide • Cattle and rice paddies emit methane
	Regional and local: Influence ecosystems have on local or regional temperature, precipitation, and other climatic factors	• Forests can affect regional rainfall levels
Water regulation	Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge, particularly in terms of the water storage potential of the ecosystem or landscape	• Permeable soil facilitates aquifer recharge • River floodplains and wetlands retain water – which can decrease flooding during runoff peaks – reducing the need for engineered flood control infrastructure
Erosion regulation	Vegetative cover retains soil; coral reefs protect coastal areas	• Vegetation such as grass and trees prevents soil loss due to wind and rain, and prevents siltation of water ways • Forests on slopes hold soil in place, thereby preventing landslides
Water purification and waste treatment	Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through soil and subsoil processes	• Wetlands remove harmful pollutants from water by trapping metals and organic materials • Soil microbes degrade organic waste, rendering it less harmful
Disease regulation	Influence that ecosystems have on the incidence and abundance of human pathogens	• Intact forests reduce the occurrence of standing water – a breeding area for mosquitoes – and thereby can reduce the prevalence of malaria
Soil quality regulation	Role ecosystems play in sustaining soil's biological activity, diversity and productivity; in regulating and partitioning water and solute flow; and in storing and recycling nutrients and gases	• Some organisms aid in decomposition of organic matter, increasing soil nutrient levels • Some organisms aerate soil, improve soil chemistry, and increase moisture retention • Animal waste fertilizes soil
Pest regulation	Influence ecosystems have on the prevalence of crop and livestock pests and diseases	• Predators from nearby forests – such as bats, toads, and snakes – consume crop pests
Pollination	Role ecosystems play in transferring pollen from male to female flower parts	• Bees from nearby forests pollinate crops
Natural hazard regulation	Capacity for ecosystems to reduce the damage caused by natural disasters such as hurricanes to maintain natural fire frequency and intensity	• Mangrove forests and coral reefs protect coastlines from storm surges • Biological decomposition processes reduce potential fuel for wildfires

1.2 Objectives of this manual

The objectives of this manual are:

- to identify and evaluate different methodologies for valuing regulating services in economic terms;
- to provide guidance on the main issues that need to be considered and addressed when using these different valuation methodologies;

- to demonstrate, through case studies, the application of these methodologies to the valuation of regulating services and the scope for incorporating these values into decision-making processes.

The theory and general guidance is provided in the main text of the manual. The case studies are presented in the Appendix.

1.3 Users of this manual

This manual is directed towards practitioners in environmental economics. Its primary use is expected to be as a supporting tool for estimating the economic value of regulating services provided by a particular ecosystem in a particular area and for a specified time period.

Policy-makers, interest groups and the public require reliable information on the environmental, social and economic value of regulating services to make informed decisions on optimum use and on the conservation of ecosystems. Information on the economic value of regulating services is thus needed for evaluating different land-use options.

The manual attempts to answer some of the basic questions that may arise in the mind of policy-makers: What are the economic values of various regulating services and why are these values useful? In what contexts should these economic values be used? Whose perspective is considered while estimating these values? How can these values be put into practice? The discussion is supported by a compendium of case studies (presented in the Appendix).

Although the manual has been developed for practitioners, it is recognized that decision-makers and other stakeholders may wish to use the manual to develop their own understanding of the valuation process. To make the manual accessible to these other potential users, the text has been written with this wider readership in mind and a glossary has been provided at the start of the manual.

2. Background to economic valuation of regulating services

Environmental decision-makers must make choices between options that are often characterized by a wide range of conflicting impacts, which are expressed in incommensurable units. Impacts may be expressed in physical terms (e.g., change in forest cover), monetary terms or qualitatively. To simplify decision-making it is advantageous to convert these impacts to a commensurable unit.

Economic value establishes a common metric of value (money). Because all values are estimated using this common metric, values of different goods and services can be aggregated, i.e., commensurable values can be established (DEFRA 2007). Various stakeholders have different and often competing interests in natural resources which provide regulating services (Pagiola et al. 2004). Estimating the values of unlike goods and services provides the opportunity to make comparisons on the best use for a given natural resource. Such comparison should be made in specific decision contexts with specific trade-off criteria (Barbier et al. 1997, Gregersen et al. 1999).

Despite the perceived ecological, environmental and socio-economic values of regulating services, there are many shortcomings in the management, utilization, conservation and protection of ecosystems that produce these services. One reason for this is that their true economic values have not been estimated accurately.

Ecosystems produce various goods and services which contribute to meeting needs of mankind in different ways. These contributions occur through: (1) direct use of the goods and services; (2) indirect use of the goods and services; (3) option for future use of goods and services; and (4) the mere existence of ecosystems. Ideally, values of goods and services should reflect the best alternative use for resources (true opportunity cost), or the true willingness to pay for the goods and services, excluding government interventions and including all the externalities. However, conventional analysis, based mostly on marketable value, often fails to capture the benefits completely. This is because many of these services do not enter the market, only a part of the total benefits are actually recorded by market transactions and many of these benefits are actually misattributed (Panayotou 1998). For example, the water regulation services provided by a wetland may appear as higher profits in water using sectors and not as benefits provided by the wetland ecosystem (Barbier et al. 1997).

Economic value estimates and measures are based on people's preferences. It is generally assumed that individuals, and not the government, are the best judges of what they want. People express their preferences through the choices and trade-offs they make.

The economic value of any service, for example traveling in a flight from one place to another, is measured by the maximum amount of other things that a person is willing to give up. In a market-based economy, money is the universally accepted measure of economic value. Thus, the number of dollars that a person is willing to pay for traveling on a flight from one place to another should equate to the other goods and services that they are willing to give up to take that flight. This is often referred to as "willingness to pay (WTP)".

In general, if the price of a good or service increases, the demand for that particular good or service decreases. This is referred to as the law of demand. By estimating the demand for a good or service at different prices and plotting a graph, we can construct the demand curve for that good or service.

A common mistake is to think that the market price of a good or service is its actual economic value. In fact, the market price only tells us the minimum amount that people are willing to pay for that good or service. As discussed previously, markets are rarely perfect so market price is unable to reflect the true economic value of an ecosystem good or service. When the market doesn't capture the value of these services, techniques associated with "shadow pricing" can be used to indirectly estimate their value (Panayotou 1998, DEFRA 2007, Dasgupta 2010, Polasky and Segerson 2009, Barbier 2007, Morse-Jones et al. 2009).

In order to make a case for efficient resource allocation based on economic valuation of regulating services, we require an estimate of the net economic benefit from that regulating service. The total net economic benefit from the service is the sum of consumer surplus and producer surplus.

Consumer surplus is the additional amount that the consumers are willing to pay for a particular regulating service, beyond what they actually pay, is the consumer surplus associated with that regulating service. This amount can be estimated easily if we are able to derive the demand curve for the regulating service. It is important to note here that consumer surplus is sensitive to the market price of a particular regulating service, whereas the willingness to pay for that service is independent of its market price.

Complementary to the demand curve, the supply curve shows the quantity of supply for a particular good or service at different prices. Producers of goods and services receive economic benefits based on the profits they make from selling. Economic benefits in this case are measured by producer surplus which is the amount that producers receive for a given good or service by selling it, beyond the amount they are willing to sell that good or service for.

Generally, regulating services are not sold and bought in markets, so people do not pay for these services directly. However, it should not be assumed that services do not have value, just because they are not traded in the market. People derive utility from the services provided by ecosystems. This paradigm of value, based on the principle of human welfare, is known as the utilitarian concept. All methods of economic valuation are based on the theoretical axioms and principles of welfare economics. These measures of change in welfare are reflected in people's WTP or willingness to accept (WTA) compensation for changes in ecosystem goods and services. Although WTP and WTA are often used interchangeably, WTP, which provides a measure of how much purchasing power people are willing to give up to get a particular (or set of) regulating services, should be used when beneficiaries of ecosystem services do not own the resource or when service levels are being increased. In contrast, WTA is appropriate when beneficiaries own the resource providing the service or when the service levels are being reduced (MA 2005).

3. Role of valuation in decision making

Regulating services are generally under-valued in a decision-making context so it is hardly surprising that ecosystems are being rapidly modified, converted, over-exploited and degraded in the interests of other more 'productive' land and resource management options, which appear to yield much higher and more immediate profits (Emerton 2003). Typically, even if individuals are aware of the regulating services provided by an ecosystem, they are neither compensated for providing these services nor penalized for misusing them (MA 2005).

The problem is not that regulating services have no economic value, but rather that this value is poorly understood, rarely articulated, and as a result is rarely taken into account during decision-making (Emerton et al. 2002). Although conventional analysis states that the most efficient allocation of resources is the one that maximizes economic returns, calculations of the returns to different land, resource and investment options have for the most part failed to deal adequately with values of regulating services (Heal 2000).

Decisions regarding land-use management have generally been made on the basis of partial information and have thus favored short-term (and often unsustainable) development imperatives (See Box 1). In the absence of information on the 'true' economic value of regulating services, substantial misallocation of resources has occurred (James 1991). Valuation of regulating services can provide a powerful instrument for placing this issue on the agenda of decision-makers. The basic aim of valuation is to determine people's preferences: how much are people willing to pay for regulating services, and how much better or worse off would they consider themselves to be as a consequence of changes in the supply of these regulating services. By reflecting these preferences, valuation aims to make regulating services comparable with other economic sectors when decisions are taken regarding land and resource use. When properly valued, the total economic value (TEV) of regulating services in most instances exceeds the economic gains, mainly financial, from activities which are based on ecosystem conversion or degradation (Emerton et al. 2002, Pagiola et al. 2004).

Box 1: Dual nature of regulating services (Gregersen et al. 1999)

A forester suggests to a regional governor that reforestation and related activities could reduce soil erosion rates on abandoned agricultural land in a river valley by as much as 7 tons per hectare per year. Reducing soil erosion is a positive environmental impact. However, in and of itself, the reduced soil loss is not necessarily a benefit to humans. The governor would ask how the environmental impact will affect the people in his jurisdiction.

The economic benefits involved depend on where the environmental impact occurs. If the river valley is unpopulated and the river flows into the ocean with little or no use by humans, the benefits from the reduced erosion are likely to be quite small in terms of economic values. At the other extreme, if the river flows into a dam reservoir that provides hydro-power and drinking and irrigation water for hundreds of thousands of people in the governor's territory, the reduced erosion could reduce sediment build-up and loss of necessary capacity of the reservoir and thus avoid losses below the dam that have direct economic impacts.

In essence, a positive environmental impact due to a reduction in erosion will mean little to the decision-maker unless it is translated into economic terms, i.e., into impacts on people, e.g., through avoidance of loss of on-site production values, reduction in loss of life due to flooding, and reductions in loss of irrigated crops and in hydro-power values.

The values required for decision-making and the methodology (or methodologies) used to estimate them, will depend on the decision context (Gregersen et al. 1999). In all cases, we are interested in incremental changes in values rather than absolute values (Pagiola et al. 2004). These incremental changes in the values of regulating services associated with a proposed activity should be compared with the status quo, i.e., the comparison should be between estimates in situations "with and without" the proposed activity (Bingham, et al., 1995, DEFRA 2007).

4. Understanding regulating services

Regulating services such as water and disease regulation often tend to change over much longer time scales than do provisioning services. Consequently, managers often overlook impacts on more slowly changing regulating services when pursuing increased usage of provisioning services.

Regulating services contribute to provisioning services by providing enabling conditions for the flow of such provisioning services. For example, regulating services reduce soil erosion and modulate micro-climatic conditions that are beneficial to crop production, indirectly enhancing agricultural productivity. On a large scale, various parts of ecosystems, such as land cover, soil organisms and phytoplankton, regulate climate (Falkowski et al. 2000).

Growing evidence indicates that many indigenous communities recognize the importance of regulating services provided by different ecosystems. Certain traditions and customs help to conserve biodiversity, providing protection against excessive land-clearing and maintaining water quality (Ramakrishnan et al. 1998, Atran, et al. 1999, Berkes and Kslalioglu, et al. 1998, Berkes 2003, Folke 2004).

Most of the decisions about ecosystem services involve trade-offs (Rodríguez, et al. 2006). Trade-off occurs between different services as well as between the present and future supply of a service. For example, consider the simple case of agriculture. Agriculture improves food availability (provisioning service) by clearing forest which leads to a decline in services such as water purification and climate regulation (regulating services) provided by the patch of forest that existed before. In such decisions about ecosystem services which involve trade-offs, people generally prefer provisioning and cultural services over regulating services (Carpenter et al. 2006). Thus, people often tend to undervalue regulating services that create other services. Consequently, decision-makers often ignore these regulating services in ways that seriously undermine the long-term existence of provisioning services from different ecosystems.

Impacts of extreme events can be moderated by building ecological resilience through greater attention to regulating services. These services are associated with the capacity of ecosystems to cope with, or to adapt to, disturbances of various kinds (Carpenter, Bennett and Peterson 2006). Thus, maintenance and enhancement of regulating services provide important insurance and adaptability against accelerating ecological changes.

De Groot et al. (2002) have demonstrated that regulating services do not always show a one-to-one correspondence: sometimes a regulating service is the product of two or more processes whereas in other cases a single process contributes to more than one service. For example, the gas regulation service is based on biogeochemical processes which maintain a certain air quality but also influence the greenhouse effect and thereby regulate climate.

5. Regulating services across various ecosystems

5.1 Air quality regulation

Life on Earth exists within a narrow band of chemical balance in the biosphere. Any change in this balance can have serious implications on social and economic processes (de Groot et al. 2002). Regulating services help to maintain the general chemical composition of the atmosphere, thereby contributing in keeping the planet habitable.

Trees trap airborne particulate matter and help to improve air quality and human health. Air quality regulation is particularly important in the urban context, with rising populations and industrial growth. A study conducted in Tuscon, Arizona estimated that planting 500,000 mesquite trees would remove 6,500 tonnes of particulate matter annually once the trees reach maturity (McPherson 1992, Dwyer et al. 1992). Tuscon spends approximately US$ 1.5 million on an alternative dust-control program. Thus, the air quality regulation value of each tree in Tuscon is US$ 4.16.

5.2 Biodiversity regulation

Although this category of regulating service has a limited use value, be it direct or indirect, biodiversity regulation is important for many reasons, including its role as a storehouse for genetic material that can be used in the future (option value) and its contribution to natural pest and disease control (Krieger 2001). The US Forest Service estimates that replacing the pest control services of birds in forests with chemical pesticides would cost more than US$ 17 per hectare (Moskowitz and Talberth 1998). Moskowitz and Talberth (1998) report that the cost to US agriculture of replacing natural pest control services by ecosystems with chemical pesticides would be approximately US$ 54 billion annually. Reid (1999) reports a case of a banana plantation in Costa Rica which pays an adjacent forested conservation area US$ 1.00 per hectare annually to provide natural pest control services. Because such costs have not actually been incurred, these estimates represent only the cost of replacing these regulating services and not the actual value of these services.

5.3 Pollination

Worldwide, there has been growing realization of the importance of pollination services for both wild plant communities and agricultural systems (Buchmann and Nabhan 1996, Allen-Warden 1998). Many economically important species require pollination to produce marketable crops. Yet, hard figures on the economic value of pollination are still lacking. Very few studies have specifically conducted analyses that match the scales at which land-use decisions are made. Estimates of the annual monetary value of pollination vary widely, from US$120 billion annually for all pollination services (Costanza et al. 1997), to US$ 200 billion per year for global agricultural alone (Richards 1993). This wide range, to a certain extent, represents the lack of common methods for valuing pollination. There are no precise estimates for the dependence of food production on pollination across the world, a range of approximately 1/4 to 1/3 is usually quoted as the amount of food produced that is dependent on pollination based on yields, recognizing that there is marked regional variation (Gemmill et al. 2009, FAOSTAT 2009) (See Case studies 08 and 18). The heterogeneity in the methodology is due to differences in context, purpose and availability of data.

Pollinator-dependent crops in Africa are presented in Table 2. The table provides estimates of the yield increase from pollinator visits and an indication of the estimate uncertainty. Estimates of yield increases are primarily taken from Crane and Walker (1984). The regulating service of pollination provides benefits to US agriculture in the range of US$ 4 to 7 billion annually (Moskowitz and Talberth 1998, Taylor 2004).

Table 2. Pollinator-dependent crops in Africa (Gemmill et al. 2009)

Commodity	Combined rank, acreage and production	Estimated yield increase from pollinator (%)	Certainty of estimate (%)
1. Groundnuts in shell	5	10	40
2. Oil palm fruit	7	100	100
3. Seed cotton	10	50	50
4. Cow peas, dry	13	10	90
5. Beans, dry	17	40	40
6. Cocoa beans	18	90	90
7. Tomatoes	18	2 to 25	80
8. Citrus fruit	23	10 to 20	50
9. Coffee, green	30	20	80
10. Oranges	33	10 to 20	50
11. Coconuts	34	Not available	0
12. Sesame seed	37	50	40
13. Sunflower seed	37	75	80
14. Broad beans, dry	38	30	30
15. Mangoes	39	100	50
16. Pulses	39	30	30
17. Soyabeans	39	10	10
18. Watermelons	44	100	100
19. Dates	45	50	50
20. Cashew nuts	46	80	50
21. Pumpkins, squash, gourds	50	100	100
22. Okra	53	90	40
23. Melonseed	56	100	100
24. Apples	56	100	100
25. Papayas	62	100	100
26. Cucumber and gherkins	62	100	100
27. Karite Nuts (sheanuts)	62	Not available	0
28. Chick peas	63	0	20
29. Pimento, all spice	63	100	50
30. Peas, dry	65	40	20
31. Pigeon peas	72	20	10
32. Almonds	75	100	100
33. Peaches and nectarines	75	50	50
34. Kolanuts	75	100	50

Commodity	Combined rank, acreage and production	Estimated yield increase from pollinator (%)	Certainty of estimate (%)
35. Eggplants	79	60	90
36 Figs	80	100	100
37. Peas, green	87	40	20
38. Lemons and limes	89	10 to 20	50
39. Pears	90	80	50
40. Lentils	93	5	50
41. Grapefruit and pomelos	94	20	20
42. Vetches	94	25	50
43. Beans, green	95	75	25
44. Linseed	96	50	50
45. Apricots	96	80	100
46. Avocados	102	50	50
47. Broad beans, green	107	30	30
48. Cloves, whole + stems	109	100	50
49. Anise, badian, fennel	110	50	50
50. Safflower seed	112	50	50
51. Plums	113	30	80
52. Castor beans	114	10	50
53. Rapeseed	119	90	80
54. Cashewapple	123	80	50
55. Strawberries	125	90	75
56. Lupins	127	Not available	0
57. Pyrethrum, dried flowers	138	30	25
58. Quinces	139	80	20
59. Pepper, white/long/black	140	10	10
60. Vanilla	141	100	100
61. Pistachios	145	20	50
62. Tung nuts	146	100	80
63. Cherries	148	100	80
64. Nutmeg, mace, cardamons	157	100	80
65. Raspberries	165	50	50
66. Blueberries	168	50	50
67. Cranberries	170	80	50
68. Kiwi fruit	172	100	70

5.4 Shoreline protection

Valuation of the shoreline protection services provided by natural infrastructures requires an understanding of the protection afforded by different types of natural systems in different natural settings, under different storm scenarios, coupled with information on property values in areas receiving at least some protection from the natural systems under analysis (WRI 2009). The usual methodology used for valuing this function is the "avoided cost" approach. It involves estimating the likely damage (and associated economic losses) to a coastal area from a given storm event, both with and without the natural infrastructure presence. The difference is "avoided damages", which can be attributed as the benefits derived from these natural systems (Das and Vincent 2007).

Some of the essential elements of understanding the damages avoided due to the presence of natural infrastructures (WRI 2009) include:

- Understanding the storm regime for an area (frequency, intensity, storm surge, wave height associated with expected storm as well as the historic damage caused by such storms).
- Identifying vulnerable land areas susceptible to wave-induced erosion and storm damage. These areas can generally be classified based on elevation and coastal proximity.
- Identifying coastal segments which are protected by natural infrastructures.
- Evaluating the share of coastal protection provided by natural systems.
- Estimating the property values of land areas identified as both vulnerable to and protected against storm-damages. The damages should also account for the revenues generated by businesses in the area.
- Combining all these individual elements to estimate the reduction in damages attributable to natural systems.

There are inevitable uncertainties associated with this multi-stage modeling approach. To reflect the uncertainties surrounding these estimates, ranges (such as +/- 20%) can be established around the central estimates (WRI 2009).

The Institute of Marine Affairs in Trinidad developed a coastal protection classification index which integrates nine physical characteristics to estimate the relative resistance of each coastal segment to wave-induced erosion and storm-damages (WRI 2009). These indices can be used to evaluate the role that natural infrastructures play in reducing vulnerability to erosion and damage (See Box 2 and Table 3). The methodology has been developed keeping in mind that reliable estimates of the cost of replacement by man-made structures are limited, making estimation of value difficult.

Box 2. Coastal Protection Index (WRI 2009)

The coastal protection index integrates data on coastal geomorphology (limestone cliff, beach, etc.); coastal geology (igneous, metamorphic, etc.); coastal exposure (protected by headland, seawall, or riprap, or exposed); wave energy (typically maximum wave height); storm frequency (frequency of tropical storms and hurricanes); natural infrastructure characteristics (type of reef, continuity, and distance from shore); coastal vegetation (mangroves, wetlands, etc.); coastal elevation (meters); coastal slope (percent); and the presence of erosive anthropogenic activities like sand mining. The coastal protection index is the average value for the ten factors having different values combined. This integration of individual factors is done in a geographic information system. Each of the above factors can range in value from 0 to 4 (4 being the highest stability). The factors and their associated values are provided in Table 3. As comprehensive data is not always available for all the factors, one should include as many factors as possible (above a bare minimum of five).

5.5 Soil stabilization and erosion control

Ecosystems such as forests, wetlands and mangroves help to stabilize soils, reducing erosion. The vegetative cover shelters soil from the force of rain by intercepting rainfall while roots help to maintain the soil structure (Myers 1996). Plants growing along shorelines and submerged vegetation near coastal areas contribute greatly in controlling erosion and facilitating sedimentation (See Case study 04).

Table 3. Coastal Protection Factors (WRI 2009)

<table>
<tr><th colspan="2" rowspan="2">Factor</th><th colspan="9">Level of Coastal Protection</th></tr>
<tr><th colspan="2">Very High
4</th><th colspan="2">High
3</th><th colspan="2">Medium
2</th><th colspan="2">Low
1</th><th>None
0</th></tr>
<tr><td colspan="2">Coastal geomorphology</td><td colspan="2">Rocky, cliffed coastline or sea wall</td><td colspan="2">Soft (limestone) cliffs or low bluffs</td><td colspan="2">Mangroves</td><td colspan="2">Beaches</td><td>N/A</td></tr>
<tr><td colspan="2">Coastal geology</td><td colspan="2">Igneous and/or volcanic</td><td colspan="2">Metamorphic</td><td colspan="2">Sedimentary</td><td colspan="2">Unconsolidated sediments</td><td>N/A</td></tr>
<tr><td colspan="2">Coastal protection structures</td><td colspan="2">Significantly protected by a large atoll or 2 prominent headlands</td><td colspan="2">Protection by atoll, or by headlands</td><td colspan="2">Slightly protected by atoll</td><td colspan="2">Protected by one or two small headlands</td><td>No protection by atoll or headlands</td></tr>
<tr><td rowspan="3">Coral Reef Index (sum of 3 factors/10*4)</td><td>Reef type</td><td colspan="2">Emergent reef (barrier or windward side atoll)</td><td colspan="2">Fringing and leeward side of atoll</td><td colspan="2">Patch</td><td colspan="2">–</td><td>No reef present</td></tr>
<tr><td>Reef distribution</td><td colspan="2">–</td><td colspan="2">–</td><td colspan="2">Continuous</td><td colspan="2">Discontinuous</td><td>No reef present</td></tr>
<tr><td>Reef distance offshore (mts)</td><td><250 meters</td><td>250-500 meters</td><td>0.5-1.0 kms</td><td>1-2 kms</td><td>2-4 kms</td><td>4-8 kms</td><td>8-16 kms</td><td>>16 kms</td><td>No reef present</td></tr>
<tr><td colspan="2">Wave energy (~ maximum wave height)</td><td colspan="2"><25 cm</td><td colspan="2">25-50 cm</td><td colspan="2">50-100 cm</td><td colspan="2">1-2 mt</td><td>>2 mts</td></tr>
<tr><td colspan="2">Storm/ hurricane events</td><td colspan="2">Affected by at east a category 1 every 25 years</td><td colspan="2">Affected by at least a category 2 every 25 years</td><td colspan="2">Affected by at least a category 3 every 25 years</td><td colspan="2">2 or more category 3 or higher expected every 25 years</td><td>N/A</td></tr>
<tr><td colspan="2">Coastal elevation (mts)</td><td colspan="2">>12 mts</td><td colspan="2">6-12 mts</td><td colspan="2">2-5 mts</td><td colspan="2">0-1 mts</td><td>N/A</td></tr>
<tr><td colspan="2">Coastal vegetation (type)</td><td colspan="2">Mangroves</td><td colspan="2">Forest/coastal woodlands</td><td colspan="2">Shrub and thicket</td><td colspan="2">Savannah and wetlands</td><td>None</td></tr>
<tr><td colspan="2">Coastal anthropogenic activities</td><td colspan="2">No sand mining, coastal development, etc.</td><td colspan="2">Misc. other activities</td><td colspan="2">Either sand mining or coastal development</td><td colspan="2">Sand mining and coastal development</td><td>N/A</td></tr>
</table>

The costs associated with erosion include loss of soil productivity for agriculture, damage to roads and other infrastructure, filling in of ditches and reservoirs, reduced water quality and impacts on fish populations (Krieger 2001). The value estimates of this service primarily reflect the costs associated with sedimentation.

Another aspect of this regulating service is the soil formation function. Soil is formed through the weathering of rocks and gradually becomes fertile through the accretion of organic matter and minerals (de Groot 2002). This slow process (Pimentel et al. 1997) has significant implications for maintenance of crop productivity on cultivated lands (See Case study 15).

5.6 Water quality regulation

Ecosystems such as forests and wetlands help to purify water by stabilizing soils and filtering pollutants from water. The quantity and quality of water flowing through the watersheds are important inputs to agriculture, hydro-power plants, and municipal water supplies. The cost of constructing and operating a water treatment plant to purify the polluted water is a common measure of the value of water purification service. Estimates of water quality values range from US$ 0.26 per acre-foot for electricity generation to as high as US$50 per acre-foot for irrigation and municipal use in US (Krieger 2001).

Water quality is of particular importance to the municipalities. The U.S. Environmental Protection Agency estimates that approximately 60 million people in the US obtain water through 3,400 public water systems from watersheds that contain natural forests (Sedell et al. 2000). The value of this service (water purification and treatment) from different ecosystems is reflected in the costs that society incurs to protect these ecosystems for ensuring continuous water supply of desired quality (See Case study 06). Similarly, Portland, Oregon and Portland, Maine spend US$ 920,000 and US$ 729,000 respectively per year to protect the watersheds that supply water (Reid 1999).

5.7 Waste treatment and processing

Ecosystems play an important role in the treatment of wastes introduced into the natural environment, but there are some inherent limits to this waste processing capability. For example, aquatic systems "cleanse" on average 80 percent of their global incident nitrogen loading, but this intrinsic self-purification capability is being reduced by the loss of wetlands across the globe.

As the characteristics of both wastes and ecosystems receiving these wastes vary, environments vary in their capability to absorb and treat wastes.

5.8 Water-flow regulation

Watersheds capture and store water, thereby contributing to the quantity of water available and the seasonal flow of water. The so-called "albedo" effect refers to the process by which vegetation increases evaporation of water from the earth's surface to cause increased cloud formation and rainfall (Myers 1997). Through this effect, ecosystems dominated by vegetation, such as forest ecosystems, play a significant role in determining rainfall patterns at a regional scale. Vegetation also acts as a 'sponge', soaking up and storing water when abundant and releasing it slowly during the dry periods (See Case studies 03 and 10). This system of water regulation reduces the impacts of flood and drought on downstream communities (Myers 1996).

Sedell et al. (2000) reviewed values associated with water flowing from forests in the US and found that the average value of water in streams was around US$ 40 per acre-foot for off-stream uses, i.e., irrigation, industrial and municipal use. Estimates of the marginal value of stream-flow for generating electricity ranged from US$ 0.26 to US$ 17.00 per acre-foot, with most of the values below US$ 2.00.

Studies in Colorado and Alabama have found substantial existence values for stream-flow. On average, Colorado households were willing to pay US$ 95 and Alabama households $57 a year to preserve natural stream-flow in rivers (Brown 1992).

Box 3. Quantifying the changes in water services (Pagiola et al 2004)

Ecosystems such as forests are widely believed to provide a variety of hydrological services, including reducing erosion, thus reducing sediment loads in waterways; regulating the timing of water-flows, thus reducing flood risk and dry season water shortages; increasing the volume of available water; and improving water quality. The evidence on these links is often far from clear, however (Bruijnzeel 1990, Bruijnzeel 2004, Calder 1999, Chomitz and Kumari 1998). This is partly a reflection of the diversity of conditions encountered: hydrological services, for example, depend on the rainfall regime, on the type of soil, and on topography. Deforestation can have multiple, often contradictory impacts, making the net impact on water services hard to determine. It can reduce infiltration, for example, but also reduce water use through evapotranspiration. The net impact of these changes (both in total and within a year) depends on the balance between these effects.

Table 4 presents economic values that have been estimated for watershed protection (CBD 2001). The unit value for watershed protection may seem to be small due to various reasons. Firstly, it is important to note here that these small unit values are aggregated across large areas. Secondly, being a 'public good', the benefits accruing from such functions of watershed accrue to all the people living in the region. Another reason is that valuation studies typically focus on a single attribute of the protective function, like nutrient retention or flood prevention.

Table 4. Economic values of watershed protection (CBD 2001)

Study	Type of watershed protection function	Results
Guatemala forest (Ammour, Windevoxhel and Sencion 2000)	• Prevention of soil erosion. ❍ Universal soil loss equation ❍ Valued at cost of soil replacement and at costs of preventing soil loss	Negligible
	• Prevention of nutrient loss. ❍ Nutrients in aerial biomass ❍ Valued at fertilizer prices	$12 ha/a out of $30 ha/a for all NTFPs and environmental services
Malaysian Forest (Kumari 1996)	• Protection of irrigation water ❍ Valued at productivity of water in crop	$15/ha
	• Protection of domestic water supplies ❍ Valued at treatment cost for improved quality	$0/ha
Korup, Cameroun (Ruitenbeek 1989)	• Flood protection only	$3/ha
Mt. Cameroun, Cameroun (Yaron 2001)	• Flood protection ❍ Valued at value of avoidable crop and tree losses	$0-24/ha
Eastern Indonesia (Pattanayak and Kramer 2001)	• Drought mitigation from forest protection and re-growth ❍ Valued at gain in profits to rice and coffee production	$3-35 per household
Turkey (Bann 1998)	• Soil erosion ❍ Valued by replacement cost of nutrients	$46/ha
	• Flood damage	
Mexico (Adger et al. 1995)	• Sedimentation effects on infrastructure	Negligible
Malaysia (Shahwahid et al. 1997)	• Impacts of RIL compared to total protection of forests on hydroelectricity	$4/ha
Philippines (Hodgson and Dixon 1988)	• Fisheries protection from avoided logging	$268/ha
Johor, Malaysia (Bann 1999)	• Shoreline protection by mangrove forest	$845/ha
	• Fisheries protection by mangrove forest	$526/ha
Northern Nigeria (D. Anderson 1987)	• Shelterbelts for crop protection	Rate of return increases from 5% to 13-17%
	• Farm forestry	Rate of return increases from 7% to 14-22%
Venezuela (Anonymous 2001)	• Avoided sedimentation of hydro-reservoir	$14-21/ha
	• Urban water supply	$6-13/ha
	• Protection of irrigation	$1-6/ha

5.9 Nutrient cycling

Ecosystems regulate the flows and concentrations of nutrients such as nitrogen, phosphorus and potassium through a number of complex processes. Life on earth depends on the continuous (re)cycling of about 30-40 of the 90 chemical elements which occur in nature (de Groot et al. 2002) (See Case study 01).

5.10 Natural hazard regulation

Changes to ecosystems have contributed to a significant rise in the number of floods, storms and major fires across all continents since 1940s (MA 2005).

This regulating service relates to the ability of different ecosystems to mediate "natural" hazards and disruptive natural events (de Groot et al. 2002). For example, ecosystems regulate the effects of extreme events such as floods, storms and fires by affecting both the probability and severity of events (Krieger 2001). Soils store large amounts of water and help in preventing or reducing floods and fires. Coral reefs buffer waves and protect adjacent coastlines from storm damage. Wetlands attenuate floods by absorbing runoff peaks and storm surges.

This regulating service contributes to the safety of human life and protection of man-made infrastructure (See Case study 05).

5.11 Disease regulation

Ecosystems play an important role in the emergence or resurgences of infectious diseases. Modifications of ecosystems related to infrastructure developments such as dam building or expansion of agricultural irrigation, have sometimes increased the local incidence of vector diseases such as malaria, schistosomiasis and arbovirus infections (MA 2005).

5.12 Carbon storage and sequestration

Many studies indicate large values for the carbon storage functions of forests. It is however important to distinguish between carbon stored in a standing forest that is close to 'carbon balance' and carbon sequestered in a growing forest (CBD 2001).

The carbon stored in a standing forest has an economic value, much of which would be lost if the forest is burned or logged, depending on the future land-use. Thus baseline determines if this type of forest can realize carbon storage value. The baseline would consider what is likely to happen to the forest in the absence of some sustainable resource use practices. If a forest is unlikely to experience any land-use change, then the storage value is unlikely to be realized. However, forests that are threatened in the near future have a storage value which can be realized through protective measures. One can also consider the lost carbon storage value of the forest in case of land-use change. On the other hand, carbon sequestration relates to the net addition of carbon by a growing stock. Although the value of carbon sequestered would be the same as in the case of carbon storage, the value of carbon sequestration will be aggregated over the rotation life of the growing stock (See Case study 07).

Verma (2008) has estimated present value of carbon stock and carbon flux for 20 years at 5 per cent discount rate as US$ 5,552/ha and US$ 33/ha respectively using IPCC – GPG 2003 guideline default value for forests of Himachal Pradesh State of India.

Brown and Pearce (1994) suggest benchmark figures for carbon content and loss rates for tropical forests, as shown in Table 5. A close primary forest has approximately 280 tC/ha and more than 60 percent would be lost if converted to either shifting cultivation, permanent agriculture or pasture. Open forests are likely to lose between a quarter and third of 115tC/ha on conversion.

However, using such estimates raises the question of the economic value of the carbon stocks. There are numerous studies on the economic value of global warming damage and translation of these estimates into the economic value of a marginal unit of carbon (Clarkson 2000, Tol et al. 2000, Zhang 2000). A review of the literature (Clarkson 2000) suggested an agreed value of US$ 34 tC. It has also been suggested that estimates of marginal damage due to climate change will not exceed US$ 50 tC (Tol et al. 2000). Thus, the value of forests as carbon store comes out to be very high taking the range of US$ 34-50 tC. However, many argue that the real guide to the value of carbon is the price at which it is traded in the carbon market (CBD 2001). If there are no limitations placed on worldwide carbon trading, carbon credits will exchange at just under US$10 per tC (Zhang 2000). Taking the US$ 10 tC as a conservative estimate, Table 5 can be used to estimate the monetary value of land-use changes in tropical forests from the perspective of changes in carbon storage.

Table 5. Changes in carbon with land-use conversions: tropical forests (tC/ha) (Brown and Pearce 1994)

		Shifting agriculture	Permanent agriculture	Pasture
	Original carbon	**79** (53 soil, 25 biomass)	**63** (mainly soil)	**63** (mainly soil)
Closed primary forest	**283** (116 soil, 167 biomass)	-204	-220	-220
Closed secondary forest	**194** (84 soil, 110 biomass)	-106	-152	-122
Open forest	**115**	-36	-52	-52

5.13 Climate regulation

Climate regulation relates to the maintenance of a favorable climate, both at local and global scales, which has important implications for health, crop productivity and other human activities (See Case study 11).

Forest ecosystems help in climate regulation by trapping moisture and cooling the earth's surface, thus regulating rainfall and temperature. Costanza et al. (1997) found that forests yield US$ 450 per hectare per year in terms of climate regulation benefits.

The climate regulation service is also significant in an urban context. Strategic planting of trees can reduce cooling costs and energy use. Computer simulations estimate that 100 million mature trees in US cities could reduce annual energy costs by US$ 2 billion (Dwyer et al. 1992). As in the case of Tuscon, Arizona, each tree would give benefits in the range of US$ 20.75 annually by reducing cooling costs for buildings (McPherson 1992).

6. Scale in valuing regulating services

In quantifying and monitoring the flows of regulating services provided by various ecosystems, the scale at which these services occur must be defined. In this context, scale refers to the physical dimension, in space or time, of phenomena or observations (O'Neill and King 1998). According to one of the earliest definitions of ecological scale, ecosystems can be defined at a wide range of spatial scales ranging from the level of a small lake up to the forest ecosystem spreading across thousands of kilometers (Tansley 1935).

Regulating services occur at various scales (see Table 6). Biological nitrogen fixation enhances soil fertility at a small scale while carbon sequestration influences the climate at a global scale. Therefore the range of spatially defined ecological scales must be established prior to valuation of regulating services (Holling 1992, Levin 1992). This manual borrows the concept of using different scales for regulating services from the Environmental Economics Tool Kit (Hein 2006). The scales used in the manual vary from the level of the individual plant, via ecosystems and landscapes, to the global system.

Indicators can be used to monitor changes in the flow of regulating services at different scales in a number of ways (see Tables 7 and 8). At the national level, trends in the changes associated with flow of regulating services across ecosystems can be monitored over periods and across regions. At the project level, indicators can be used to monitor the effectiveness of measures implemented to improve the flow of regulating services. Table 8 evaluates the policy relevance of regulating service indicators.

Table 6. Indicators for the biophysical assessment of regulating services (Hein 2006)

Key goods and services provided	Potential indicators
Carbon sequestration	Carbon contents of the above and below ground biomass, and in terms of soil organic matter; exchange of carbon between these three compartments and the atmosphere.
Climate regulation through control of albedo, temperature and rainfall patterns	Appropriate indicator for vegetation cover, e.g., leaf area index or total crown cover; role of vegetation in determining moisture fluxes and temperature, resulting impacts on local and regional circulation and moisture conditions, etc.
Hydrological service: regulation of the timing and volume of river flows	Impact of vegetation on water flow, as a function of the topography, peak flows, vegetation cover, absorbing capacity of the soil, infiltration rates, etc. (see (Bosch & Hewitt, 1982)).
Protection against flood by coastal/ riparian systems	Storm protective capacity depends on vegetation structure, topography and length and width of the vegetation belt.
Control of erosion and sedimentation	Control of erosion and sedimentation depends on the ground cover of the vegetation, and is further a function of rainfall erosivity and soil erodibility (slope characteristics, texture, organic matter contents, etc.).
Nursery service: regulation of species reproduction	Nursery function depends on habitat characteristics (vegetation structure, topography) in relation to the reproduction requirements of the species involved. It can be measured in terms of numbers of juveniles produced per area unit.
Breakdown of excess nutrients and pollution	In particular wetland ecosystems have the capacity to filter water and recycle plant nutrients and, to some extent, absorb inorganic pollutants. The function depends on the retention time of water in the ecosystem, the temperatures affecting plant growth rates, vegetation structure, etc. It can be measured in terms of the difference in pollutant concentration between water flowing in and water flowing out of the system.
Pollination	Natural vegetation may support pollination of external agricultural fields by providing a habitat for pollinators, especially bees but also other insects, bats, etc. The impact may be measured by comparing crop yields in areas with adequate pollination with crop yields in areas without adequate pollination.
Regulation of pests and pathogens	Ecosystems may contribute to the control of certain pests and pathogens by harboring population of species that control such pests. The impact may be measured by comparing crop yield in areas with and without such control, or health impacts in areas with and without such control.
Protection against storms	Ecosystems, or rows of trees, may act as windbreaks prevent wind erosion and limiting losses of crops and infrastructure from storms. This may be measured by analyzing impacts of past storms, or by modeling of erosion processes.
Protection against noise and dust	Vegetation belts along highways or around industrial zones can filter air and improve air quality with regards to dust and noise. The biophysical impacts can be assessed by comparing noise levels, particulate matter levels, and concentrations of specific pollutants on either side of the vegetation belt.
Biological nitrogen fixation (BNF)	Through fixation of atmospheric nitrogen, leguminous plants can enhance soil fertility. Their impact can be measured in terms of soil organic matter contents.

Table 7. State and performance indicators for various ecosystem services derived from wetlands

Services	State indicator	Performance indicator
Air quality regulation: e.g., capturing dust particles	Leaf area index, NOx-fixation, etc.	Amount of aerosols or chemicals "extracted" - effect on air quality
Climate regulation: regulation of greenhouse gases, temperature, precipitation, and other climatic processes	Greenhouse gas-balance (esp. C-fix), DMS production, Land cover characteristics, etc	Quantity of greenhouse gases, etc., fixed and/or emitted - effect on climate parameters
Hydrological regimes: groundwater recharge/ discharge; storage of water for agriculture or industry	Water storage capacity in vegetation, soil, etc., or at the surface	Quantity of water stored and influence of hydrological regime (e.g. irrigation)
Pollution control and detoxification: retention, recovery and removal of excess nutrients / pollutants	Denitrification (kg/N/ha/y), Accumulation in plants, -kg –BOD/ ha/y, chelation (metal-binding)	Maximum amount of waste that can be recycled or immobilized on a sustainable basis; influence on water or soil quality
Erosion protection: retention of soils	Vegetation cover, root-matrix, etc	Amount of soil retained or sediment captured
Natural hazard mitigation: food control, storm and coastal protection	Water storage (buffer) capacity in m3; ecosystem structure characteristics	Reduction of food danger and prevented damage to infrastructure
Biological regulation: e.g., control of pest species and pollination	Number and impact of pest control species; number and impact of pollinating species	Reduction of human diseases, livestock pests, etc.; dependence of crops on natural pollination
Biodiversity and nursery: habitats for resident or transient species	Number of resident, endemic species, habitat integrity, minimum critical surface area, etc.	"Ecological value" (i.e., difference between actual and potential bio-diversity value); dependence of species or other ecosystems on the study area
Soil formation: sediment retention and accumulation of organic mater	Amount of topsoil formed (e.g., per ha per year)	These services cannot be used directly but provide the basis for most other services, especially erosion protection and waste treatment
Nutrient cycling: storage, recycling, processing and acquisition of nutrients	Amount of nutrients (re-) cycled (e.g., per ha per year)	

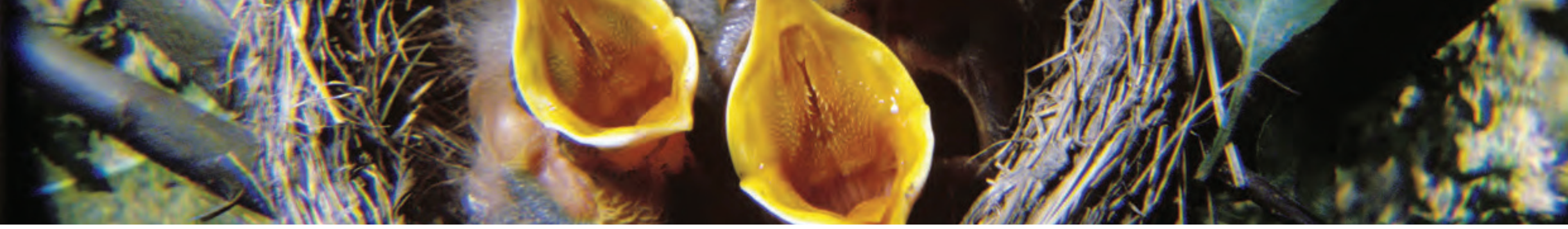
Table 8. Relevance to policy making of various indicators of regulating services (Layke 2009)

Indicator	Proxy indicator	Data units	Ability to convey information	Data availability	Global compiling agency
Air quality regulation			**High**	**Low**	
Flux in atmospheric gases	Yes	Teragrams carbon, nitrogen per year	High	Low	None
Atmospheric cleansing (troposheric oxidizing)	No	No units noted	High	Low	None
Global climate regulation			**Medium**	**Medium**	
Atmospheric gases flux (CO2, CH4, etc),	No	Teragrams carbon, nitrogen per year	Medium	Medium	IPCC
Carbon accumulation	No	Teragrams, metric tons	High	Medium	IPCC
Carbon uptake	No	Teragrams, metric tons	Medium	Medium	IPCC
Cloud formation	No	No units noted	Medium	High	IPCC
Evapotranspiration	No	Percent	Medium	Low	IPCC
Carbon sequestration capacity	No	Megagrams per hectare, metric tons	Medium	Medium	IPCC
Surface albedo	No	Albedo	Low	High	IPCC
Regional and local climate regulation			**Medium**	**Low**	
Canopy stomatal conductance	No	No units noted	Medium	Low	None
Cloud formation	No	No units noted	Medium	Medium	None
Evapotranspiration	No	Cubic meters	Medium	Low	None
Water regulation			**High**	**Low**	
Soil water infiltration	No	No units noted	High	Low	None
Soil water storage	No	No units noted	High	Low	None
Erosion regulation	**No Indicators Identified**				
Water purification and waste treatment			**High**	**Low**	
Amount of waste processed by ecosystems	No	Volume/mass of waste processed	Medium	Low	None
Capacity of ecosystem to process waste	No	Volume/mass of waste potentially processed	High	Low	None
Value of ecosystem waste treatment and water purification	No	Currency	High	Low	None
Disease Regulation			**High**	**High**	
Disease vector predator populations	Yes	Number	High	High	None
Estimated change in disease burden as a result of changing ecosystems	Yes	Number of disease cases	High	High	None
Population increase in disease vectors mosquitoes following ecosystem conversion	Yes	Mosquito population	High	High	None
Soil quality regulation	**No Indicators Identified**				
Pest regulation	**No Indicators Identified**				
Pollination	**No Indicators Identified**				
Natural hazard regulation			**Medium**	**Low**	

Indicator	Proxy indicator	Data units	Ability to convey information	Data availability	Global Compiling agency
Changes in seasonality of flood events	Yes	Percentage change in number of events	Low	Low	None
Economic losses associated with natural disasters	Yes	Currency	Low	Low	None
Flood attenuation potential: residence time of water in rivers, reservoirs and soils	No	Days required for water falling as precipitation to pass through system	High	Low	None
Floodplain water storage capacity	No	Days of river discharge floodplain can store	Medium	Low	None
Soil capacity to transfer groundwater	No	No units noted	High	Low	None
Soil water storage capacity	No	No units noted	Medium	Low	None
Trends in number of damaging natural disasters	Yes	Number of events	Low	Low	None
Low	Indicators and data availability are inadequate for support policy-making				
Medium	Indicators and data availability are sufficient to partially inform policy-making				
High	Indicators and data availability are sufficient to inform policy-making				

In developing an aggregate indicator, the services included in the equation must be weighted relative to each other and to account for the tradeoffs of increasing one service at the expense of another. For example, water is much more valuable in the Sahara region than in Amazon. Consequently, the "indicator equation" must have differential geographic weighting for different parts of the the world. The indicator must be clear, concise, easily explained, and retain enough information to highlight the most important aspects of ecosystem services. A great deal of basic research is necessary for the creation of an aggregate indicator. We also need to examine what is gained and what is lost through aggregation, in order to ensure that an aggregate indicator provides additional benefits that a suite of disaggregated measures does not.

The challenges associated with this task are formidable, but are not insurmountable. Today's widely accepted economic indicators were developed over decades, not days. The science of ecosystem services remains a major research challenge for our community, and we believe that the creation of an aggregate measure of ecosystem services is central to the valuation process. Quantification of ecosystem services and communication of the information to decision-makers and the public is critical to the responsible and sustainable management of natural resources. A concise, credible, and reliable reporting system is urgently required to meet this need.



7. Merging classification of ecosystem services (stock, flow, final and intermediate services)

Although the valuation exercise is generally carried out for ecosystem services, it is important to bear in mind that ecosystems have both flow and stock values. Ecosystems provide their "flow" of services depending on various factors like the present state of the ecosystem, i.e., the "stock", management policy and the type of ecosystem. There will be a change in the overall flow of ecosystem services if any of the above factors change. These changes may not necessarily result in total loss of ecosystem services, but a change in mix and magnitude of specific services is very likely. As a result, the valuation approach should focus on the change in the value of services resulting from a given change in ecosystem management (Pagiola et al. 2004, MA 2005). Flow and stock value relationships lie at the heart of debates about sustainability of biological resource systems (Gregersen et al. 1999).

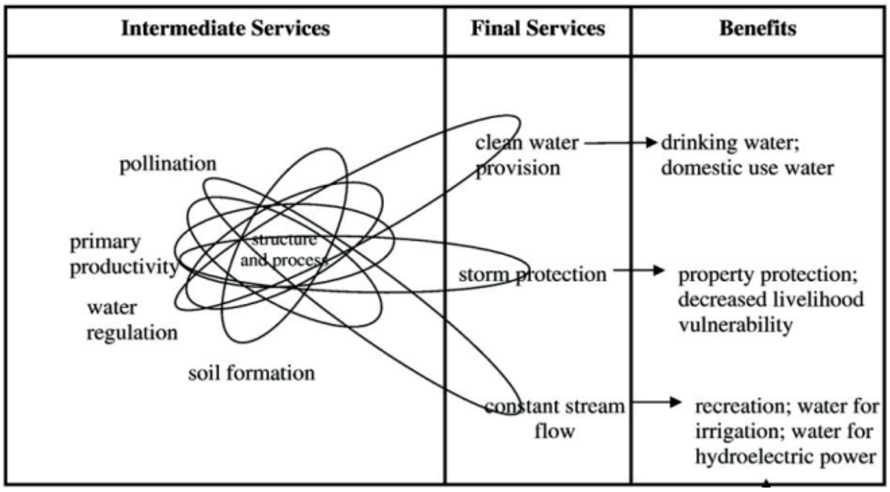
There have been very few instances when the changing stocks of natural resources have been considered in national accounts. Failing to account for these changes in stock results in overestimation of the value of the income generated because depreciation associated with the changes in the stock of natural resources is not accounted for. When changes in stock values are not accounted for, policy-makers receive incorrect signals about the total availability or actual status of natural resources and hence are not in a position to make informed decisions.

There are two main approaches to quantify the change in the flow of benefits generated from any ecosystem. If flows of an ecosystem service are relatively constant, then the change in the value of benefits can be expressed by a change in the value of the annual flow of benefits. On the other hand, the present value approach is best suited for "flows" of an ecosystem service that are likely to vary over time. The present value of flow is also known as the change in the capital value of the ecosystem (see Case Study 14).

Quantifying the changes in "flows" of ecosystem services has been the Achilles' heel of ecological economics. To estimate the changes in "flow", one must quantify the change in the physical flow of benefits by exploring the biophysical relationships between ecosystems and the services they produce. This involves tracing through and quantifying a chain of causality. It is a common problem for valuation of ecosystem services in general, and for regulating services in particular, that information is only available for some of the links in the chain. Information that is available is generally in incompatible units. If the loss of a given service due to a policy change is irreversible, then the loss of option value associated with that service should also be included in the valuation process.

Ecosystem services can also be divided into two categories based on a time frame: they can be classified as 'intermediate' or 'final' (See Figure 1). Normally, services associated with the supporting function of the ecosystem are categorized as intermediate services because society does not directly use them. These services affect other services that society values. For example, the nutrient cycling service affects the soil fertility. This has an important implication when we are trying to value ecosystem services because for such services the valuation exercise need not be performed directly. In fact, due to a recognized lack of scientific understanding of the interdependencies of ecosystem services, direct valuation tends to lead to an underestimation of value. However, it is worth mentioning that monitoring of these intermediate services is necessary to ensure the final services.

Figure 1. Conceptual relationship between intermediary and final services (Fisher et. al, 2009)



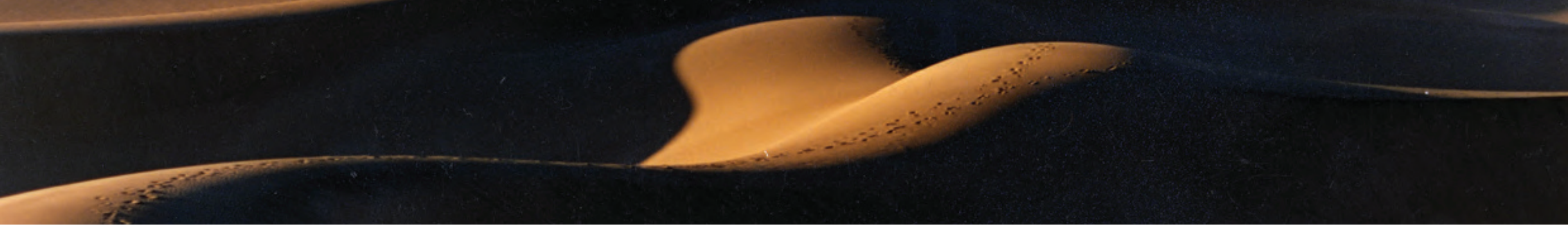
The emphasis on stocks of ecosystem services so as to ensure continuous and reliable supply of regulating services supports a new paradigm for sustainable development. The new paradigm centralizes the process of managing a portfolio of assets to preserve and enhance opportunities people face (The World Bank 1997). Owing to debates about stock and flow value relationships, there is a growing interest in the introduction of natural resource accounting in national accounts. There is an anomaly in national income accounts that leads to an overestimation of the value of income generated by national resources because the degradation of natural resources is not accounted for (The Economics of Ecosystem and Biodiversity TEEB 2010). Ideally, degradation should be internalized by including an appropriate amount of depreciation which would reflect declining productive capacity of assets (both natural and man-made) and the investment necessary to sustain a certain level of productive capacity over time (Gregersen et al. 1999).

Among several issues concerning valuation of regulating services, the issue of flow and stock values has a significant importance. Biological resources have both flow and stock values. For example, a forest has a standing stock that can produce flows of timber and other non timber forest products (NTFPs). While valuing regulating services, the flow of these services is normally used as a basis for estimating the values. However, it is important to note that these regulating services originate from natural ecosystems. The health of these ecosystems determines the flow of these regulating services. Thus, flow and stock value relationships lie at the heart of debates about sustainability of biological resources when we talk about regulating services.

Although we usually associate some provisioning services or cultural services like recreation with biodiversity conservation, closer examination reveals that regulating services may also find their origin in biodiversity conservation. Regulating services build the capacity of ecosystems to adapt to and cope with changes of various fluctuations in the environment. Resilience of ecosystem services depends partly upon species existing in the ecosystem.

In an ecosystem, sets of species that perform similar ecosystem processes are referred to as functional groups (Walker et al. 1999, Elmqvist et al. 2003). Biodiversity within these functional groups helps to maintain the rate of ecosystem processes during disturbances because individual species within an ecosystem have a tendency to respond differently to fluctuations in the environment (Frost et al. 1995, Ives et al. 1999, Cottingham et al. 2001, Elmqvist et al. 2003, Norberg 2004, Folke et al. 2005). This phenomenon, known as response diversity provides insurance against future environmental change. Biodiversity conservation in this sense thus has an option value corresponding to the regulating services, as opposed to the indirect use values which are mainly associated with regulating services. Reduction in the resilience of an ecosystem often leads to a decrease in the supply of regulating services associated with the ecosystem. Because such regulating services are instrumental in the generation of provisioning services, the yield of provisioning services also decreases as well.

Response diversity also results from the diversity of spatial pattern (Elmqvist et al. 2003). When species are dispersed among patches in heterogeneous landscapes, disturbances affect only a part of the landscape (Peterson et al. 1998, Nystrom and Folke 2001, Loreau et al. 2003, Cardinale et al. 2004). Thus if any process is eliminated from a particular part of the landscape but is present in other patches within the dispersal range, then the missing process can be re-established. This means that replication of ecological processes across different scales confers resilience (Peterson, Allen, and Holling 1998). It is important to note that although response diversity links biodiversity and resilience of the ecosystem service, changes in species richness may sometimes decrease resilience (for e.g. invasive species).



8. Strengths and limitations of various valuation methods

Although the concept of ecosystem valuation has been popular since 1990, it is still an evolving one. There remain serious shortcomings in methods and their data requirements. Table 9 provides a summary of various valuation methods based on information collated from a number of studies (Barbier et al 1997, DEFRA 2007, Stuip et al. 2002, Wilson and Carpenter 1999, de Groot et al. 2006).

Many still question the basic idea of assigning values to ecosystems, arguing that they are invaluable. In theory, the valuation methods discussed here can be applied to calculate the total economic value of ecosystems, i.e. their contribution to human well-being. In practice, however, there are many obstacles. Few studies have tried to estimate the total economic value of an ecosystem and even fewer attempts have been made to value the regulating services of ecosystems. Thus, although the concept of total economic value seems theoretically valid, only partial and often subjective information is provided by it.

In summary, four main reasons explain why valuation of regulating services is difficult in spite of well-established techniques (Lescuyer et al. 2007). Firstly, the total economic value associated with regulating services, which consists of indirect-use value and option value of an ecosystem, can be estimated directly only by using the stated preference methods, which have their own set of caveats. Secondly, monetary quantification of natural assets is difficult because we don't have a complete understanding of how ecosystems work. Thirdly, assumptions of ecological economics are conservative due to existing uncertainty in valuation procedures. We often end up with under-estimates. Fourthly, it has been observed that in practice, estimates of total economic value result from aggregating only certain values that the analyst was able to quantify in monetary terms (Lampietti and Dixon 1995, Nunes and Bergh 2001). The concept of total economic value thus corresponds to the sum of a few economic values selected subjectively by the analyst, rather than to the sum of all the values that actually constitute total value. This is an important issue associated with valuation of regulating services because often familiarity and understanding of local context is required to understand the set of regulating services associated with an ecosystem in a particular region.

Table 9A. Choice of valuation method

Valuation method	Market price method	Travel cost
Valuation Type	Revealed WTP	Revealed WTP
Element of TEV captured	Direct and indirect use	Direct and indirect use
Approach	Exchange value (based on marginal productivity cost) that ecosystem services have in trade	Derive demand from data on actual travel costs
Ecosystem service(s) valued	Those that contribute to marketed products, e.g., timber, fish, generic information	All ecosystem services that contribute to recreational activities
Data requirements	• Demand of goods • Price of finished good • Cost of production	• Monetary costs of travel • Opportunity cost of time spent • Other expenses made during the visit
Benefits of approach	• Market data readily available and robust • Uses observed data of actual preferences • Uses standard economic techniques	• Based on observed behaviour • Relatively inexpensive • On-site surveys provide opportunity for large sample sizes • Results easy to interpret and explain
Limitations of approach	• Limited to those ecosystem services for which a market exists • Market imperfections and policy failures distort market prices • Doesn't consider seasonal variations in price • Cannot be used to measure the value of large scale changes that are likely to influence the supply/demand itself	• Generally limited to recreational benefits • Difficulties arise when trips are made to multiple destinations • Data intensive • Availability of substitute sites affects the estimate • Interviewing visitors on site can introduce biases

Table 9B. Choice of valuation method

Valuation method	Production function approach / factor income	Public pricing
Valuation Type	Revealed WTP	Revealed WTP
Element of TEV captured	Indirect use	Use (direct and indirect) and non-use
Approach	Trace impacts of change in ecosystem services on produced goods	Public investment, for instance via land purchase or monetary incentives, as a surrogate for market transactions
Ecosystem service(s) valued	Environmental services that serve as input to market products, e.g., effects of air and water quality on agricultural production and forestry output, pollination on agricultural production, etc.	All ecosystem services that can be influenced by public investments
Data requirements	• Change in ecosystem services; impact of these changes on production • Net value of produced goods	• Prices of goods • Characteristics (both environmental and non-environmental) of goods
Benefits of approach	• Uses standard economic procedures • Relatively inexpensive	• Market data readily available and robust • Results are easy to interpret and analyze
Limitations of approach	• Limited to those resources that can be used as inputs in production of market goods • Data intensive • Physical data on changes in services and the impact on production are difficult to obtain • Chances of double counting • If changes in resource affect the market price of the final good, the method becomes complicated	• Property rights sometimes difficult to establish • Care must be taken to avoid perverse incentives

Table 9C. Choice of valuation method

Valuation method	Hedonic pricing	Cost based approaches
Valuation Type	Revealed WTP	Imputed WTP
Element of TEV captured	Direct and indirect use	Direct and indirect use
Approach	Extract effects of environmental factors (amenities) on price of goods that include those factors	Use cost of replacing the lost good or services
Ecosystem service(s) valued	Ecosystem services that contribute to air quality, visual amenity, landscape, quiet, i.e., attributes that can be appreciated by potential buyers	Depends on the existence of relevant markets (e.g., man-made defences being used as proxy for wetlands storm protection; cost of water filtration as proxy for value of water pollution damages)
Data requirements	• Prices of goods • Characteristics (both environmental and non-environmental) of goods	• Extent of loss of goods and services • Cost of replacing these goods and services
Benefits of approach	• Estimates value based on actual market transactions • Estimates are robust because property markets are relatively efficient • Data on property sales and characteristics are readily available	• Market data readily available and robust • Less data and resource intensive • It is often easier to estimate the costs of producing the benefits rather than measuring the value of the benefits themselves
Limitations of approach	• Limited to services that are primarily related to property prices • Very data intensive • Only captures willingness to pay for the perceived benefits • Requires a high degree of statistical expertise • Results depend heavily on model specification	• Do not consider social preferences for ecosystem services • Can potentially overestimate the actual value • Assumption that costs of avoided damage or substitutes match the original benefit is not often valid

Table 9D. Choice of valuation method

Valuation method	Contingent valuation (CV)	Choice modelling
Valuation Type	Expressed WTP	Expressed WTP
Element of TEV captured	Use (direct and indirect) and non-use	Use (direct and indirect) and non-use
Approach	Ask respondents directly their willingness to pay for a specified service	Ask respondents to choose their preferred option from a set of alternatives with various attributes
Ecosystem service(s) valued	All ecosystem services	All ecosystem services
Data requirements	• Survey that represents hypothetical scenario and elicits willingness to pay for specified service	• Survey represents a hypothetical scenario and asks the respondent to state a preference between one group of environmental services or characteristics and another
Benefits of approach	• Can be used to estimate the total economic value of most goods whether they are marketed or not • Able to capture both; use and non-use values • Results easy to analyze and interpret	• Can be used to estimate the total economic value of most goods whether they are marketed or not • Able to capture both; use and non-use values • Useful where a set of possible actions might result in different impacts on ecosystem services
Limitations of approach	• Bias in responses • Resource-intensive method • Hypothetical nature of the market • Estimates of non-use value are difficult to validate through other means • Decision-makers are not totally convinced about the robustness of the methodology	• Bias in responses • Resource-intensive method • Hypothetical nature of the market • Estimates of non-use value are difficult to validate through other means • Decision-makers are not totally convinced about the robustness of the methodology • Analysis of data is complex

Table 9E. Choice of valuation method

Valuation method	Group CV, citizen's jury, focus group, Delphi technique, expert panel, consensus conference	Benefits transfer
Valuation Type	Group valuation	Benefits transfer
Element of TEV captured	Use (direct and indirect) and non-use	Use (direct and indirect) and non-use
Approach	Same as CV but as an interactive group process	Use estimates obtained from one context in a different context
Ecosystem service(s) valued	All ecosystem services	All ecosystem services for which suitable comparison studies are available
Data requirements	• Survey that represents scenario and elicits WTP for specified service	• Valuation studies at another, similar site
Benefits of approach	• Considers group preferences rather than individual preferences which is useful for achieving social equity • Biasness in a group valuation is less than in individual CV	• If suitable studies are found, it saves a lot of time and resources • Suitable for crude estimation • Can be used as a screening technique to determine if a more detailed valuation exercise should be conducted
Limitations of approach	• The assumption that group members will pool their unique, 'unshared' information with other members may not always be true • Resource intensive	• Can only be as accurate as the original study • Good studies for services in question may not be available • Can be very inaccurate, as many factors vary even when contexts seem 'similar' • Estimates can become outdated • To be used with caution

Various challenges exist as far as data availability is concerned. Data availability for industrial countries is greater than that for developing countries. Data for certain resources such as crop production are more readily available than data for many of the regulating services provided by ecosystems. Resource constraints (e.g., time, finances, and skills) determine which data collection methods can be implemented effectively. Because almost all the regulating services have an indirect linkage with the ecosystems that generate those services, it is often necessary to conduct experimental studies to determine the linkage. If previously conducted studies have identified and assessed the linkages, the task of valuation becomes much simpler. But this is often not the case. Geographical Information System (GIS) and other similar geospatial techniques are believed to have the potential to contribute greatly to the development of models. These models can predict the observed effects of any policy decision on ecosystem and hence its services. However, understanding various complexities in the way ecosystems function will still continue to be the bottleneck in valuation of regulating services (Barbier et al. 1997).

It is difficult to understand completely the linkage between ecosystems, ecosystem functions, ecosystem services and human activities (Bingham et al. 1995). This leads to underestimation of ecosystem benefits. If the estimated benefits are more than the benefits associated with alternative management regime which is likely to degrade the natural resources, valuation can prove helpful. But many times due to very shallow understanding of the linkages, a very low value is estimated for the benefits of the ecosystem and alternative policy which is likely to degrade the ecosystem is selected. The better our understanding and knowledge about ecosystem linkages, the better our valuations will be.

Ecosystems depend on each other for their functioning. This means that if we estimate the value associated with each and every ecosystem service and add all of them, it would not be the total value of all the services (Daily 1997). On the other hand, a resource may have conflicting uses (e.g., waste treatment and recreation) and care should be taken to avoid double counting. Problems occur when different service users have interests in different uses of an ecosystem and the uses are conflicting in nature (Turner et al. 1998). In such cases, there is dilemma of which services to consider for valuation.

If it were possible to use the results of a particular valuation exercise carried out for a particular ecosystem service everywhere else, valuation would be a much easier task. But this is not the case. Ecosystems, their characteristics and dependence on the services have geographical and temporal specificity (Daily 1997). Valuation of ecosystem services is based on the concept of WTP and may vary according to region. Inter-generational differences may also be observed in the preferences for an ecosystem. These characteristics of ecosystems make temporal and spatial extrapolation unreliable (Turner et al. 1998).

The market price method is usually not the right method for valuing regulating services because of their indirect nature. Since these services are not used directly, the market price method usually fails to estimate the value of such services. Even in instances where the market can value the service, it does not deal with the issues of distribution and equity (de Groot 1992).

In many cases, aggregating individual willingness to pay values may not be enough to influence decisions involving large scale consequences to society and future generation. In this regard, it is important to recognize future services apart from those currently used by society. Many feel that energy-based measurements are more appropriate to measure the importance of ecosystems. This kind of approach can quantify the indirect services more easily than the economic methods. But this concept fails to relate functions valued and human well-being (Toman 1997). This can seriously influence policy decision.

Since life would not be possible on this planet without these ecosystems, the total value of ecosystems is infinite. Determining marginal values is a critical part of the economic valuation approach. Again ecosystem services are not provided by certain parts, but by the entire ecosystem. Because of lack of scientific understanding, we do not know how ecosystem services would change if certain parts of an ecosystem and not the entire ecosystem are disrupted (Daily 1997).

Of all the issues involved in economic valuation of ecosystems, discount rate is probably the most controversial one. A human being values a particular thing more now than he/she would in future. Basically the discount rate determines the present worth of future benefits. For environmental functions, the discount rate used is usually much lower than the standard discount rate used in financial transactions. A higher discount rate implies that the needs of future generations are not considered. This higher discount rate may jeopardize the provision of an important resource.

9. Communicating economic values of regulating services

As discussed , valuation of regulating services strengthens decision making by providing information on the efficacy of the response policies. If the value of the regulating service is absent in the decision making tool, the decision could very well lead to undesirable outcomes for the society. In the case of regulating services of ecosystems, the decision makers while doing valuation must address the following aspects:

a) *Spatial dimension of the services:* the location of delivery of the service entering into the domain of beneficiaries and the location of the person/group responsible for allowing the services to flow are critical. Hydrological flow or carbon sequestration are good examples of this. Spatial mapping of the services will help the policy planners in designing efficient responses for management of those services and ecosystems.

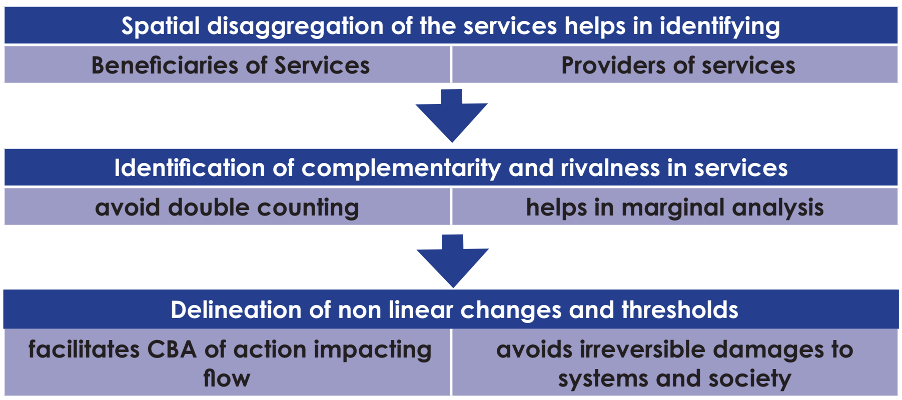
b) *Complementary and conflicting (rival) services:* many services can be viewed as could be complementary. For example, carbon storage and hydrological flow in forests can complement each other. Conversely, some services may be viewed as rival services, such as bioremediation by lake water and withdrawal of water for irrigation in floodplain wetlands. Understanding the complimentary and/or rival nature of services can help to avoid double counting. A meaningful marginal analysis of changes in ecosystem condition and subsequent change in flow of the service can also be performed better if complementarities and conflicts are known.

c) *Nonlinear changes and threshold effects:* these are typically found in case of regulating services (Walker et al. 2009). It is important to understand these when evaluating the potential costs and benefits of an intervention (action or inaction).

Decision-making framework must follow the sequence of these events (Figure 2). These sequential steps are the necessary and sufficient elements in any ecosystem services assessment and decision support system, and may help to guide future ecosystem valuation studies towards more rigorous valuation estimates (Turner et al. 2009)

Although regulating services have high economic value, paradoxically, they have been long perceived by decision-makers and other relevant stakeholders as having little value. This is owing to the fact that the true value of regulating services is not captured by the conventional systems of national accounts as these services are not traded in the market. Consequently, it is hardly surprising that the ecosystems which provide these 'life-supporting' services are being rapidly modified and exploited unsustainably. These acts for getting short-term benefits actually degraded the ecosystems and would compromise their ability to provide the flow of regulating services in future.

Figure 2. Considerations for decision-making



Although valuation of regulating services provides an estimate which attempts to reflect the 'real value' of these services, conducting the valuation exercise, by itself, does not lead to conservation and sustainable use of these ecosystems. Once valuation of regulating services is conducted, one needs to communicate this value to a broader group of stakeholders – firstly to those who use or provide these services and secondly to those who influence the decision-making that governs ecosystem management. It is essential that the results of valuation exercises are communicated and disseminated to all the relevant decision-makers and stakeholders.

The MA concluded that one of the significant factors driving loss and degradation of regulating services globally was that decision-makers either lack, or choose to ignore, information on the total value of regulating services when considering development decisions that impact natural ecosystems. As a result, ecosystems which tend to benefit a range of stakeholders with the full spectrum of ecosystem services (including regulating services) are converted to a particular land-use which generally benefits only a particular group of stakeholders (de Groot et al. 2006).

Owing to the indirect nature of regulating services, clearly establishing the relationship between regulating services and human well-being is sometimes difficult. The high degree of influence many stakeholders exercise in ecosystem maintenance-related decisions on local, national and international levels makes the explanation and accessibility of valuation results to all stakeholders essential. Dissemination forms should be designed in such a way that they help in identifying the users and beneficiaries of regulating services so as to attract investments in natural infrastructure and secure sustainable financial streams and incentives for restoration of the ecosystems that provide these 'life-supporting' services. It is also imperative that the users of the regulating services pay for their use and that the local community conserving the ecosystems receive a proper share of the benefits. The methods used for dissemination should ensure that they not only provide the value estimates of regulating services but also provide the distribution of benefits associated with the use of those services and the costs of conserving ecosystems across all the relevant stakeholders.

As far as decision-makers are concerned, the task of valuation is to convince them that the benefits of conservation of ecosystems which would result in improved quality and flow of regulating services outweighs the costs. The dissemination methods must demonstrate the contributions of regulating services to the local, regional, national and global economy so as to build support for the conservation of ecosystems that provide these services.

Broadly, strategies for effective communication include:

- *Target the message to the audience:* Different stakeholders have different information requirements. There is never 'one size fits all' for content or strategy. With an understanding of the information requirements and motivations of the stakeholders, the dissemination method can be designed to compel attention and action.
- *Use a variety of communication methods:* The purpose of valuation, type and range of stakeholders involved, and their role in decision-making would determine the appropriate form and approach to be used for dissemination of value estimates of regulating services. Methods range from conducting dissemination workshops, distributing leaflets or flyers that provide information in a brief and easily understandable manner, and other multimedia systems. More information on choosing appropriate communication, education and public awareness (CEPA) tools can be obtained from the website of the Ramsar Convention on Wetlands website.
- *Get feedback on communication approaches:* After the communication strategies are implemented, one needs to gather feedback on them and how they could be improved. Is the intended audience receiving and understanding what is being communicated? Are the stakeholders being bombarded with information on value estimates or are the approaches also briefing on what can be done with these value estimates and their relevance?

Ecosystem valuation (particularly that of regulating services) is a new and emerging stream of science and it is essential that the value estimates and the methodologies used to arrive at these estimates are disseminated to a wide audience. Various on-line portals and databases are now available which provide access to existing literature, case studies and value estimates of regulating services from regions across the globe (for example see www.naturevaluation.org). It is important to encourage and build more such portals which provide a platform for further discussion and exchange of information on the value of regulating services.

10. Conclusion

The economic value of regulating services of ecosystems must be equated with the discounted net present value of the flows (Hanley and Barbier 2009). Decision makers while making choices about, for example, the conservation of urban floodplains or coastal wetlands, would like to see that the marginal benefit of conservation of urban or coastal wetlands equates with the marginal costs of its conservation. Typically, regulating services like bioremediation and nutrient cycling by wetlands are ignored as they are outside of the conventional market, the marginal cost of conservation exceeds the marginal benefit of conservation, providing and incomplete signal to the policy-makers. Social choice becomes suboptimal and inefficient. Valuation of regulating services in this context would make the decision efficient and optimal (Kumar et al. 2001). There are many other decision contexts where valuation of regulating services would be beneficial such as in public policy cost benefit analysis, the evaluation of damages to ecosystems and in resource allocation for conservation goals to name a few.

There have been numerous studies in recent years either advocating the need of inter-disciplinarity in economic valuation or actually demonstrating how the joint effort of ecology and economics can yield credible and acceptable estimates of economic value of ecosystem services (Heal 2005, Balmford 2002, Maler 2009, Hanley and Barbier 2009, Naeem et al. 2009, Polasky 2009, Farley 2009, Kumar and Wood 2010).

After assessing the evidence base of valuation of regulating services across the world, and analyzing them, it emerges clearly that valuation of regulating services is still evolving and is in a nascent stage. That definitely does not reflect its need by the decision-makers. While doing valuation of regulating services with the help of non market based, survey oriented methods, the usual precautions like size of samples, composition of respondents, gender specific responses must be kept in mind. The numerators and investigators must acknowledge and embrace the fact that even if everything remains the same, the response of female would be different from the male respondents as the use pattern and dependence might vary across the gender. There are not many reliable studies based on sound ecological economic foundation using credible dataset acceptable to the policy-makers. There are few studies where the regulating services of ecosystem is correlated with biodiversity especially functional biodiversity (Tilman et al. 1996). The emerging challenges in valuation are bound to motivate economists and ecologists to come out with more studies in near future.

11. References

Adger, N, K Brown, R Cervigni, and D Moran. "Total economic value of forests in Mexico." Ambio 24, no. 5 (1995): 286-296.

Alcamo, J, et al. "Changes in nature's balance sheet: model-based estimates of future worldwide ecosystem services." Ecology and Society 10, no. 2 (2005).

Allen-Warden. "The potential consequences of pollinator decline on the conservation of biodiversity and stability of food crop yields." Conservation Biology 12 (1998): 8-17.

Ammour, T, N Windervoxhel, and G Sencion. "Economic Valuation of Mangrove Ecosystems and Sub-tropical Forests in Central America." In Sustainable Forest Management and Global Climate Change, edited by M Dore and R Guevara, 166-197. Cheltenham: Edward Elgar, 2000.

Anielski, M, and S Wilson. Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems. Ottawa: Canada Boreal Initiative and the Pembina Institute, 2005.

Atran, S, et al. "Folkecology and commons management in the Maya lowlands." Proceedings of the National Academy of Sciences. 1999. 7598-7603.

Aylward, B, J Echeverria, K Allen, R Mejias, and I Porras. Economic Incentives for Watershed Protection: A Case Study of Arenal, Costa Rica. CREDD Final Report, London: International Institute for Environment and Development, 1998.

Badola, Ruchi, and S A Hussain. Valuation of the Bhitarkanika mangrove ecosystem for ecological security and sustainable resource use. Dehradun: Wildlife Institute of India, 2004.

Balmford, A, A Bruner, P Cooper, R Costanza, S Farber, and and others. "Economic reasons for conserving the wild nature." Science, no. 397 (2002): 950-953.

Bann, C. "Contingent Valuation of the Mangroves of Benut." Report to DANCD, Copenhagen, Johor State, 1999.

Barbier, E. "Valuing ecosystem services as productive inputs." Economic Policy 22, no. 49 (2007): 177-229.

Barbier, E. "Valuing environmental functions: tropical wetlands." Land Economics 70, no. 2 (1994): 155-173.

Barbier, E, G Heal, and M Geoffrey. "Valuing Ecosystem Services." The Economists Voice, 2006.

Barbier, Edward, Mike Acreman, and Duncan Knowler. Economic valuation of wetlands. Ramsar Convention Bureau, 1997.

Barrett, C B. "Fairness, stewardship and sustainable development." Ecological Economics, 1996: 11-17.

Bateman, I J, A P Jones, N Nishikawa, and R Brouwer. Benefits Transfer in Theory and Practice: A Review and Some New Studies. CSERGE and School of Environmental Sciences, University of East Anglia, 2000.

Bateman, I, I Landford, R K Turner, K Willis, and G Garrod. "Elicitation and Truncation Effects in Contingent Valuation Studies." Ecological Economics 12, no. 2 (1995): 161-179.

Berkes, F. Sacred ecology. Traditional ecological knowledge and resource management. Philadelphia: Taylor and Francis, 2003.

Berkes, F, M Kslalioglu, C Folke, and M Gadgil. "Exploring the basic ecological unit: ecosystem-like concepts in traditional socieities." Ecosystems, 1998: 409-415.

Berrens, R P. "The safe minimum standard approach: an alternative to measuring non-use values for environmental assets?" Forestry, economics and environment (CAB International) 28, no. 2 (2001).

Bingham, G, et al. "Issues in ecosystem valuation: improving information for decision making." Ecological Economics, 1995: 73-90.

Bockstael, N E, A M Freeman, R J Kopp, P R Portney, and V K Smith. "On measuring economic values for nature." Environmental Science and Technology, no. 34 (2000): 1384-1389.

Bosch, J M, and J D Hewitt. "A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration." Journal of Hydrology 55 (1982): 3-23.

Bossel, Hartmut. Indicators for Sustainable Development: Theory, Method, Applications. Winnipeg, Canada: International Institute for Sustainable Development, 1999.

Boyd, D. "Why a course on Indicators for Sustainable Development?" In Advanced Course on Indicators for Sustainable Urban Development, by IIUE, 21-36. Nivo, 1997.

Boyle, K, and J Bergstrom. "Benefit transfer studies: myths, pragmatism and idealism." Water Resources Research 28, no. 3 (1992): 657-663.

Brent, R J. Applied Cost-Benefit Analysis. 2nd Edition. Cheltenham: Edward Elgar, 2006.

Brookshire, D, and H Neil. "Benefits transfers: conceptual and empirical issues." Water Resources Research 28, no. 3 (1992): 651-655.

Brouwer, R. The Validity and Reliability of Environmental Benefits Transfer . PhD Thesis, University of East Anglia, 2000.

Brown, J, and D W Pearce. "The economic value of carbon storage in tropical forests." In The Economics of Project Appraisal and the Environment, edited by J Weiss, 102-23. Cheltenham: Edward Elgar, 1994.

Brown, T C. "Streamflow needs and protection in wilderness areas in the economic value of wilderness." Proceedings of the Conference. General Technical Report SE-78. Asheville, North Carolina: United States Department of Agriculture and Forest Service, 1992. 161-172.

Buchmann, S L, and G P Nabhan. The Forgotten Pollinators. Washington DC: Island Press, 1996.

Cardinale, B J, A R Ives, and P Inchausti. "Effects of species diversity on the primary productivity of ecosystems: extending our spatial and temporal scales of inferences." Oikos, no. 104 (2004): 437-450.

Carpenter, S, E Bennett, and G Peterson. "Scenarios for ecosystem services: an overview." Ecology and Society 11, no. 1 (2006).

Carson, R T. "Constructed Markets." In Measuring the Demand for Environmental Quality, edited by J B Braden and C D Kolstead. Amsterdam, 1991.

CBD. The Value of Forest Ecosystems. CBD Technical Series No. 4, Montreal: Secretariat of the Convention on Biological Diversity, 2001, 67.

Chavas, J P. "Equity considerations in economic and policy analysis." Journal of Agriculture Economics, 1994: 1002-1033.

Clarkson, R. Estimating the social cost of carbon emissions. London: Department of the Environment, Transport and the Regions, 2000.

Costanza, R, and C Folke. "Valuing ecosystem services with efficiency, fairness and sustainability as goals." In Nature Services: Societal Dependence on Natural Ecosystems, by G Daily, 49-68. Washington D.C.: Island Press, 1997.

Costanza, R, et al. "The total value of the world's ecosystem services and natural capital." Nature, 1997: 253-260.

Cottingham, K L, B L Brown, and J T Lennon. "Biodiversity may regulate the temporal variability of ecological systems." Ecology Letters, no. 4 (2001): 72-85.

Crane, E, and P Walker. Pollination Directory for World Crops. London: International Bee Research Association, 1984.

Crowards, Tom M. "Safe minimum standards: costs and opportunities." Ecological Economics 25, no. 3 (1998): 303-314.

Daily, Gretchen C. Nature's services: societal dependence on natural ecosystems. Washington: Island Press, 1997.

Daily, Gretchen C, et al. "ECOSYSTEM SERVICES: Benefits Supplied to Human Societies by Natural Ecosystems." Issues in Ecology 2 (1997).

Daily, Gretchen C, et al. "ECOSYSTEM SERVICES: Benefits Supplied to Human Societies by Natural Ecosystems." Issues in Ecology 2 (1997).

Danielsen, F, et al. "The Asian Tsunami: A Protective Role for Coastal Vegetation." Science CCCX (2005): 643.

Das, Saudamini, and Jeffrey Vincent. Mangrove protected villages and reduced death toll during Indian super cyclone. PNAS, 2007.

Dasgupta, P. "Nature's role in sustaining economic development." Phil. Trans. R. Soc. B, no. 365 (2010): 5-11.

DCLG. Multi-criteria analysis: a manual. London: Department for Communities and Local Government, 2009.

De Groot, R S. Functions of nature: evaluation of nature in environmental planning, management and decision making. Amsterdam: Wolters-Noordhoff, 1992.

De Groot, Rudolf S, Matthew A Wilson, and Roelof M Boumans. "A typology for the classification, description and valuation of ecosystem functions, goods and services." Ecological Economics, 2002.

De Groot, Rudolf, Mishka Stuip, Max Finlayson, and Nick Davidson. Valuing wetlands: guidance for valuing benefits derived from wetland ecosystem services. Ramsar Convention Bureau, 2006.

DEFRA. An introductory guide to valuing ecosystem services. DEFRA, 2007.

DEFRA. An introductory guide to valuing ecosystem services. DEFRA, 2007.

DEFRA. An introductory guide to valuing ecosystem services. DEFRA, 2007.

DEFRA. Use of multi-criteria analysis in air quality policy. DEFRA, 2003.

De Fries, R, and S Pagiola. "Analytical approaches for assessing ecosystem condition and human well-being." In Ecosytems and Human Well-being: Current state and trends, by Millenium Ecosystem Assessment. Washington: World Resources Institute, 2005.

Delft, Y van. "An Introduction to Indicators and Monitoring." In Advanced Study Course on Indicators for Sustainable Urban Development, by IIUE. Nivo, 1997.

Dixon, J, and S Pagiola. Economic analysis and environmental assessment. Environmental Assessment Sourcebook Update, The World Bank, 1998.

Dudley, N, and S Stolton. "Running Pure: The importance of forest protected areas to drinking water." WWF. 2003. http://assets.panda.org/downloads/runningpurereport.pdf (accessed Dec 25, 2009).

Dwyer, J F, E G McPherson, H W Schroeder, and R A Rowntree. "Assessing the benefits and costs of the urban forest." Journal of Arboriculture 18, no. 5 (1992): 227-234.

ECO2. Assessment of Environmental and Resource Costs in the Water Framework Directive . Final Draft, Working Group 'Integrated River Basin Management' (WG2B), 2004.

EFTEC. Valuing our Natural Environment. Final Report NR0103, London: EFTEC & Environmental Futures Limited, 2006.

Elliman, K, and N Berry. "Protecting and restoring natural capital in New York City's Watersheds to safeguard water." In Restoring Natural Capital: Science, Business and Practice, edited by J Aronson, S J Milton and J N Blignaut, 208-215. Washington DC: Island Press, 2007.

Elmqvist, T, et al. "Response diversity, ecosystem change and resilience." Frontiers in Ecology and the Environment, no. 1 (2003): 488-494.

Emerton, L. Participatory Environmental Valuation: Subsistence Forest Use Around the Aberdares, Kenya. Nairobi, Kenya: African Wildlife Foundation, 1996.

Emerton, L, L Iyango, P Luwum, and A Malinga. The Economic Value of Nakivubo Urban Wetland, Uganda. Nairobi: Uganda National Wetlands Programme, Kampala and IUCN - The World Conservation Union, 1999.

Emerton, L, R Seilava, and H Pearith. "Bokor, Kiriron, Kep and Ream National Parks, Cambodia: Case studies of Economic and Development Linkages." Review of Protected Areas and their Role in the Socio-economic Development of the Four Countries of the Lower Mekong Region. Karachi: International Centre for Environmental Management, 2002.

Emerton, Lucy. Valuing wetlands in decision-making. Wetland Valuation Issues Paper No. 1, IUCN, 2003.

EPA. Improving the Practice of Benefit Transfer: A Preference Calibration Approach. Interim Final Report, Washington DC: U.S. Environmental Protection Agency, 2000.

EPA. Valuing the protection of ecological systems and services. EPA-SAB-09-012, EPA Science Advisory Committee, 2009.

EPI. 2010 Environmental Performance Index. New Haven: Yale Center for Environmental Law, 2010.

ESI. 2005 Environmental Sustainability Index. Yale University and Columbia University, 2005.

ESRI. What is ArcGIS? 2004. http://www.esri.com/sofware/arcgis/about/literature.html.

Falkowski, P, et al. "The global carbon cycle: a test of our knowledge of Earth as a system." Science, 2000: 291-296.

FAOSTAT. FAOSTAT. 2009. http://faostat.fao.org/default.aspx (accessed Dec 28, 2009).

Farley, J. "The role of prices in conserving critical natural capital." Conservation Biology 22 (2008).

Finlayson, C M, R D'Cruz, and N Davidson. Ecosystems and Human Well-being: Wetlands and Water: Synthesis. Washington: Millenium Ecosystem Assessment, World Resources Institute, 2005.

Fisher, B, and K Turner. "Ecosystem services: classification for valuation." Biological Conservation, no. 141 (2008): 1167-1169.

Fisher, B, R K Turner and P Morling. "Defining and classifying ecosystem services for decision making." Ecological Economics 68 (2009):643-653.

Fisher, J, and P McMahon. Economics and Environmental Decision-Making. Hertfordshire: Water, Economics and Environment Agency, 2003.

Folke, C. "Traditional knowledge in social-ecosystems [editorial]." Ecology and Society 9, no. 3 (2004): 7.

Folke, C, et al. "Regime shifts, resilience and biodiversity in ecosystem management." Annual Review of Ecology Evolution and Systematics, no. 35 (2005): 557-581.

Foster, J. Valuing Nature? Economics, Ethics and Environment. London: Routledge, 1997.

Foster, V, and S Mourato. Behavioral Consistency, Statistical Specification and Validity in the Contingent Ranking Method: Evidence from a Survey of the Impacts of Pesticide Use in the UK. CSERGE Working Paper 97-09, University of London, 1997.

Freeman, A M. "On assessing the state of the art of the contingent valuation method for valuing environmental changes (Chapter 10)." In Valuing environmental goods: an assessment of the contingent valuation method, edited by R G Cummings, D S Brookshire and W D Schulze. New Jersey: Rowman and Allanheld, 1986.

Freeman, A. The measurement of environmental and resource values: theory and methods. 2nd Edition. Washington DC: Resources for the Future, 2003.

Frost, T M, S R Carpenter, A R Ives, and T K Kratz. "Species compensation and complementarity in ecosystem function." In Linking species and ecosystems, by C Jones and J Lawton, 224-239. New York, USA: Chapman and Hall, 1995.

Gemmill, B, M Gikungu, G Njoroge, W Kunithia, and P Kwapong. "Case studies on conservation of pollination services as a component of agricultural biological diversity." FAO. 2009. http://www.fao.org/AG/agp/AGPS/C-CAB/Castudies/pdf/2-002.pdf (accessed Dec 28, 2009).

Goulder, L, and J Kennedy. "Valuing ecosystem services: philosophical bases and empirical methods." In Nature's Services: Societal Dependence on Natural Ecosystems, edited by G Daily. Washington DC: Island Press, 1997.

Gowdy, J M. "The monetary valuation of biodiversity: promises, pitfalls and rays of hope." In Managing human-dominated ecosystems: proceedings of the symposium at the Missouri Botanical Garden, St. Louis, Missouri, by V C Hollowell, 141-149. St. Louis: Missouri Botanical Garden Press, 2001.

Gregersen, H M, J M Arnold, A L Lundgren, and A Contreras-Hermosilla. Valuing forests: context, issues and guidelines. Rome: FAO, 1999.

Gregory, R, and K Wellman. "Bringing stakeholder values into environmental policy choices: a community based estuary case study." Ecological Economics, 2001: 37-52.

Gren, I, and T Soderqvist. Economic valuation of wetlands: a survey. Beijer Discussion Paper Series No. 54, Stockholm: Beijer International Institute of Ecological Economics, Royal Swedish Academy of Sciences, 1994.

Guo, Zhongwei, Xiangming Xiao, and Dianmo Li. "An assessment of ecosystem services: water flow regulation and hydroelectric power production." Ecological Applications 10, no. 3 (2000): 925-936.

Habermas, J. The theory of communicative action. Boston, MA: Beacon Press, 1984.

Hanley, N, and C L Spash. "Cost-benefit analysis and the environment." Vermont, 1993: 278.

Hanley, N, and E Barbier. Pricing nature cost benefit analysis and environmental policy. Cheltenham: Edward Elgar, 2009.

Haughton, G, and C Hunter. Sustainable Cities. Wiltshire: Cromwell Press Limited, 1994.

Heal, G. "Valuing ecosystem services." Ecosystems 3, no. 1 (2000): 24-30.

Hein, Lars. Environmental Economics Tool Kit: Analyzing the Economic Costs of Land Degradation and the Benefits of Sustainable Land Management. Netherlands: UNDP/GEF, 2006.

Hellin, J, M Haigh, and F Marks. "Rainfall characteristics of Hurricane Mitch." Nature, no. 359 (1999): 316.

Hodgson, G, and J Dixon. "Measuring Economic Losses due to Sediment Pollution: Logging versus tourism and fisheries." Tropical Coastal Area Management, 1988: 5-8.

Hoevenagel, R. The contingent valuation method: scope and validity. Amsterdam: Vrije Universiteit, 1994.

Holling, C S. "Cross-scale morphology, geometry and dynamics of ecosystems." Ecological Monographs 62 (1992): 447-502.

Hougner, Cajsa, Johan Colding, and Tore Soderquist. "Economic valuation of a seed dispersal service in the Stockholm National Urban Park, Sweden." Ecological Economics 59 (2006): 364-374.

Howard, P. "The Economics of Protected Areas in Uganda: Costs, Benefits and Policy Issues." A dissertation for the University of Edinburg, 1995.

ICRAF. The Program for Developing Mechanisms for Rewarding the Upland Poor in Asia for Environmental Services (RUPES). Indonesia: World Agroforestry Centre, 2003.

IIED. Valuing Forests: A Review of Methods and Applications in Developing Countries. London, UK: Environmental Economics Programme, IIED, 2003.

Ives, A R, J L Klug, and K Gross. "Stability and variability in competitive communities." Science, no. 286 (1999): 542-544.

James, R. Wetland valuation: guidelines and techniques. PHPA/AWB Sumatra Wetland Project Report No 31, Bogor, Indonesia: Asian Wetland Bureau, 1991.

Kaiser, B, and J Roumasset. “Valuing indirect ecossytem services: the case of tropical watersheds.” Environment and Development Economics 4, no. 7 (2002): 701-714.

Kaiser, Brooks, and James Roumasset. “Valuing Indirect Ecosystem Services: the case of Tropical Watersheds.” Environment and Development Economics, 2002: 701-714.

Kjabbi, M. “An economic assessment of the natural resources of the Baltic Oil Shale Basin: Case study of Estonia.” In Environmental Valuation: A worldwide compendium of case studies, 127-133. London: Earthscan Publications, 1998.

Krieger, D J. Economic value of forest ecosystem services: a review. Washington D.C.: The Wilderness Society, 2001.

Kuik, O J, and A J Gilbert. “Indicators for Sustainable Development.” In Handbook of Environmental and Resource Economics, by Bergh J.C.J.M. Van den. Cheltenham: Edward Elger, 1999.

Kumar, P, and M D Wood. Valuation of Regulating Services of Ecosystems: Methodology and Applications. Routledge, 2010.

Kumar, P, C Babu, R Sharma, and A Love. Valuation of ecological services of wetland ecosystems: a case study of Yamuna floodplain in the corridors of Delhi. Mimeograph, New Delhi: IEG, 2001.

Kumari, K. An environmental and economic assessment of forest management options: a case study in Malaysia. Environment Department Paper No 26, Washington DC: The World Bank, 1995.

Kusama, Indah D. Economic valuation of natural resource management: a case study of the Benuaq Dayak tribe in Indonesia. A Dissertation, Louisiana State University, 2005.

Lampietti, J A, and J A Dixon. To See the Forest for the Trees: A Guide to Non-timber Forest Benefits. Environment Department Papers No. 013, Washington D.C.: The World Bank, 1995.

Layard, R, and S Glaister. Cost-Benefit Analysis. Cambridge: Cambridge University Press, 1994.

Layke, Christian. Measuring Nature’s Benefts: A Preliminary Roadmap for Improving Ecosystem Service Indicators. WRI Working Paper, Washington DC: World Resource Institute, 2009.

Lescuyer, Guillaume, CIFOR, Cameroon, and Yaoundé. “Valuation techniques applied to tropical forest environmental services: rationale, methods and outcomes.” Paper presented at “West and Central Africa Tropical Forest Investment Forum: Issues and Opportunities for Investment in Natural Tropical Forests”. Accra: ITTO, August 28-30, 2007.

Levin, S A. “The problem of pattern and scale in ecology.” Ecology 73 (1992): 1943-1967.

Loreau, M, N Mouquet, and A Gonzalez. “Biodiversity as spatial insurance in heterogenous landscapes.” Proceedings of the National Academy of Sciences, no. 100 (2003): 12765-12770.

Lowry, John. Low-cost GIS software and data for wetland inventory, assessment and monitoring. Ramsar Technical Report No. 2, Gland, Switzerland: Ramsar Convention Secretariat, 2006.

Lynam, T J, B M Campbell, and S J Vermeulen. Contingent Valuation of Multipurpose Tree Resources in the Smallholder Farming Sector, Zimbabwe. Published in ‘Studies in Environmental Economics and Development’, Gothenburg: Gothenburg University, 1994.

MA Follow-up Advisory Group. The Millennium Ecosystem Assessment Follow-up: A Global Strategy for Turning Knowledge into Action. Convention on Biological Diversity , 2008.

MA. Millenium Ecosystem Assessment. Island Press, 2005.

Maler, K G. "Production Function Approach in Developing Countries." In Valuing Environmental Benefits in Developing Countries, edited by J R Vincent, E W Crawford and J P Hoehn. Michigan State University, 1992.

Maler, K, S Anyar, and A Jansson. Accounting for Ecosystems, Environment and Resource Economics. 2009.

McPherson, E G. "Accounting for benefits and costs of urban green space." Landscape and Urban Planning, no. 22 (1992): 41-51.

Mishan, E. Cost-benefit analysis. 4th Edition. London: Routledge, 1988.

Moons, Ellen. The development and application of economic valuation techniques and their use in environmental policy - a survey. Belgium: Centre for Economic Studies, 2003.

Morse-Jones, S, K R Turner, B Fisher, and T Luisetti. Ecosystem valuation: some principles and a partial application. Working Paper EDM 10-01, Norwich: CSERGE, 2009.

Moskowitz, K, and J Talberth. The economic case against logging our national forests. Santa Fe, New Mexico: Forest Guardians, 1998.

Munasinghe, M. Environmental Economics and Valuation in Development Decisionmaking. Environment Working Paper No. 51, Washington D.C.: The World Bank, 1992.

Munasinghe, M, and E Lutz. "Environmental economics and valuation in development decision making." In Environmental economics and natural resource management in developing countries, edited by M Munasinghe. Washington DC: Committee of International Development Institutions on the Environment. The World Bank, 1993.

Myers, N. "Environmental services of biodiversity." Proceedings of the National Academy of Sciences, no. 93 (1996): 2764-2769.

Myers, N. "The world's forests and their ecosystem services." In Nature's services: societal dependence on natural ecosystems, edited by G Daily. Washington DC: Island Press, 1997.

Naeem, S, D Bunker, A Hector, M Loreau, and C Perrings. Biodiversity, ecosystem functioning and human well-being. Oxford: Oxford University Press, 2009.

Niskanen, A. "Value of external environmental impacts of reforestation in Thailand." Ecological Economics 26, no. 3 (1998): 279-298.

Norberg, J. "Biodiversity and ecosystem functioning: a complex adaptive systems approach." Limnology and Oceanography, no. 49 (2004): 1269-1277.

Nunes, P A, and van den Bergh. "Economic Valuation of Biodiversity: Sense or Nonsense?" Ecological Economics, no. 39 (2001): 203-222.

Nystrom, M, and C Folke. "Spatial resilience of coral reefs." Ecosystems, no. 4 (2001): 406-417.

O'Connell. Welfare economics theory. Boston: Auburn Publishing House, 1982.

O'Neill, J, and A W King. "Hommage to St Michal: or why are there so many books on scale?" In Ecological scale: theory and applications, edited by D L Peterson and V T Parker, 3-15. New York: Columbia University Press, 1998.

Pabon, L. "Valuing Nature: Assessing Protected Area Benefits." The Nature Conservancy. 2009. http://www.nature.org/initiatives/protectedareas/files/valuing_nature_assessing_protected_area_benefits.pdf (accessed Dec 25, 2009).

Pagiola, Stefano, Konrad Von Ritter, and Joshua Bishop. Assessing the economic value of ecosystem conservation. World Bank, 2004.

Panayotou, Theodore. Developments of change: motivating and financing sustainable development. London: Earthscan Publications Ltd, 1998.

Pattanayak, S. "Valuing watershed services: concepts and empirics from Southeast Asia." Agriculture Ecosystem Environment, no. 104 (2004): 171-184.

Patterson, M. "Commensuration and theories of value in ecological economics." (Ecological Economics) 25, no. 1 (1998): 105-125.

Pearce, D. "Cost-benefit analysis and environmental policy." Oxford Review of Economic Policy 14, no. 4 (1998): 84-100.

Pearce, D, and C Nash. The Social Appraisal of Projects: A Text in Cost-Benefit Analysis. Basingstoke: Macmillan, 1981.

Peterson, G, C R Allen, and C S Holling. "Ecological resilience, biodiversity and scale." Ecosystems, no. 1 (1998): 6-18.

Pimentel, D, et al. "Economic and Environmental Benefits of Biodiversity." Bioscience 47, no. 11 (1997): 747-757.

Polasky, S, and K Segerson. Integrating Ecology and Economics in the Study of Ecosystem Services: Some Lessons Learned. Annual Review of Resource Economics, 2009, 409-34.

Priess, J A, M Mimler, A Klein, S Schwarze, T Tscharntke, and I Steffan-Dewenter. "Linking deforestation scenarios to pollination services and economic returns in coffee agroforestry systems." Ecological Applications 17, no. 2 (2007): 407-417.

Primavera, J H. "Magroves, fishponds, and the quest for sustainability." Science, no. 310 (2005): 57-59.

Ramakrishnan, P, K Saxena, and D Chandrashekara. Conserving the sacred: for biodiversity management. New Delhi, India: Oxford University Press, 1998.

Reid, W. Capturing the value of ecosystem services to protect biodiversity. Washington DC: World Resource Institute, 1999.

Richards, K W. "Non-apis bees as crop pollinators." Suisse Zoology 100 (1993): 807-822.

Richards, Michael, and Jonathan Davies. The use of economics to assess stakeholder incentives in participatory forest management: a review. European Union Tropical Forestry Paper, London: Overseas Development Institute, 1999.

Ricketts, T H. "Tropical forest fragments enhance pollinator activity in nearby coffee crops." Conservation Biology 18, no. 5 (2004): 1262-1271.

Ricketts, T H, G C Daily, P R Ehrlich, and C D Michener. "Economic value of tropical forest to coffee production." PNAS 101 (2004): 12579-12582.

Rietbergen-McCracken, J, and H Abaza, . Environmental Valuation: A Worldwide Compendium of Case Studies. Earthscan Publications, 1998.

Rodenburg, C A, E S van Leeuwen, and P Nijkamp. A comparative framework of assessment indicators for urban green spaces. Netherlads: University of Amsterdam, 2002.

Rodríguez, J, et al. "Trade-offs across space, time and ecosystem services." Ecology and Society 11, no. 1 (2006).

Rosales, R M, M F Kallesoe, P Gerrard, P Muangchanh, S Phomtavong, and S Kahmsomphou. Balancing the Returns to Catchment Management: The Economic Value of Conserving Natural Forests in Sekong, Lao PDR. IUCN Water, Nature and Economics Technical Paper No. 5, IUCN - The World Conservation Union, Ecosystems and Livelihoods Group Asia, 2005.

Rothmans, J. "Indicators for Sustainable Development." In Perspectives on Global Change - The Target Approach, by J Rothmans and B de Vries, 89-104. Cambridge: Cambridge University Press, 1997.

Sagoff, M. The Economy of the Earth. Cambridge: Cambridge University Press, 1988.

Sedell, J, M Sharpe, A Dravnieks, M Copenhagen, and M Furniss. Water and the Forest Service. FS-660, Washington DC: US Department of Agriculture and Forest Service, 2000.

Segnestam, Lisa. Environmental Performance Indicators. Environmental Economic Series Paper No. 71, Washington DC: The World Bank, 1999.

Selman, M, S Greenhalgh, E Branosky, C Jones, and J Guiling. Water Quality Trading Programs: An International Overview. Washington DC: World Resources Institute, 2008.

Shyamsundar, Priya. Poverty-Environment Indicators. Environmental Economic Series Paper No. 84, Washington DC: The World Bank, 2002.

Tallis, H, P Kareiva, M Marvier, and A Chang. "An ecosystem services framework to support both practical conservation and economic development." Proceedings of the National Academy of Sciences 105, no. 28 (2008): 9457-9464.

Tansley, A G. "The use and abuse of vegetational terms and concepts." Ecology 16 (1935): 284-307.

TEEB. The Economics of Ecosystem and Biodiversity: TEEB for Policy Makers. Summary Report, UNEP, 2009.

The World Bank. Expanding the measure of wealth: indicators of environmentally sustainable development. Environmentally Sustainable Development Studies and Monographs Series No. 17, Washington DC: The World Bank, 1997.

Tilman, D, D Wedin, and J Knops. "Productivity and sustainability influenced by biodiversity in grassland ecosystem." Nature, no. 379 (1996): 718-20.

Tol, R, S Fankhauser, R Richels, and J Smith. "How much damage will climate change do? Recent estimates." World Economics, 2000: 179-206.

Toman, M A. "Ecosystem valuation: an overview of issues and uncertainties." In Ecosystem function and human activities: reconciling economics and ecology, by R D Simpson and N L Christensen, 25-44. New York: Chapman and Hall, 1997.

Turner, R K, W N Adger, and R Brouwer. "Ecosystem services value, research needs, and policy relevance: a commentary." Ecological Economics, 1998: 61-65.

UNCED. "United Nations Conference on Environment and Development (UNCED)." The Earth Summit. Rio de Janeiro, Brazil, 1992.

UNECE. "Protocol on SEA." UNECE. 2010. http://www.unece.org/env/eia/sea_manual/annexA51.html#Trends (accessed February 04, 2010).

UNEP. Global Environment Outlook - 3. Geneva, Switzerland: United Nations, 2002.

Van Beukering, P J, H J Cesar, and M A Janssen. "Economic valuation of the Leuser National Park on Sumatra, Indonesia." Ecological Economics 44 (2003): 43-62.

Verma, Madhu. "Framework for forest resource accounting : factoring in the intangibles". International Forestry Review Vol. X, no. 2 (June 2008): 362-375.

Voora, Vivek, and Stephan Barg. Pimachiowin Aki World Heritage Project Area Ecosystem Services Valuation Assessment. Winnipeg, Canada: IIED, 2008.

Walker, B H, A P Kinzig, and J Langridge. "Plant attribute diversity, resilience and ecosystem function: the nature and significance of dominant and minor species." Ecosystems, no. 2 (1999): 95-113.

Wilson, Matthew, and Richard Howarth. "Discourse-based valuation of ecosystem services: establishing fair outcomes through group deliberation." Ecological Economics, 2002: 431-443.

Wilson, R, and E Crouch. Risk-benefit analysis. 2001.

WRI. Value of Coral Reefs & Mangroves in the Caribbean Economic Valuation Methodology V3.0, WRI, 2009.

Yaron, G. "Forest, plantation crops or small-scale agriculture? An economic analysis of alternative land use options in the Mount Cameroun Area." Journal of Environmental Planning and Management 44, no. 1 (2001): 85-108.

Zhang, Z X. "Estimating the size of the potential market for the kyoto flexibility mechanisms." University of Groningen, 2000.

Appendix: Valuation case studies

Table A1. A guide to the case studies in this Appendix

Case study	Region	Ecosystem	Regulating services valued	Methodology/approach used for valuation	Any other specific comments
01	Uganda, Africa	Wetland	Wastewater purification (nutrient retention function)	Replacement costs and mitigative/avertive expenditure	
02	Canada, North America	Mainly forests	Carbon sequestration; carbon storage; air quality regulation; water purification; erosion control; biological control	Spatially-based regulating service valuation approach; benefits transfer	Values derived for resident and non-resident population
03	China, Asia	Forests	Water flow regulation	Process-based simulation model to estimate water flow	90 types of vegetation-soil-slope complexes used in the analysis
04	India, Asia	Mangroves	Nutrient retention; storm protection	Market price method; damage cost avoided;	
05	India, Asia	Mangroves	Natural hazard regulation	Damage cost avoided	Study across more than 400 villages
06	New York, North America	Mainly forests	Water purification	Replacement cost approach	
07	India, Asia	Forests	Carbon sequestration	Modelling	
08	Global	General	Pollination	Bio-economic approach integrated with the production dependence ratio on pollinators for 100 crops listed by FAO for human food worldwide	
09	Lao PDR, Asia	Forests	Watershed protection; carbon sequestration	Production function approach; avoided cost approach; benefits-transfer approach	
10	Hawaii, Oceania	Forests	Groundwater recharge	Modelling; shadow price approach	
11	Uganda, Africa	Forests	Watershed protection; carbon sequestration and local climate regulation	Production function approach; replacement cost approach	
12	Mexico, Central America	Forests	Carbon sequestration; watershed protection	Avoided cost approach; modelling	
13	Malaysia, Asia	Forests	Water regulation; carbon sequestration	Production function approach; spatial analysis; damage cost avoided; benefits-transfer;	
14	Guatemala, Central America	Forests	Nutrient cycling; erosion control	Universal Soil Loss Equation; replacement cost; preventive cost method	Calculates value for both: stock and flow
15	Philippines, Asia	Coastal	Erosion regulation;	Productivity function approach; cost-benefit analysis over 10-year time horizon	Decision making framework
16	Malaysia, Asia	Mangroves	Shoreline protection; fisheries protection	Contingent valuation method	
17	Mt. Cameroon, Africa	Forests	Carbon storage; flood prevention; sediment prevention	Damage cost avoided; shadow pricing	Comparison across forests, plantation crops and small-scale agriculture
18	Sweden, Europe	Mainly forests	Pollination	Replacement cost approach	
19	Costa Rica, Central America	Forests	Pollination	Production function approach	
20	Indonesia, Asia	Forests	Erosion prevention; carbon sequestration	Benefits transfer approach	Total economic value of indigenous people

Table A2. Examples of case studies for specific regulating services

Regulating service	Case studies
Climate regulation	· Lescuyer et al. (2007), based on a review of previous studies, estimated the value of climate regulation by tropical forests in Cameroon at US$ 842-2,265 per hectare per year.
Water regulation	· Yaron (2001) estimated the value of flood protection by tropical forests in Cameroon at US$ 24 per hectare per year. · Van Beukering et al. (2003), estimate the NPV for water supply from 2000 to 2030 of the Leuser Ecosystem comprising approximately 25,000 km2 of tropical forest at US$ 2,419 billion
Groundwater recharge	· Kaiser and Roumasset (2002) valued the indirect watershed benefits of tropical forests in the Ko'olau watershed, Hawaii, using shadow prices. The net present value of the contribution to groundwater recharge of the 40,000 hectare watershed was estimated at US$ 1.42-2.63 billion.
Pollination	· Priess et al. (2007) estimated the average value of pollination services provided by forests in Sulawesi, Indonesia, at 46 Euros per hectare. As a result of ongoing forest conversion, pollination services are expected to decline continuously and directly reduce coffee yields by up to 18 percent and net revenues per hectare up to 14 percent within the next two decades.
Water purification and waste treatment	· US$2 billion natural capital solution (restoration and maintenance of watershed) versus a US$7 billion technological solution (pre-treatment plant) (Elliman and Berry 2007) · In Te Papanui Catchment, the Central Otago conservation area is contribution to Dunedin's water supply, saving the city US$93 million. One third of the world's hundred largest cities draw a substantial proportion of their drinking water from forest protected area (Dudley and Stolton 2003).
Erosion regulation	· The National Protected Area system in Venezuela prevents sedimentation that would reduce farm earnings by around US$3.5 million per year (Pabon 2009)
Natural hazard regulation	· As a consequence of the severe floods in the Yangtse River in 1998, the Chinese government decided to invest over US$ 40 billion into the Sloping Land Conversion Programme (Tallis et al. 2008). · In Combodia, the Ream National Park provides ecosystem services such as storm protection and erosion control valued at US$300,000 (Emerton et al. 2002).

Case studies

Case study 01: Managing Nakivubo swamp in Uganda for regulating services

A study was carried out in Nakivubo Swamp in Kampala, Uganda's capital city, aimed to quantify the value of wetland wastewater purification and nutrient retention functions, so that they could be balanced against the potential gains from wetland conversion for industrial and residential developments. A key concern was thus to choose methods which would not require complex, lengthy or costly primary data collection, and which could be easily replicable. At the same time it was necessary to produce an economic argument which was defendable, and would stand up to outside scrutiny.

Two valuation methods were applied to the case of Nakivubo: the avoided costs of replacing natural wetland functions with manmade alternatives, and the foregone expenditures on mitigating or offsetting the effects of wetland loss. Replacement costs included two components: connecting Nakivubo channel to an upgraded sewage treatment plant which could cope with the resulting additional wastewater load, and constructing elevated pit latrines to prevent sewage from low-cost settlements from entering the wetland. The major mitigative or avertive expenditure required to offset the effects of impaired water quality arising from wetland loss would be to move the inflow for Kampala's water supply to an alternative location sited away from the outlet of wastewaters.

The results of the valuation exercise showed that the wastewater purification and nutrient retention services of Nakivubo Swamp have a high economic value - between US$ 1 million a year (using replacement cost methods) and US$1.75 million a year (using mitigative expenditures methods). Even taking account of the costs of managing the wetland so as to simultaneously optimize its waste treatment potential and maintain its ecological integrity (some US$ 235,000) results in a significant net benefit. These figures provided a powerful economic argument against further drainage and reclamation of the wetland.

Source: Adapted from Emerton et al. (1999)

Case study 02: Assessment of ecosystem services in Canada

A detailed assessment of ecosystem services was carried out in Canada for a 40,000 km^2 landscape located across Eastern Manitoba and Northwestern Ontario. The study estimated the economic value of the ecosystem services by mapping its land covers and using valuation studies from similar environments. Ecosystem service values were derived for the resident and non-resident populations of the site.

The study used spatially based ecosystem services valuation approach to efficiently value the site. Measuring and establishing the surface areas of different land covers (20 land cover classes) was used as a basis for estimating the types and amounts of ecosystem services that could potentially flow from them.

Regulating service	Methodology used	Estimated economic value
Carbon sequestration	Previous estimates for carbon sequestration were used and adjusted for nine different forest types	CDN$ 12.32 to $21.27 million a year
Carbon storage	Based on previous estimates and land cover data	CDN$ 2.70 to $17.51 billion
Air filtration	Multiplying average number of trees with the air filtration service economic value reported by Anielski and Wilson (2005)	CDN$ 350 to $600 billion a year
Water purification	Based on nutrient retention and treatment capacity of wetlands and the equivalent costs of treating these nutrients by using treatment plants	CDN$ 31.83 million a year
Erosion control	Increased sedimentation linked with decreasing water quality	CDN$ 3.35 million a year
Biological control	Expenditures on insect control activities, disease prevention, and replacement cost of replacing bird biological control services by pesticides or genetic engineering were used	CDN$ 21.09 to $36.40 million a year

Source: Adapted from Voora and Barg (2008)

Case study 03: Assessment of water flow regulation and hydroelectric power generation

Forest ecosystems in the watersheds of the Yangtze river regulate water flow in the rivers. The value of water flow regulation by ecosystems is usually not realized in situ but may transfer spatially through rivers to another spot out of watersheds where conditions are suitable to realize it. To take into account the transfer of value of biological resources spatially, a process-based simulation model was developed to estimate the capacity of water flow regulation by terrestrial ecosystems, taking into account such major processes as canopy interception, litter absorption, and soil/ground water conservation. Guo, Xiao and Li (2000) combined models and a GIS-embodied spatial database to assess the capacity and benefits of water flow regulation by ecosystems in Xingshan County, Hubei Province, China. The capacity of water flow regulation differed substantially among the 90 types of vegetation–soil–slope complexes in the watersheds. The simulation model estimated that in a wet season the watershed can retain ~868.07 × 106 m3 water, which may result in a decrease of water flow by ~111.63 m3/s in the Yangtze River. The model also estimated that in a dry season the watershed can discharge ~80.74 × 106 m3 water, resulting in an increase of water flow by 10.38 m3/s. As the result of water flow regulation, the Gezhouba hydroelectric power plant increases its electricity production by up to 40.37×106 kWh in a year and generates an additional economic value of ~6×105 US$/yr.

Source: Adapted from Guo et al. (2000)

Case study 04: Valuation of Bhitarkanika mangrove ecosystem

An attempt was made in Bhitarkanika Mangrove Ecosystem (BME) to estimate the value of various use and non-use benefits derived from the mangrove ecosystem. Among the four services chosen for valuation, the value of nutrient retention was estimated to be the highest. Market price method estimated the benefits derived from nutrient retention to be around Rs 160 million i.e. Rs 16450/acre/year. Based on the damage cost avoided approach, the value of storm protection service provided by BME was estimated to be around Rs 5500 per household in the villages with mangrove cover. Mangrove ecosystems also play an important role in land formation along the coast by trapping sediments. This service provided by the mangrove ecosystem was valued at Rs 46 million based on the current market price of land in that area. The total value of goods and services provided by BME was found to be significantly higher than other land-uses in the area including aquaculture, paddy and other development options.

Source: Adapted from Badola and Hussain (2004)

Case study 05: Mangrove protected villages and reduced death toll during Indian super cyclone

A study on more than 400 villages was conducted to test the impact of mangroves on human deaths during a 1999 super cyclone that struck Orissa. The results show the villages with wider mangroves between them and the coast experienced significantly fewer deaths compared to those which had narrower or no mangroves. A wide range of environmental and socioeconomic variables were controlled to increase the reliability of results. It was found that the retention of remaining mangroves in Orissa is economically justified even without considering the many benefits they provide to human society besides storm-protection services. Also mangroves will continue to provide such services in future. Using the average price of agriculture land near mangroves, it was found that the average opportunity cost of saving a life by retaining mangroves was Rs 11.7 million per life saved, less than the value of reductions in mortality risks implied by wage differentials in India. When historical mangrove data was used as a control variable, it was found that the vegetation itself, and not the physical aspect of the habitat, is providing protection against cyclone. Using regression analysis it was predicted that there would have been 1.72 additional deaths per village within 10 km of the coast if mangrove width had been zero.

Source: Adapted from Das and Vincent (1999)

Case study 06: The New York csase

Before it became overwhelmed by agricultural and sewage runoff, the watershed of the Catskill Mountains provided New York City with water ranked among the best in the Nation by Consumer Reports. When the water fell below quality standards, the City investigated what it would cost to install an artificial filtration plant. The estimated price tag for this new facility was US$ 6-8 billion — a high price to pay for what once was free. New York City decided instead to invest a fraction of that cost (US$ 660 million) in restoring the natural capital it had in the Catskill's watershed. In 1997, the City raised an Environmental Bond Issue and is currently using the funds to purchase land and halt development in the watershed, to compensate property owners for development restrictions on their land, and to subsidize the improvement of septic systems.

Source: Adapted from ESA (2009)

Case study 07: Carbon budget of Indian forest ecosystem

Forests act as source and sink of carbon. Haripriya (2001) used a model which takes into account the growing stock, additional tree organs, dead biomass, litter layer, and soil organic matter, harvesting and harvesting losses, effects of pests, fires, etc., allocation of timber to wood products, life span of products including recycling and allocation of landfills to calculate the net carbon balance for the year 1993-94. According to the assumptions underlying the model and data, the study indicated that Indian forest sector acted as a source of 12.8 TgC (1 Tg = Tera gram (10^{12}g)) including accumulation of carbon in the dead biomass for the year 1994.

Source: Adapted from Haripriya (2001)

Case study 08: Economic valuation of the vulnerability of world agriculture confronted with pollinator decline

There is a growing evidence of pollinator decline all over the world and the consequences of it as far as agriculture is concerned could be significant. A study assessed these consequences by measuring the contribution of insect pollination to the world agricultural output economic value and the vulnerability of world agriculture in the face of pollinator decline.

The study used a bio-economic approach integrated with the production dependence ratio on pollinators for the 100 crops used directly for human food worldwide as listed by FAO. The total economic value of pollination worldwide amounted to €153 billion, which represented 9.5% of the value of the world agricultural production used for human food in 2005. In terms of welfare, the consumer surplus loss was estimated between €190 and €310 billion based upon average price elasticities of - 1.5 to - 0.8, respectively. The study showed that vegetables and fruits were the leading crop categories in value of insect pollination with about € 50 billion each. The results of the study suggest that looking at the capacity to nourish the world population after pollinator loss, the production of 3 crop categories – namely fruits, vegetables, and stimulants - will clearly be below the current consumption level at the world scale. Although the valuation exercise clearly demonstrates the economic importance of insect pollinators, according to the authors it cannot be considered as a scenario since it does not take into account the strategic responses of the markets.

Source: Adapted from Gallai et al. (2009)

Case study 09: Economic value of regeneration of natural forests

The study estimates the total economic value of regeneration of natural forests in Sekong Province, Lao PDR, including watershed protection and carbon sequestration.

For watershed protection, the production value of fisheries, agriculture and hydropower, both existing and potential, were estimated. The avoided cost due to protection from floods and erosion was also estimated and represented in the value of watershed protection. The estimates for carbon sequestration were derived through benefit-transfer approach.

Regulating service	Annual value (US$)	Annual value (US$/ha)
Watershed protection		
Fisheries and aquatic resources	135,919	0.47
Agricultural production	714,550	2.5
Micro-hydropower facilities	792-5,367	0.003-0.02
Potential hydropower supply	67,255,472-455,575,755	233-1,581
Flood control	26,597,000	92.3
Carbon sequestration	649,400,000	1,284

Source: Adapted from Rosales et al. (2005)

Case Study 10: Valuing indirect ecosystem services of tropical watersheds

This study provides and illustrates an approach for valuing the indirect benefits, especially the watershed benefits of a tropical forest, without resorting to survey-based methods. The conservation of trees prevents a reapportionment from groundwater recharge to runoff that would otherwise occur. The value of the water saved is valued at the shadow prices obtained from an optimizing model. The study estimates the net social welfare as a function of the contribution of forest quality to groundwater recharge. It then uses different scenarios to estimate the change in net social welfare which is actually the present value of water regulating services.

The study illustrates this approach by giving an example of Ko'olau watershed in Hawaii. Using the demonstrated optimization model which takes an account of the extraction cost, saltwater seepage, rate of extraction among others; it calculates the net present value of the Ko'olau forested watershed's contribution to groundwater recharge at US$1.42 billion to US$2.63 billion.

The study modeled the indirect benefits of conservation according to the increase in the maximum present value of the recipient resource. This approach overcomes the problem that market prices may underestimate the value. It was also found that conservation of existing natural capital can have significant returns to investment, with an example of a benefit-cost ratio exceeding 50:1.

Source: Adapted from Kaiser and Roumasset (2002)

Case study 11: Economic value of protected areas in Uganda

Howard (1995) assessed the overall benefits and costs associated with Uganda's protected area systems so as to determine the net benefit to society of maintaining them. The study identified a host of values attributable to protected areas and the array of measures that can be used in valuation. A cost-benefit analysis was also used to compare the financial net benefit to the economic net benefit, reflected in social benefits and social costs.

The study estimated the value of watershed protection, carbon sequestration and potential influence on the local climate. The value of watershed protection was derived as a portion of the value of fish catch and was estimated to be US$13.8 million annually. However, for estimating the value of carbon sequestration, two different approaches were used. Based on figures of the damage that would occur if the land were converted and carbon released in the atmosphere, the value of Uganda's protected areas as a carbon sink was estimated at US$245 million, which amounts to a US$17.4 million annually (discounted at 5% over 25 years). The replacement cost approach was also used to estimate the cost of replacing this carbon sink functions through an afforestation scheme and was valued at US$20.3 million annually.

Source: Adapted from Howard (1995)

Case study 12: Total economic value of Mexican forests

This study demonstrates the economic techniques for estimating the Total Economic Value (TEV) of Mexican forests. The study estimates value of two regulating services: carbon sequestration and watershed protection. It argues that the avoided cost approach is usually appropriate for estimating TEV of regulating services. Specifically, the study states that avoidance or postponement of the impact of future climate change through the build up of atmospheric GHGs should be used for estimating the value of carbon sequestered. However, for watershed protection the valuation methodology should focus on onsite and offsite costs of soil erosion which occurs when forests are lost in critical upland areas.

For estimating the carbon sequestration benefits, it follows a two stage process. Firstly, the carbon sequestration and storage is estimated through physical models of forest type and land-use change. These models taken into account the species mix, organic matter content of the species, age distribution of the stand, and soil and climate factors. After estimating the physical amount of carbon sequestered, the study places a monetary value on this physical estimate to value this function in terms of global warming damage avoided. The results show that the value of avoiding the carbon fluxes associated with changing land-use range from US$20 to US$100 per hectare per year.

For valuing watershed protection, the study used costs of mitigation or reparation of damages as a surrogate measure of the value of these protective functions. However, data limitations confine estimates to those from sedimentation damages on infrastructure which were estimated to be US$2.3 million annually.

Source: Adapted from Adger et al. (1995)

Case study 13: An environmental and economic assessment of forest management options

The study seeks to demonstrate, using the total economic value (TEV) approach, the economics of shifting from a narrow "sustained timber practice" to a "sustainable forest management" system for a specific forest site in Malaysia. The results have management and policy relevance, both at the national and global levels. The incremental costs and benefits of shifting from less sustainable to more sustainable forms of management provide meaningful insight into whether sustainable forest management is a realistic option at the national level.

The study showed that shift to increasingly sustainable regimes would result in substantial increase in forest's carbon stock function. Similarly, increases occur in the agro-hydrological service as the management option shifts towards greater sustainability. The table shows valuation approaches used for estimating different regulating services.

Regulating service	**Product/ function**	**Valuation method**	**Data source/ approach**
Water regulation	Agricultural	Production function approach	Equal to second crop of rice. Data on the hydrological disturbance used to determine the effect of water-shortage on the crop of rice. Physical information for this based on land satellite photographs was verified against field checks. The total extent of canals and the rate of increase in these waterways were established from these photographs. The loss of water through seepage was established from detailed hydrological studies and this allowed the total water loss from the peat forests to be estimated.
	Domestic	Market price	Water abstracted from the Main Canal of the peat forests to meet the domestic requirements for the residents at the agricultural scheme. The value of this service is based on the total water abstracted from the forests multiplied by the incremental treatment costs incurred due to the turbidity and coloration of the water from forests.
Carbon sequestration	Carbon sink	Damage cost avoided	Used information on the biomass and carbon stock in peat swamp forests to determine the amount of carbon stored in the forests. Establish the rate of carbon sequestration from the growth activity. To assign the economic value, the global damage cost estimate of US$14/tC was used.

The study demonstrates the use of valuation techniques for regulating services within the context of a developing country. It does not limit itself in giving the values to different services by the forest, but also shows how the flow of benefits from them changes under a range of management options.

Source: Adapted from Kumari (1995)

Case study 14: Physical and economic valuation methods: the case of tropical forests in Guatemala

This study estimated the value of nutrient cycling and erosion control services by tropical forests in Guatemala. It is a very comprehensive valuation study which also estimates the value of other goods and attributes (e.g., biodiversity) besides valuing the above stated regulating services.

For valuing erosion regulation, erosion soil loss was calculated using the USLE (Universal Soil Loss Equation). The regulating service was then valued using two different approaches: the replacement cost which allows for quantifying the nutrient loss through soil loss calculated with the USLE; and the preventive cost method to measure soil conservation practice costs. Although this value (in terms of per hectare) was reported to be small, this function results in high total values as the watershed areas are large.

The stock and flow value of nutrient cycling function was estimate through the proportion of nutrients (nitrogen, phosphorus, and potassium) in dry aerial biomass and humus dry biomass respectively. The economic value of fertilizer was then used to calculate the monetary value of this regulating service and was found to be US$ 12 per hectare per year.

Source: Adapted from Ammour et al. (2000)

Case study 15: Monetizing erosion and sedimentation costs where steeplands meet the sea

The study estimates the benefits of erosion regulating. It argues that although the financial costs of erosion control measures are usually known or easily calculated, greater uncertainty exists over the size of potential benefits. It evaluates alternative development plans that impinge on a coastal zone in the Philippines where two industries, tourism and fisheries, are affected by a third, the logging industry.

In order to assess the linkages between steepland logging, soil erosion, and the impact of sediment on downstream sectors, a year-long study was carried out. In this study, erosion rates were measured in the uplands and sediment delivery at both river-mouth and in the bay was observed. Within the bay measurements of sediment deposition, coral cover and diversity, and fish biomass over a year period enable to estimate the physical links between eroded soil in the steeplands and the health and productivity of the bay's ecosystems. This physical link formed the basis for the economic analysis. Two options, continued logging and a logging ban, were then analyzed.

A cost-benefit analysis predicted that over a 10-year time horizon, logging would generate gross revenues of US$ 8.6 million, much less than the predicted revenue foregone from the fisheries and tourism industries due to logging impacts (US$ 6.2 million and 13.9 million respectively). Economic analysis showed that the logging ban generated greater benefits, both financial and social. Hence, it was recommended that the viability of logging be carefully re-examined. This did happen, and logging was banned by the national government and the bay was declared a Marine Reserve.

Source: Adapted from Hodgson and Dixon (1988)

Case study 16: Contingent valuation of mangroves

In order to estimate the benefits provided by mangrove ecosystems of Johor, a contingent valuation study was carried out at Benut mangroves in Malaysia. The questionnaire used for the study included sections like: attitude towards the environment, current use of the mangrove area, valuation of the mangrove resource, and socio-economic characteristics. Maps, texts and graphics were used to communicate information on the mangroves and the regulating services provided by them. Respondent were then asked their willingness-to-pay (WTP) to a biodiversity fund, for the implementation of the new management plan which would ensure that the mangroves of the region were protected. Two elicitation approaches were used – the payment ladder approach, and a referendum question followed by a double-bounded dichotomous choice question. The sample size for the study was 243 households.

The study estimated the value of shoreline protection of mangroves to be US$ 845 per hectare per year. Fisheries protection value was also estimated and was found to be US$ 526 per hectare per year. Other use and non-use values associated with mangroves were also estimated. Given the high economic value of mangroves of Benut, it was recommended that this site be afforded protection status either as a State park or a protected forest reserve

Source: Adapted from Bann (1999)

Case study 17: Forest, plantation crops or small-scale agriculture?

The study carried out detailed analysis of the Total Economic Value of sustainable forest use, small-scale agriculture and plantation agriculture in the Mount Cameroon Area, Africa using rich sources of primary data. These values were then examined in terms of local, national and international beneficiaries – to see "who gets what" from alternative land-uses. The analysis shows why local people face incentives to convert forest land.

As far as regulating services are concerned, the study analyzed the changes in the flow of three services: carbon storage, flood prevention and sediment prevention across alternative land-use options. Firstly, for carbon storage, it was found that carbon fixing by the forest is worth £1,400 per hectare with small-scale farming and plantations valued at £527 per hectare and £487 per hectare respectively. Secondly, for estimating the value of flood prevention, the implied loss of agricultural production from increased flooding was used. This lost value can be treated as a cost of conversion to plantation or agriculture and subtracted from the net present value of these activities. Following the stated methodology, it was found that flood prevention is an important potential benefit that can accrue to the preservation of forest and was estimated to be around US$ 24 per hectare per year. Lastly, the value of sediment prevention was evaluated using additional time spent on collecting acceptable drinking water and the shadow wage rate associated with it. The estimates for sediment prevention function ranged from £3 per hectare to £65 per hectare in areas with high population density.

Source: Adapted from Yaron (2001)

Case Study 18: Economic valuation of a seed dispersal service

The study uses replacement cost approach to estimate the value of seed dispersal service performed by Eurasian jay (Garrulus glandarius) in the Stockholm National Urban Park, Sweden. The park holds one of the largest populations of giant oaks in Europe. The primary objective of the study is to estimate the number of seed-dispersed oak trees that resulted from jays and to determine the costs of replacing this service through human means.

The results show that depending upon seedling or planting technique chosen, the cost of replacing a pair of jays in the park is US$ 4,900 and US$ 22,500 respectively. Based on the park's aggregated oak forest-area, average replacement cost for natural oak forest generation by jays was estimated to be US$ 2,100 to US$ 9,400 respectively.

The study argues that approaches such as production function and replacement cost are particularly motivated in cases of known functional ecological relationships, and critically important in estimating management measures where mobile link organisms and keystone species (such as oak in Europe) form key mutual relationships that generate high biodiversity benefits.

Source: Adapted from Hougner et al. (2006)

Case study 19: Economic value of wild pollinators to coffee crops

Ricketts valued pollination services from forest-dwelling bees to surrounding coffee farms. They found that coffee fields near forest fragments had higher productivity because of more pollinator visits than coffee fields more distant from forest.

The study was conducted in Costa Rica, near the city of San Isidro. It analyzed bee visits to coffee bushes at different distances from forest – ranging from within 100 meters to over 1.5 kilometers away. The results showed that pollinator diversity near forest was much higher than further away thus providing a form of insurance against decline in any one species. It was also found that the pollinators visited coffee flowers at twice the rate near the forests. Pollinators near forest also seemed to be providing more stable pollination services over time.

The results of analysis showed that beyond 1 kilometer from forest, pollination services were insufficient, and coffee produced approximately 20% lower. Consequently, farmers beyond 1 kilometer from forests suffered 20% lower yields due to inadequate pollination. Using these results, the economic value of two largest forest patches in the landscape was estimated based on productivity function approach. For a single, large farm, pollination services from these two patches of forests was approximately US$ 60,000 of additional income annually. It was also found that this estimate was approximately equal to the expected annual earnings if these forested lands were converted to common agricultural use.

Source: Adapted from Ricketts (2004) and Ricketts et al. (2004)

Case study 20: Economic valuation of natural resource management: a case study of the Benuaq Dayak tribe in Indonesia

The unavailability of total economic values of indigenous people in Indonesia, both in the short and long term, has created the rejection of their existences in the forest area. A study was conducted to estimate the total economic value of sustainable forest management conducted by indigenous tribes in Indonesia. The study used benefits transfer approach to estimate the values associated with regulating services provided by forests.

The erosion prevention value was estimated based on Morgan and Finney equation. The calculation was estimated for 16 years, starting from 1992 to 2008. Based on the average value of erosion prevention multiplied by $US 1.5 per hectare per year, the erosion prevention value is calculated. Based on this methodology, the erosion prevention value was estimated to be US$ 287 per hectare per year.

Benefit transfer data for the carbon sequestration value for the forest area was required to express the value of these regulating services. The carbon sequestration values used were from two different timber concession companies nearby. Further, the data is an estimation using the photosynthetic processes approach developed by Baker (1950). Based on this calculation, the carbon sequestration potency of the study area is US$ 2,869 per hectare per year.

Source: Adapted from Kusama (2005)

www.unep.org

United Nations Environment Programme
P.O. Box 30552 Nairobi, 00100 Kenya
Tel: (254 20) 7621234
Fax: (254 20) 7623927
E-mail: uneppub@unep.org
web: www.unep.org

UNEP