Chapter 1

Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation

Coordinating Lead Author:

Rudolf de Groot

Lead Authors:

Brendan Fisher, Mike Christie

Contributing Authors:

James Aronson, Leon Braat, John Gowdy, Roy Haines-Young, Edward Maltby, Aude Neuville, Stephen Polasky, Rosimeiry Portela, Irene Ring

Reviewers:

James Blignaut, Eduardo Brondízio, Robert Costanza, Kurt Jax, Gopal K. Kadekodi, Peter H. May, Jeffrey McNeely, Stanislav Shmelev

Review Editor:

Gopal K. Kadekodi

March 2010

Contents

Key messages

- Linking biophysical aspects of ecosystems with human benefits through the notion of ecosystem services is essential to assess the trade-offs (ecological, socio-cultural, economic and monetary) involved in the loss of ecosystems and biodiversity in a clear and consistent manner.

- Any ecosystem assessment should be spatially and temporally explicit at scales meaningful for policy formation or interventions, inherently acknowledging that both ecological functioning and economic values are context, space and time specific.

- Any ecosystem assessment should first aim to determine the service delivery in biophysical terms, to provide solid ecological underpinning to the economic valuation or measurement with alternative metrics.

- Clearly delineating between functions, services and benefits is important to make ecosystem assessments more accessible to economic valuation, although no consensus has yet been reached on the classification.

- Ecosystem assessments should be set within the context of contrasting scenarios - recognising that both the values of ecosystem services and the costs of actions can be best measured as a function of changes between alternative options.

- In assessing trade-offs between alternative uses of ecosystems, the total bundle of ecosystem services provided by different conversion and management states should be included.

- Any valuation study should be fully aware of the 'cost' side of the equation, as focus on benefits only ignores important societal costs like missed opportunities of alternative uses; this also allows for a more extensive range of societal values to be considered.

- Ecosystem assessments should integrate an analysis of risks and uncertainties, acknowledging the limitations of knowledge on the impacts of human actions on ecosystems and their services and on their importance to human well-being.

- In order to improve incentive structures and institutions, the different stakeholders - i.e. the beneficiaries of ecosystem services, those who are providing the services, those involved in or affected by the use, and the actors involved at different levels of decision-making - should be clearly identified, and decision making processes need to be transparent.

1 Introduction

In spite of the growing awareness of the importance of ecosystems and biodiversity to human welfare, loss of biodiversity and degradation of ecosystems still continue on a large scale. Fundamental changes are needed in the way biodiversity, ecosystems and their services are viewed and valued by society. A major difficulty is that many ecosystem[i] services [ii] are (mixed) public goods, and use levels are therefore difficult to regulate, even when they are at or near the point of exhaustion. Although many people benefit from ecosystem services, individuals or groups usually have insufficient incentives to maintain ecosystems for continued provisioning of services. For example, open access fisheries provide valuable harvests but often suffer from over-exploitation that leads to declines in fish populations and lowered future harvests.

The problems of management and governance of ecosystems stem from both poor information and institutional failures. In some cases, knowledge is lacking about the contribution of ecosystem processes and biodiversity to human welfare and how human actions lead to environmental change with impacts on human welfare. In other cases institutions, notably markets, provide the wrong incentives.

These two types of failures, and the complex dynamics between the ecology-economy interface, often lead to large scale and persistent degradation of the natural environment and accelerating loss of ecosystem services and biodiversity. Given the large scale of human activities on the planet, the point has been reached where the cumulative losses in ecosystem services are forcing society to rethink how to incorporate the value of these services into societal decision-making.

The release of the Millennium Ecosystem Assessment (MA 2005a) helped foster use of the concept of ecosystem services by policy makers and the business community. However, progress in its practical application in land use planning and decision making has been slow (e.g., Daily et al. 2009, Naidoo et al. 2008).

This lack of progress stems not only from failures of markets and systems of economic analysis and accounting (notably GDP) to capture values of ecosystem services, but also from our limited understanding of: a) how different services are interlinked with each other and to the various components of ecosystem functioning and the role of biodiversity; b) how different human actions that affect ecosystems change the provision of ecosystem services; c) the potential trade-offs among services; d) the influence of differences in temporal and spatial scales on demand and supply of services; and e) what kind of governance and institutions are best able to ensure biodiversity conservation and the sustainable flow of ecosystem services in the long-term.

Without changes in institutions and incentives, further declines in natural capital are likely, as those who gain from actions that deplete natural capital will continue to avoid paying the full costs of their actions and pass these costs to poor societies and future generations (Srinivasan et al. 2008). Although such estimations are fraught with difficulties, it can be argued that the cumulative loss of '*natural capital*' (see further) over the past decades has cost, and still costs, the global community large sums of money in terms of damage, repair and replacement costs (Bartelmus 2009).

One of the aims of the TEEB study is to provide more and better data and understanding of the (economic) significance of these losses and the consequences of policy inaction on halting biodiversity loss at various scales (global, regional and local). Although emphasis is on the economic, notably monetary, effects of the loss of ecosystem services, TEEB will give due attention to the underlying changes in ecological 'values' (ecosystem integrity and life-support functions) and socio-cultural implications.

This TEEB D0 report provides the science basis of the economics of ecosystems and biodiversity, whereas the other TEEB products (D1-D4) are dedicated to specific audiences, including policy makers, administrators, business or consumers.

Chapter 1 summarizes recent developments and describes our TEEB framework, building upon the TEEB Interim report (European Commission, 2008) to further operationalise the economics of biodiversity and ecosystem services. Each step within the framework roughly coincides with a chapter in the entire D0 report.

Chapters 2 and 3 explore the ecological basis of the assessment. Chapter 2 presents our current state of knowledge on the relationships among biodiversity, ecosystems and ecosystem services. It provides an elaboration of relevant ecological concepts, and highlights the uncertainties and risks associated with ecosystem change caused by humans at an ever-increasing pace. Once biodiversity is lost and ecosystems have irreversibly changed, it can be very expensive or no possibilities may remain to restore these systems and recover associated ecosystem services. Chapter 3 provides a review of existing biophysical measures and indicators that are used to quantify and map current knowledge on biodiversity and ecosystem services, including their merits and shortcomings. Research efforts are needed towards better indicators, especially for measuring changes in biodiversity and the provision of services to serve as a basis for economic valuation.

Chapters 4 to 6 address the 'human well-being' component of the framework. Chapter 4 establishes the basis for a much-needed encompassing understanding of valuation, including ecological, economic and social values, before it more specifically discusses the social and cultural contexts of biodiversity and ecosystem service valuation. Chapter 5 then provides a detailed discussion of the merits, issues and challenges to applying (i) monetary valuation techniques and then (ii) benefits transfer in the context of this assessment. In Chapter 6, some of the ethical issues for economic valuation are explored, in particular the use and selection of discount rates that have to be critically reconsidered both with respect to ecological uncertainties and distributional equity.

Chapters 7 to 9 use the framework to make an analysis of the economic implications of the loss of ecosystem services while taking into account the methodological recommendations developed in chapters 2 to 6. It should be realized up front that data and methodological limitations remain, and the TEEB assessments provided are therefore chosen to illustrate the benefits and costs of biodiversity conservation and sustained ecosystem service provision in different contexts and at different spatial scales. It is not the intention to make an estimate of the total economic value of ecosystem services at a global scale. Chapter 7 presents a synthesis of the empirical economic valuation literature in the form of a matrix of values for the main types of ecosystems and ecosystem services. Based on the analysis of the previous chapters, ranges of values are selected that are relevant for different geographic regions and income levels and collected in a database, that is then used in chapters 8 and 9. Chapter 8 makes a preliminary analysis of the costs of action and inaction for several biomes including terrestrial and marine. This analysis is based on a review of available models and recent global assessments, on a selection of scenarios, and on combining various methodologies and sources for the monetary valuation of benefits and costs. Chapter 9 explores the state of knowledge on assessing the impacts of changes in ecosystem services and comparing the costs of inaction and action at the macroeconomic scale.

Finally, *chapter 10* draws key conclusions and recommendations from the TEEB D0 report.

2 Review of existing frameworks linking ecology and economics

Over the past few decades many attempts have been made to systematically link the functioning of ecosystems with human wellbeing. Central elements in this "link' are the intertwined notions of natural capital 'stocks' and the ecosystem services that flow like interest or dividends from those stocks. According to the Millennium Ecosystem Assessment (MA 2005a), natural capital is "an economic metaphor for the limited stocks of physical and biological resources found on earth". The continuing depletion and degradation of natural capital has generated concerns and debate over the capacity of the economic system to substitute for these losses with human-made capital, and the conditions for sustainable development, defined as non-declining welfare over generations (Pezzey 1992; Pearce et al. 1989). While the degree of substitutability is ultimately an empirical question, it is generally recognised that substitution has limits (Barbier 1994; Daly 1996; Prugh 1999; Daly and Farley 2004), and that a critical amount of natural capital has to be preserved (see also chapters 4, 5 and 6 for the implications of this debate for the TEEB study).

This section provides a brief overview of the development of the theory and practice of ecosystem functions and services and discusses some key insights and challenges from the literature and the TEEB Interim Report (2008).

2.1 Ecosystem services: early developments and recent frameworks

Thinking about people-environment interactions and their effects on human welfare stretches back centuries and includes writings from Roman times on the increase in population and decline in what we now call ecosystem services (Johnson 2000). Early modern writers on the subject include Marsh (1874), Leopold (1949), Carson (1962), and Krutilla and Fisher (1975) to mention but a few. In 1977, Westman published a paper in *Science* examining the link between ecological and economic systems entitled “How much are Nature’s Services Worth?” (Westman 1977). Ehrlich and Ehrlich (1981) later coined the term ‘ecosystem services’ and in the following decade ecologists further elaborated the notion of ecosystems as life-support systems, providers of ecosystem services and economic benefits (see for example Ehrlich and Mooney 1983; Odum 1989; Folke et al. 1991; De Groot 1992). But it was not until the late 1990’s that the concept got widespread attention with the publications by Costanza et al. (1997) and Daily (1997). At the same time, the interdisciplinary field of ecological economics developed the concept of natural capital (Costanza and Daly 1992; Jansson et al. 1994; Dasgupta et al. 1994), which includes non-renewable resources, renewable resources and ecosystem services to demonstrate the significance of ecosystems as providing the biophysical foundation for societal development and all human economies (Common and Perrings 1992; Arrow et al. 1995). In an attempt to facilitate discussion and systematic analysis of ecosystem services, De Groot et al. (2002) created a classification system specifying the relationship between, and transitions from ecosystem processes and components and their transition to goods and services.

Based on these and other studies[iii], the Millennium Ecosystem Assessment (MA 2005a) recognized four categories of services: supporting (e.g. nutrient cycling, soil formation and primary production); provisioning (e.g. food, fresh water, wood and fiber and fuel); regulating (e.g. climate regulation, flood and disease regulation and water purification); and cultural (aesthetic, spiritual, educational and recreational) (see Figure 1).

The introduction of the concept of ecosystem services on the global agenda by the MA provides an important bridge between the imperatives of maintaining biodiversity and the challenges in meeting to meet the Millennium Development Goals.

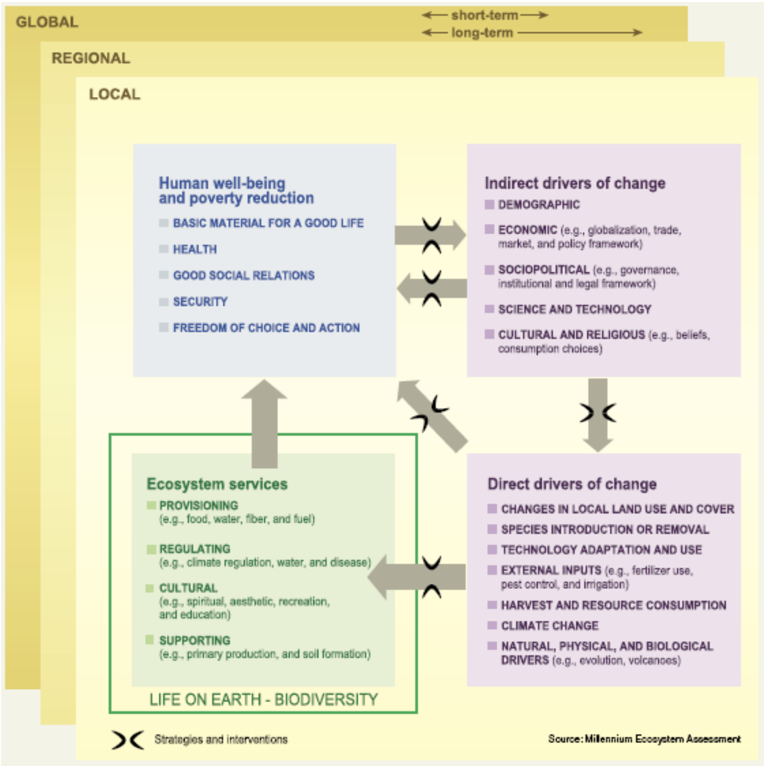

Figure 1: **MA conceptual framework: linking ecosystem services and human well-being**
Source: MA (2005a).

2.2 The TEEB Interim report and further recent frameworks

The Millennium Assessment, purposely, did not pay much attention to the economics of ecosystem change and in the preparation phase of the TEEB study (TEEB 2008), a framework was therefore proposed (see Figure 2) for articulating the ecological and economic aspects of the analysis necessary for the valuation of biodiversity loss and ecosystem degradation (Balmford et al., 2008).

This scheme stresses the need to rely on counterfactual scenarios that differ through specific actions aimed at addressing the main drivers of loss. Changes in the delivery of services need first to be estimated and mapped in biophysical terms, which requires a sufficient understanding of the factors that drive their production and how they are affected by the actions put in place. Economic valuation should then be applied to the changes in services, which requires a good understanding of the service flows and of the determinants of demand.

Being spatially explicit is important in order to take into account the spatial heterogeneity of service flows and of the economic values that can be assigned to them, as well as the variability of conservation costs. It also allows the identification of mismatches of scales as well as analyzing the distributional implications of decisions that affect ecosystems, and exploring trade-offs.

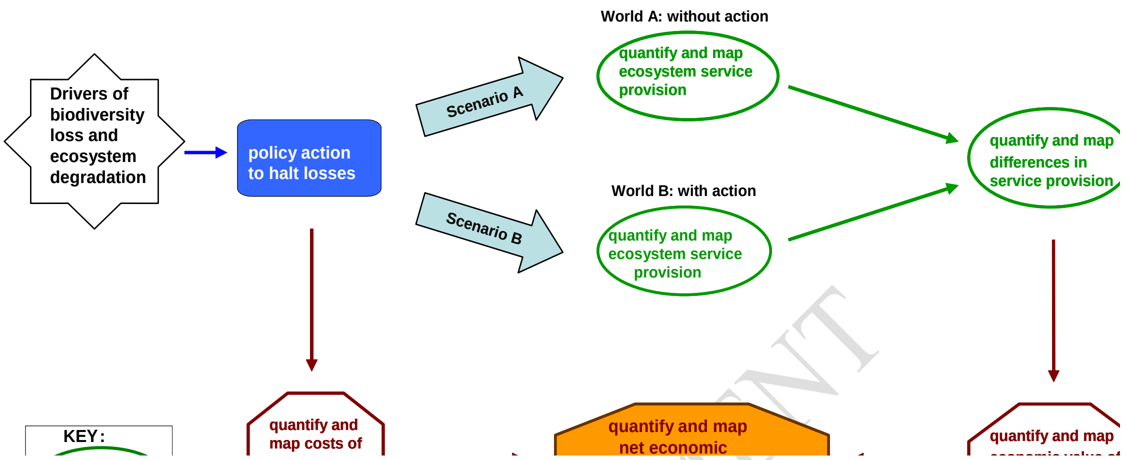

Figure 2: **An economic valuation framework: contrasting states of the world**
Source: modified after Balmford et al. (2008) and TEEB (2008).

Marginal valuation in economic thinking assumes substitutability between services and is therefore only applicable within certain ecological limitations, requiring that no irreversible ecosystem changes occur (see chapters 2 and 4 for more detail). Next to these ecological limitations, socio-cultural considerations may delimit the range of valid cases for marginal valuation (Turner et al. 2003). Therefore, any valuation of biodiversity and ecosystem services needs to take account of the range of ecological and socio-cultural values that are not covered by economic valuation, but need different approaches and methodologies to be reflected in decision making (EPA-SAB 2009).

The TEEB Interim report's valuation framework is largely consistent with others recently proposed in the analysis undertaken by the US National Research Council (NRC 2005), including the Natural Capital Project (Daily et al. 2009), the EPA Science Advisory Board (EPA-SAB, 2009), Valuing the Arc (Mwakalila et al. 2009), and the French Council for Strategic Analysis (Chevassus-au-Louis et al. 2009). In all of these efforts, the essential links between human actions, ecosystems, services and their contributions to human welfare are (see Figure 3, building on Daily et al. 2009). Human decisions lead to actions that have impacts on ecosystems, causing changes in ecosystem structure and function. These changes in turn lead to changes in the provision of ecosystem services. Changes in ecosystem services have impacts on human welfare. A clear understanding of these links can provide information that can lead to the reform of institutions and better decisions that ultimately improve the state of ecosystems and the services they provide to society.

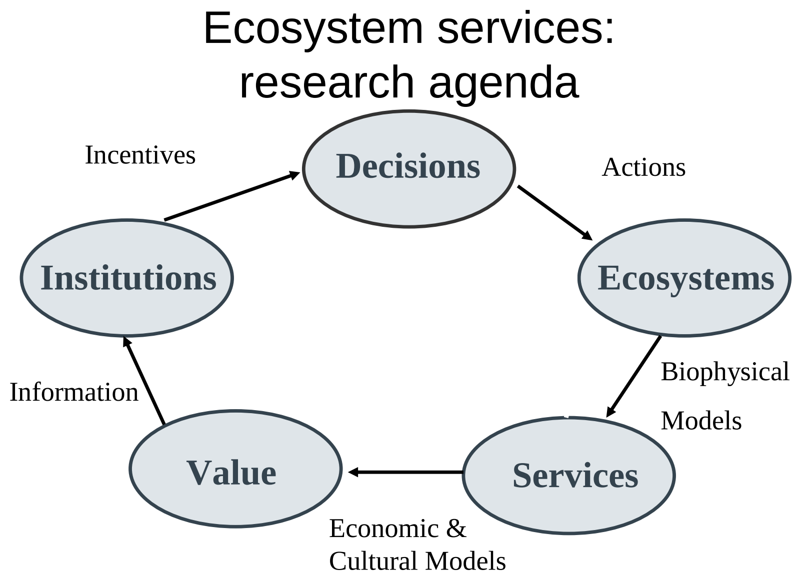

Figure 3: **Ecosystem Services: research agenda**
Source: Daily et al. (2009).

2.3 Defining ecosystem functions, services and benefits

Research efforts regarding the investigation of ecosystem services have increased strongly in the past ten years (Fisher et al. 2009). They have provided much insight in how to ensure that ecosystem service research is scientifically robust and credible, and also conveys a clear message to decision-makers in both the public and private sectors.

In spite of the work done so far, there is still much debate about definitions and classifications (e.g., Daily 1997; Boyd and Banzhaf 2007; Wallace 2008; Costanza 2008; Fisher and Turner 2008; Fisher et al. 2009; Granek et al. 2009) and perhaps we should accept that no final classification can capture the myriad of ways in which ecosystems support human life and contribute to human well-being. Yet for a global assessment like TEEB, it is essential to be clear about the terminology and classifications used. When dealing with complex relationships like coupled social-ecological systems, we need a rich language to describe their different features and interactions. While accepting that no fundamental categories or completely unambiguous definitions exist for such complex systems, and that any systematization is open to debate, it is still important have to be clear about the meaning of the core terms used.

Figure 4 gives a schematic representation of the way TEEB proposes to disentangle the pathway from ecosystems and biodiversity to human wellbeing. A central concept in this diagram is the notion of (ecosystem) service which the MA defined simply as "the benefits humans derive from nature" (MA 2005a).

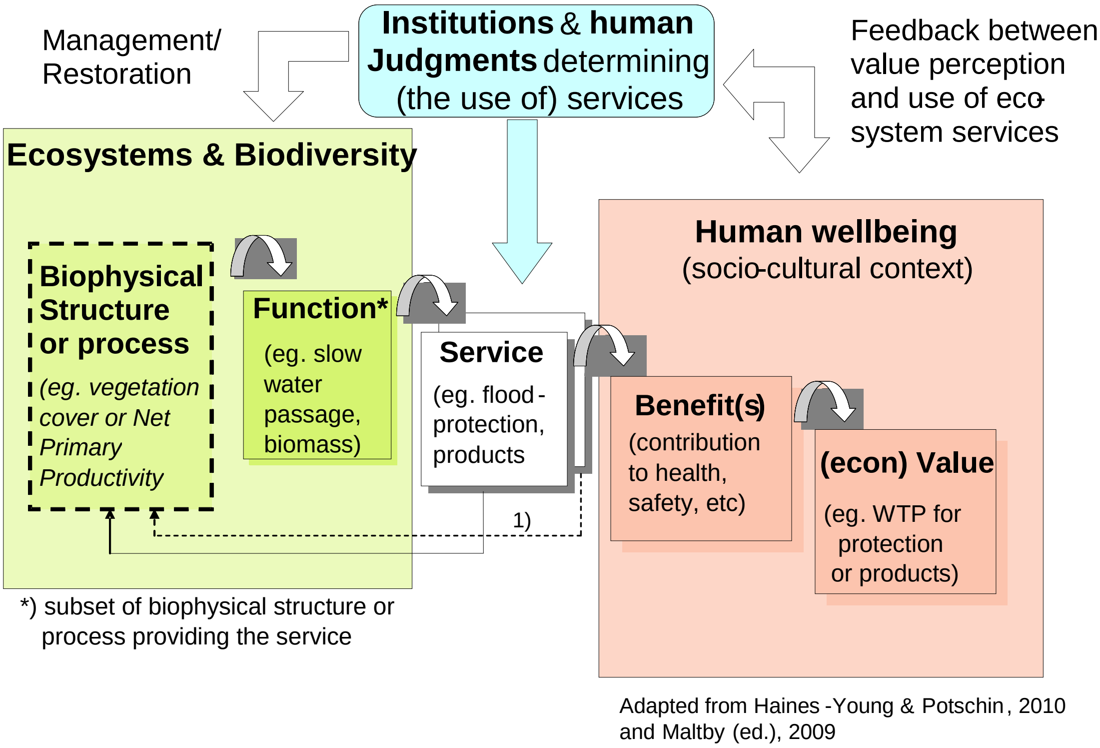

Figure 4: The pathway from ecosystem structure and processes to human well-being

2.3.1 From biophysical structure and process to ecosystem services and benefits

As Figure 4 shows, a lot goes on before services and benefits are provided, and decision-makers need to understand what this involves. It is therefore helpful to distinguish 'functions' from the even deeper ecological structures and processes in the sense that the functions represent the *potential* that ecosystems have to deliver a service which in turn depends on ecological structure and processes. For example, primary production (= process) is needed to maintain a viable fish population (= function) which can be used (harvested) to provide food (= service); nutrient cycling (=process) is needed for water purification (=function) to provide clean water (= provisioning service)[iv]. The benefits of these services are manifold, for example, food provides nutrition but also pleasure and sometimes even social identity (as part of cultural traditions); clean water can be used for drinking but also for swimming (pleasure) and other activities aimed at satisfying needs and wants. Thus, the role of woodlands in slowing the passage of water through a catchment is a function which has the potential of delivering a service (water flow regulation -> reduced flood risk) if some beneficiary exists to enjoy the benefit (safety).

Services are actually conceptualizations ('labels') of the "useful things" ecosystems "do" for people, directly *and* indirectly (see Glossary for the exact definition used in TEEB) whereby it should be realized that properties of ecological systems that people regard as 'useful' may change over time even if the ecological system itself remains in a relatively constant state.

Clearly delineating between ecological phenomena (functions), their direct and indirect contribution to human welfare (services), and the welfare gains they generate (benefits) is useful in avoiding the problem of double counting that may arise due to the fact that some services (in particular supporting and regulating services) are inputs to the production of others (Boyd and Banzhaf 2007; Wallace 2008; Fisher and Turner 2008; Balmford et al. 2008). Such differentiation is also crucial to provide a clear understanding of the spatial distribution of where the function occurs, where the provision of the service can be assessed, and ultimately where the benefits are appreciated. Although the distinction between functions, services and benefits is important, especially for economic valuation, it often is not possible to make a fully consistent classification, especially for regulating services (see section 3 for further discussion).

The short conclusion is that studies on ecosystem services should always be transparent on just what are considered services, and how they are being valued and measured. A critical missing link for some ecosystem services is the scant knowledge on how they are produced, maintained, and affected by system or abiotic changes and how they are related to levels of biodiversity. Information gaps will be rife throughout ecosystem service research and should always acknowledge the current uncertainty about how the 'system' works. It should also be realized that many people benefit from ecosystem services without realizing it, and thus fail to appreciate their value (importance). To make the dependence of human wellbeing on ecosystem services more clear, valuation studies should therefore not only include direct benefits (direct use values) but take due account of all the indirect benefits (indirect use values) and non-use values derived from ecosystem services.

Another issue is how to deal with potential benefits or the "likelihood of (future) use", e.g. currently functions like wildlife (as potential food source), water purification (keeping rivers clean) or attractive scenery in a remote area may not be used but may have great (economic) potential for future use. Finally, it should also be recognized that ecosystems may provide *disservices*, for example, when they facilitate reproduction and dispersal of species that damage crops or human health[v]. In trade-off analysis, these disservices must be considered and, ultimately, the notion of benefits and 'dis-benefits' should be looked at within a consistent ecosystem accounting framework (e.g. EEA 2009).

2.3.2 From ecosystem services to (economic) value

Since the functioning of ecosystems and their services affect so many aspects of human welfare, a broad set of indicators can and should be used to measure the magnitude ('value') of their impact. As with the interpretation of the terms 'function', 'service' and 'benefits' (see above), much debate still surrounds the use of the term 'value' in assessing the benefits of ecosystems to human wellbeing. The Oxford English Dictionary defines value as "the worth, usefulness, importance of something". The Millennium Ecosystem Assessment defined value as "the contribution of an action or object to user-specified goals, objectives, or conditions" (after Farber et al. 2002), the measurement of which could include any kind of metric from the various scientific disciplines, e.g. ecology, sociology, economics (MA 2003).

In economics, 'value' is always associated with trade-offs, i.e. something only has (economic) value if we are willing to give up something to get or enjoy it. The common metric in economics is monetary valuation and some critics say the reliance on this metric has plagued many ecosystem service assessments, failing to incorporate several types of value which are critical to understanding the relationship between society and nature (e.g. Norgaard 1998; Wilson and Howarth 2002; MA 2005a; Christie et al. 2006). See also Box 1 and chapter 4 for further discussion.

In addition to economic valuation, other ways to analyze the importance of ecosystem services include livelihoods assessments, capabilities approaches that emphasize the opportunities available to people to make choices (e.g., Sen 1993), and vulnerability assessments. Such considerations are necessary for integrating into the analysis some dimensions of human well-being that cannot (or should not) be measured in terms of money, such as freedom of choice, human rights and intrinsic values. They are also important for measuring the services and benefits that are of cultural and philosophical (spiritual) nature. However, while monetary assessments only partially capture the total importance – i.e. value – of ecosystem services, they are vitally important for internalizing so-called externalities in economic accounting procedures and in policies that affect ecosystems, thereby influencing decision-making at all levels.

Box 1 Neoclassical Economics and its Discontents (by John Gowdy)

There is a long history of antagonism between traditional neoclassical economists and those advocating a more pluralistic approach to economic theory and policy. The debate has been less fruitful than it might have been because of the failure of many on both sides to be specific as to what is being criticized and defended.

Those of us who are critical of standard economic valuation methods need to be precise in what we are criticizing. The current debates raging in economics over the Stern Review, the current financial crisis, and the significance of the findings of behavioral economics, have shown that the problem with neoclassical economics is not valuation *per se* but with the assumptions of the core Walrasian model (named after the Swiss economist Leon Walras). The purpose of that model is to prove that competitive markets achieve Pareto efficiency, that is, no one can be made better off without making someone else worse off. This is called the First Fundamental Theorem of Welfare Economics. That proof does not work unless economic agents (firms and consumers) act independently of each other. That is, my economic decisions are based on self-regarding preferences and my decisions are in no way affected by how others think, behave or how much they have. Likewise, the production and pricing decisions of one firm are independent of the actions of other firms. The independence assumption has been falsified by thousands of empirical tests. It does not make good predictions of real economic behavior and offers a poor guide for economic policy. We need to replace “rational economic man” with a science-based model of human behavior, and the model of the perfectly competitive firm with one that includes competitive institutions, cultural norms, and biophysical transformations. The characterization of consumers and firms in the Walrasian model is driven by the mathematical requirements of constrained optimization and has little to do with real-world economic behavior.

But this doesn’t mean that markets are always inefficient or that prices have no meaning. It simply means that economic policy debates need to be decided on the basis of merit and evidence, not arbitrary equations or lines on a piece of paper. The effect of minimum wage laws is a good example. It’s easy to “prove” that they raise the unemployment rate by drawing a simple graph. But the real world evidence is much more complicated.

Economists frequently use a kind of “bait and switch” technique to justify their models. We begin with the proposition that “people do the best they can with the limited means at their disposal” which is reasonable. But in the Walrasian framework this becomes “People with well-defined, stable and self-regarding preferences maximize a smooth and continuous single-valued function that is twice differentiable… and so on.” Using the mathematical relationships in this model we can calculate shadow prices for natural resources, elasticities of substitution, total factor productivity etc. But it is not clear whether these estimates are based on empirical evidence or by the mathematical assumptions used to calculate them.

Regarding discounting future costs and benefits, we can reasonably say that individuals in general would rather have something now than in the distant future (but not always). But that is not the same as using a single precise discount rate number to value everything from biodiversity loss to the effects of climate change decades or even centuries in the future.

If we discard the straightjacket of Walrasian mathematics we can begin to sort out what can be priced, what can be measured without prices, and what cannot be measured at all but still valued.

3 TEEB-conceptual framework

Following the considerations discussed in section 2, and building upon the work done in the TEEB preparation phase, this section presents the Framework adopted for the TEEB study which also forms the “backbone” for the subsequent chapters in this report (Figure 5).

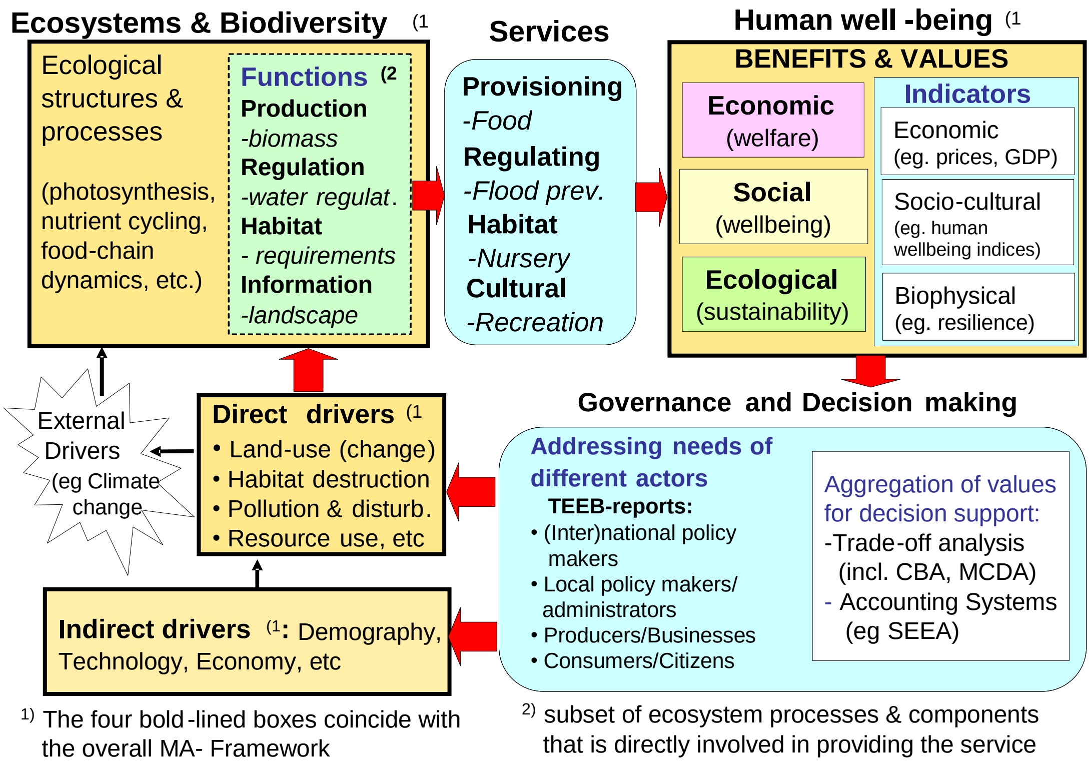

Figure 5 Conceptual framework for linking ecosystems and human well-being

To analyse the “Economics of Ecosystems and Biodiversity” a practical and consistent definition and typology of ecosystems (and biodiversity) is essential. In the TEEB assessment, we largely follow the definitions of the United Nations’ 1992 Convention on Biological Diversity. Thus we see an *ecosystem* as the complex of living organisms and the abiotic environment with which they interact at a specified location. *Biodiversity* is the sum total of organisms including their genetic diversity and the way in which they fit together into communities and ecosystems (see Glossary for exact wording).

Based on various sources, TEEB proposes a typology of 12 main *biomes* (see Table 2), sub-divided into a much larger number of ecosystem types (see Appendix 1).

Table 2: Classification of main biomes in TEEB and remaining surface area

	Biome type (a	**Surface area remaining** (in 1000 km^2) (f			**Of which in more or less natural state (c**
		MODIS LC 2005 (b	Global Cover 2005 (b	Land Cover in 2000 (c	
1	**Marine / Open Ocean**	416,546			10-15 % (g
2	**Coastal systems**				40 % (h
3	**Wetlands**		1,799		? % (i
4	**Lakes & Rivers**		6,713		? % (i
5	**Forests**	28,936	46,652		
	Wooded tundra			2,596	93 %
	Boreal forest			17,611	85 %
	Cool coniferous forest			3,130	72 %
	Temperate mixed forest			5,914	49 %
	Temp. deciduous forest			4,718	43 %
	Warm mixed forest			5,835	52 %
	Tropical forest			9,149	76 %
6	**Woodland & shrubland**	35,829	9,766	7,870 8,773	67 % 44 %
	Mediterranean shrub (e			1,741	38 %
7	**Grass & Rangeland** *(d*	23,883	8,879	19,056	50 %
	Savanna only (e			15,604	57 %
8	**Desert**	18,154	34,753	22,174	83 %
9	**Tundra**		6,453	6,375	94 %
10	**Ice/Rock/Polar**	15,930	3,166	2,290	100 %
11	**Cultivated areas**	20,617	26,472		Not applicable
12	**Urban areas**	656	336		Not applicable

a) This classification is based on various sources (see Appendix 1, which also gives a more detailed list of ecosystems for each biome). The forest, woodland and grassland biomes are sub-divided here to accommodate data on the degree of human impact (last column) and this sub-division is therefore not completely identical with Appendix 1.

b) Data on surface area provided by Rosimeiry Portela, with help from Marc Steininger and Fabiano Godoy, all Conservation International.

c) Data provided by Leon Braat, based on work done by PBL/NEEA (Netherlands Environmental Assessment Agency) for COPI-I on terrestrial systems only (Braat et al., 2008). According to this source, the world total terrestrial area is 132,836,113 km^2 .

d) Including Steppe in PBL/NEEA data set (Braat et al. 2008).

e) These categories (Mediterranean shrub and savanna) are listed separately in the RIVM data set; their surface area is *not* included in sum-total for the respective main biome categories.

f) Data on surface areas differ substantially by source due to different interpretations of biome (land cover) classes.

g) Data on aquatic systems is more difficult to find and interpret than for terrestrial systems, but Halpern et al. (2008) estimated that at least 40% of ocean systems are medium - very highly affected by human impact and the other 60% face low – medium impact. Only 10-15% can be considered to be in a more or less pristine state (Halpern personal communication, August 2009).

h) For coastal systems the figures are even harder to estimate, but according to Halpern et al. (2009), 60 % of the global coastline experience low to high impact from land-based human activities. This estimate was based on four of the most pervasive land-based impacts on coastal ecosystems: nutrient input; organic and inorganic pollution; and the direct impact of coastal human populations. If we add ocean-based human impact (i.e. over-fishing, pollution from ships, etc.) this figure will surely be much higher: a map published by UNEP (2006) shows that only about 40% of the coasts face "little or no" impact from human actions.

i) For wetlands, rivers and lakes, no reliable (global) data were found in this phase of the TEEB study but it will be attempted to further verify and complete this table in the coming months.

As Table 1 indicates, most of the biomes and associated ecosystems have been converted to human-dominated systems (agriculture, aquaculture, plantations, etc.) to a greater or lesser extent (on average approximately 1/3 of the area) or are otherwise affected by human activity, e.g. through over-exploitation and pollution of marine systems (Nelleman et al. 2008) and damming of rivers. Thus, 'biomes' or other ecology-based land categories have actually become a "construct" (e.g., Ellis 2008, Kareiva et al. 2007). Because of the predominance of so-called 'socio-ecological mosaics' (i.e. a patchwork of landscape units that range from intensively managed to unmanaged areas, all within the same landscape), fine-grained spatial analysis should be a core of any Ecosystem Service assessment (see Box 2).

Box 2.: Spatial explicitness and scale

A major critique of early ecosystem service valuation work was the rudimentary treatment of ecological systems at the scale of biomes, and the extrapolation of site specific values across the entire globe (Bockstael et al. 2000; Naidoo et al. 2008). At the other end of the spectrum, the utility of plot-scale experiments for policy formation is questionable. Recognizing this trade-off, advanced research in ecosystem services has focused on spatially-explicit economic and ecological models, moving away from standard lookup tables assuming constant marginal values and utilizing benefit transfer based on ecosystem type (Barbier et al. 2008; Nelson et al. 2009; Naidoo and Ricketts 2006; Polasky et al. 2008; Bateman et al. 2003).

Working at both ecologically understandable and policy relevant scales also allows researchers to more fully understand the values and perceptions of the relevant stakeholders (Hein et al. 2006; Fisher et al. 2008; Granek et al. 2009). Another major reason why spatial explicitness is important is that the production and use of services from ecosystems vary spatially, as along with the economic benefits they generate (many of which are local in nature), and of course the costs of action, so it matters to human well-being where conservation actions are implemented. A spatially explicit assessment of the impacts of action and quantification of benefits and costs is also helpful to show the possible mismatch between the ecological and the socio-economic scales of decision making, service provision and use, and between winners and losers in different scenarios. It is thus essential for designing effective and equitable policy interventions. (Balmford et al. 2008).

In trade-off analysis of land use change, ideally the costs and benefits of the transitions, and all or at least the main intermediate states (see Figure 6), should be based on the economic value of the total bundle of services provided by each transition or management state. This level of detail is impossible within this phase of the TEEB assessment, both for time limitations and given the paucity of studies that compare the provision of services by an ecosystem under alternative management states (Balmford et al. 2002; ICSU-UNESCO-UNU 2008), but it should be a high priority subject for follow-up studies.

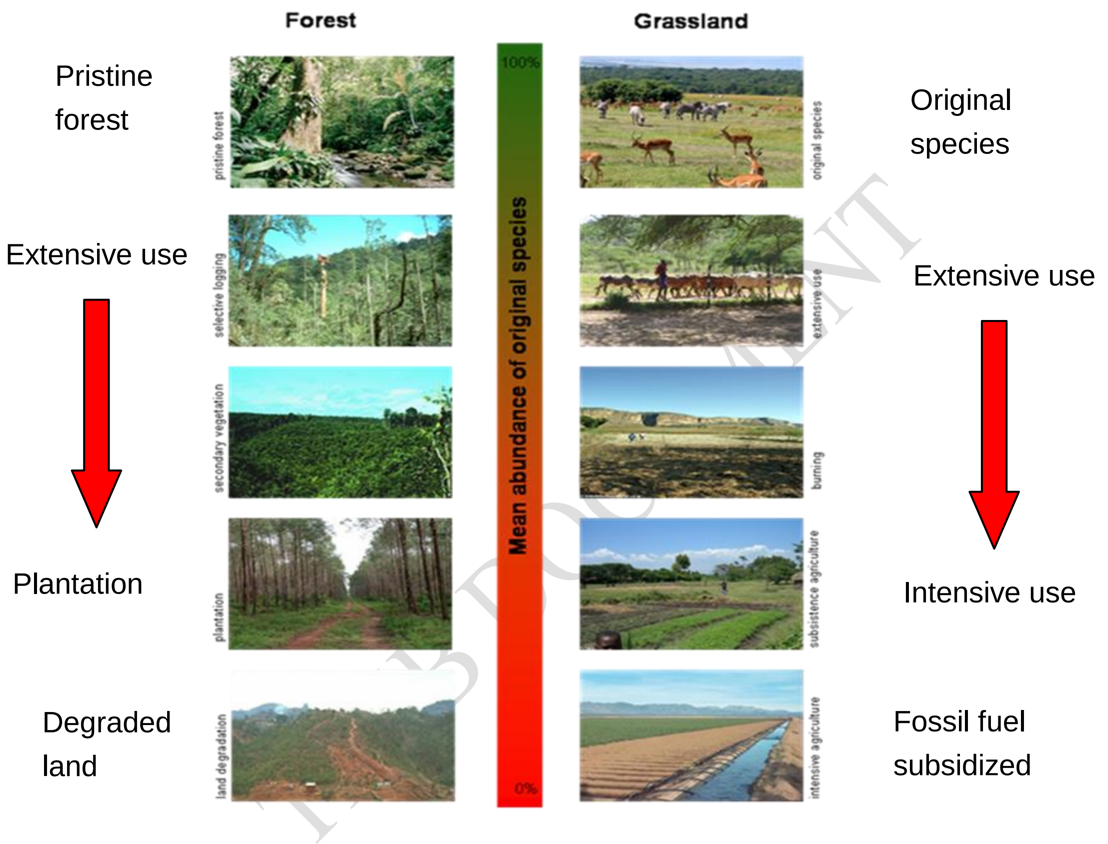

Figure 6 **Two examples of degradation pathways showing transition phases between natural and human-dominated (eco)systems**
Source: Braat et al. (2008).

The recognition of tangible ecological or physical boundaries of ecosystems, however arbitrary it may sometimes be, provides an important basis for adaptive and practical management through the mapping of particular functions and landscape units, or even so-called 'service-providing units' (see chapter 2).

3.1 Ecosystem structure, processes and functions

The TEEB framework (Figure 5) starts with the upper-left hand box which distinguishes ecosystem structure, processes and functions. *Ecosystem functions* are defined as a subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services. The building blocks of ecosystem functions are the interactions between structure and processes, which may be physical (e.g. infiltration of water, sediment movement), chemical (e.g. reduction, oxidation) or biological (e.g. photosynthesis and denitrification), whereby 'biodiversity' is more or less involved in all of them, although the precise detail of the relationship is often unclear or limited (see chapter 2).

The fundamental challenge is the extent to which it is practical (possible?) to fully predict the actual functioning of any defined ecosystem unit when relatively few (and rarely replicated) studies worldwide are available. It is often necessary to rely on various combinations of seemingly-appropriate indicators of ecosystem condition and function (see chapter 3) which can in theory be applied more generally than in just individual cases.

3.2 Typology of ecosystem services

Ecosystem services are defined in TEEB as "the direct and indirect contributions of ecosystems to human well-being." This basically follows the MA-definition except that it makes a finer distinction between services and benefits and explicitly acknowledges that services can benefit people in multiple and indirect ways (see section 3 for a more detailed discussion).

Based on the TEEB preparatory phase and other assessments and meta-analysis (see section 2), TEEB proposes a typology of 22 ecosystem services divided in 4 main categories; provisioning, regulating, habitat and cultural & amenity services, mainly following the MA classification (see Table 3 and Appendix 2 for a more detailed list and comparison with the main literature).

An important difference we adopt here, as compared to the MA, is the omission of Supporting Services such as nutrient cycling and food-chain dynamics, which are seen in TEEB as a subset of ecological processes. Instead, the Habitat Service has been identified as a separate category to highlight the importance of ecosystems to provide habitat for migratory species (e.g. as nurseries) and gene-pool "protectors" (e.g. natural habitats allowing natural selection processes to maintain the vitality of the gene pool). The availability of these services is directly dependent on the state of the habitat (habitat requirements) providing the service. In case commercial species are involved, such as fish and shrimp species that spawn in mangrove systems (= nursery service) but of which the adults are caught far away, this service has an economic (monetary) value in its own right. Also the importance of the gene-pool protection service of ecosystems is increasingly recognized, both as "hot spots" for conservation (in which money is increasingly invested) and to maintain the original gene-pool of commercial species (which we are increasingly being imitated through the creation of botanic gardens, zoos and gene banks).

Before economic valuation can be applied, the performance or availability of ecosystem services has to be measured in biophysical terms (see Chapters 2 and 3). In some cases the state of ecological knowledge and the data availability allow using some direct measures of services, while in other cases it is necessary to make use of proxies.

Table 3 Typology of ecosystem services in TEEB

	Main service types
	PROVISIONING SERVICES
1	**Food** (e.g. fish, game, fruit)
2	**Water** (e.g. for drinking, irrigation, cooling)
3	**Raw Materials** (e.g. fiber, timber, fuel wood, fodder, fertilizer)
4	**Genetic resources** (e.g. for crop-improvement and medicinal purposes)
5	**Medicinal resources** (e.g. biochemical products, models & test-organisms)
6	**Ornamental resources** (e.g. artisan work, décorative plants, pet animals, fashion)
	REGULATING SERVICES
7	**Air quality regulation** (e.g. capturing (fine)dust, chemicals, etc)
8	**Climate regulation** (incl. C-sequestration, influence of vegetation on rainfall, etc.)
9	**Moderation of extreme events** (eg. storm protection and flood prevention)
10	**Regulation of water flows** (e.g. natural drainage, irrigation and drought prevention)
11	**Waste treatment** (especially water purification)
12	**Erosion prevention**
13	**Maintenance of soil fertility** (incl. soil formation)
14	**Pollination**
15	**Biological control** (e.g. seed dispersal, pest and disease control)
	HABITAT SERVICES
16	**Maintenance of life cycles of migratory species** (incl. nursery service)
17	**Maintenance of genetic diversity** (especially in gene pool protection)
	CULTURAL & AMENITY SERVICES
18	**Aesthetic information**
19	**Opportunities for recreation & tourism**
20	**Inspiration for culture, art and design**
21	**Spiritual experience**
22	**Information for cognitive development**

Source: based on/adapted (mainly) from Costanza et al. (1997), De Groot et al. (2002), MA (2005a), Daily, Ehrlich, Mooney, et al. (2008). See Appendix 2 for details.

Actual measurements of ecosystem services should be split into a) the capacity of an ecosystem to provide a service (e.g., how much fish can a lake provide on a sustainable basis), and b) the actual use of that service (e.g., fish harvesting for food or for use in industrial processing). Measurement of the importance (value) of that fish in terms of nutrition value, a source of income and/or way of life is then part of the “human value domain”.

When applying valuation, it is necessary to clearly distinguish between potential and actual use of services with direct use value (notably provisioning and some cultural services), and services that have indirect use (notably regulating, habitat and some services). Since most ecosystems provide a bundle of services, and the use of one service often affects the availability of other services, (economic) valuation should consider not only (marginal) values from the flows of individual services but also take due account of the "stock value" (i.e. the entire ecosystem) providing the total bundle of services.[vi] When applying economic valuation the actual management regime of the ecosystem (which is determined by the institutional arrangements) should be taken into account. This regime will influence the expected value of future flows of services, which will differ depending on whether it leads to sustainable or unsustainable uses (Mäler 2008).

3.3 Human well-being: typology of benefits and values

Following the MA approach, the TEEB framework (Figure 5) makes a distinction between ecological, socio-cultural and economic benefits and values. The reason for separating benefits and values is because people have needs which, when fulfilled, are translated into (more or less objectively measurable) benefits. For example, catching fish from the ocean gives us food (health), but also cultural identity (as a fisherman/-woman) and income. How we value these benefits is subjective: some people will value the income much higher than their cultural identity (social ties etc) and may be willing to give up one aspect of their wellbeing (cultural identity) over another (e.g. material wealth). Thus, different values can be attached to a particular benefit.

Although the TEEB study focuses primarily on the measurement of economic values and the assessment of costs and benefits in a welfare economics approach, it includes equity considerations in particular for the aggregation of benefits over time and over groups of people. It specifically analyses the relationships between ecosystems and poverty ('GDP of the poor'), because of the higher dependence of the poor on ecosystem services for their livelihood (TEEB 2008).

Of course, it should also be acknowledged that many native communities ('ecosystem people') still entirely, and directly, depend on ecosystems and their services for their survival, as well as the importance of ecosystems for providing people with the ability to choose certain ways of life that they may value.

The three main types of benefits (well-being aspects) and related values and valuation metrics are briefly introduced below (for more detailed information, see chapter 3 (biophysical indicators – linked to ecological "values"), chapter 4 (socio-cultural values) and chapter 5 (economic values).

3.3.1 Ecological benefits and values

The ecological importance (value) of ecosystems has been articulated by natural scientists in reference to the causal relationships between parts of a system such as, for example, the value of a particular tree species to control erosion, or the value of one species to the survival of another species or of an entire ecosystem (Farber et al. 2002). At a global scale, different ecosystems and their constituent species play different roles in the maintenance of essential life-support processes (such as energy conversion, biogeochemical cycling, and evolution) (MA 2003).

Ecological measures of value (importance) are, for example, integrity, 'health', or resilience, which are important indicators to determine critical thresholds and minimum requirements for ecosystem service provision. These measures of value should be distinguished from what can be included in economic values because although they contribute to welfare, they cannot readily be taken into account in the expression of individual preferences, as they are too indirect and complex, albeit they may be critical for human survival. The related value paradigm could be formulated as the importance people attach to a healthy, ecologically stable environment, both as a contribution to human survival (instrumental value) and for intrinsic reasons (values). Although the notion of ecological value is still much debated, the 'value' of natural ecosystems and their components should be recognized in terms of their contribution to maintaining life on earth, including human survival in its own right (Farber et al. 2002).

3.3.2 Socio-cultural benefits and values

For many people, biodiversity and natural ecosystems are a crucial source of non-material well-being through their influence on mental health and their, historical, national, ethical, religious, and spiritual values. While conceptual and methodological developments in economic valuation have aimed at covering a broad range of values, including intangible ones (see the concept of Total Economic Value below), it can be argued that socio-cultural values cannot be fully captured by economic valuation techniques (cf. chapters 4 and 5) and have to be complemented by other approaches in order to inform decision-making. This is notably the case where some ecosystem services are considered essential to a people's very identity and existence. To obtain at least a minimum (baseline) measure of importance of socio-cultural benefits and values several metrics have been developed such as the Human Wellbeing Index.

3.3.3 Economic benefits and values

Biodiversity and ecosystem services are important to humans for many reasons. In economic terms, this can be considered as contributing to different elements of 'Total Economic Value', which comprises both use values (including direct use such as resource use, recreation, and indirect use from regulating services) and non-use values, e.g. the value people place on protecting nature for future use (option values) or for ethical reasons (bequest and existence values). The economic importance of most of these values can be measured in monetary terms, with varying degrees of accuracy, using various techniques (including market pricing, shadow pricing and questionnaire based). Chapter 5 gives a detailed overview of economic values and monetary valuation techniques.

3.4 Governance and decision making

In making decisions at any level (private, corporate or government), decision-makers are faced with the dilemma of how to balance (weigh) ecological, socio-cultural and economic values. Preferably, the importance of each of these value-components should be weighted on its own (qualitative and quantitative) dimension, e.g. through Multi-Criteria Decision Analysis. However, since TEEB is focusing on the economic, notably monetary, consequences of the loss of biodiversity, concentrates TEEB on aggregation *(1)* and economic trade-off issues *(2).* To make the link with standard macroeconomic indicators, the role of ecosystem services in environmental-economic accounting *(3)* should also be mentioned as a promising field of analysis to inform economic decisions (EEA 2009). Finally, awareness raising and positive incentives *(4)* are essential tools for better decision-making.

(1) Aggregating monetary values

Aggregation involves bringing together all the information on the monetary values of ecosystem services by ecosystem type into a single matrix to attain an aggregate monetary value of all delivered ecosystem services. This is the task of Chapter 7. Effective aggregation is challenging. Key issues requiring consideration include:

- *Accounting for uncertainties in the monetary valuation of individual services,* including possible biases due to the use of different valuation methods (see chapter 5 for discussion).
- *Interdependencies between ecosystem services at the ecosystem scale*, including issues of double counting, competing services, bundled services, etc.
- *Aggregation of values over individuals and groups of people*. The relative importance of ecosystem services will vary between different groups of people, e.g., regarding income level or dependence on ecosystem services. To integrate such considerations some adjustments can be applied such as equity weightings (Anthoff et al. 2009).
- *Aggregation of values over spatial scales*. Different ecosystem services may be best considered at different spatial scales. For example, water regulation is best considered at a watershed scale, while carbon sequestration can be considered on a national or global scale. Aggregation should take these differences into account.
- *Aggregation of values over time*: Protecting biodiversity today may have costs and benefits to future generations. In economics, discounting is a common practice to compare these future costs and benefits with current values. An important issue is the selection of the most appropriate discount rate in different decision-making contexts. Chapter 6 will further explore these issues.

(2) Trade-off analysis

A trade-off occurs when the extraction of an ecosystem service has a negative impact on the provision of other services. For example, timber extraction from a forest will affect, among others, vegetation structure and composition, visual quality and water quality which will preclude or at least affect the continuous provision of other services (e.g. wildlife harvesting, carbon sequestration, recreation) over time, since loss of structure implies loss of function, and consequently of other services and their derived benefits. Approaches to trade-off analysis include: multi-criteria (decision) analysis, cost-benefit analysis and cost-effectiveness analysis.

The foundational strength of *Cost Benefit Analysis (CBA)* is finding the 'net' benefit of an activity. Since the costs and benefits of an activity (or scenario) have different functional relationship in different circumstances – utilizing a 'benefits only' approach could greatly mislead decision-making (Naidoo et al. 2006). This benefits-only approach was common in early ecosystem service assessments (Balmford et al. 2002). A notable early exception is research on the fynbos in South Africa, where researchers enumerated the benefits and costs of both an invasive species eradication campaign and a do-nothing approach (Van Wilgen et al. 1996). An understanding of costs is also crucial in ecosystem service research since the complexity of benefit delivery might preclude a full understanding of service delivery. In these cases a *cost-effectiveness approach* can be highly informative especially where the costs vary more than the benefits (Ando et al. 1998; Balmford et al. 2003; Naidoo et al. 2006, EEA 2009).

(3) Systems of Ecological–Economic Accounting: macro-economic implications

A growing number of governments recognize the need to include ecosystem services in economic accounts in order to ensure that their contribution to well-being is recorded in the macroeconomic indicators that are the most widely acknowledged and used in policy making. If ecosystems are regarded as assets that provide services to people, then accounts can be used to describe the way they change over time in terms of stocks and flows. These changes can be described both in physical terms, using various indicators of ecosystem quantity and quality, and ultimately in monetary values (EEA, 2009). Ecosystem accounting, linked to geographical information systems and to socio-economic data, can thus offer a useful framework for systematically collecting and analyzing data to support assessments of changes in the production and use of ecosystem services, taking into account their spatial heterogeneity.

Several relevant initiatives are currently under way. For example, the European Environment Agency is developing a framework for land and ecosystem accounts for Europe, building on land cover data and following the System of Environmental and Economic Accounts (SEEA) guidelines of the United Nations.

The development of ecosystem accounting will have to be gradual, integrating progressively more ecosystem services, and build on existing information in different countries. This is addressed in more detail in the TEEB report for national and international policy makers (TEEB 2009). An analysis of how the value of some ecosystem services can be recorded at macroeconomic level for some economic sectors is presented in chapter 9 of this report.

(4) Awareness raising and positive incentives

Of special importance in the TEEB context are the numerous decisions by producers and consumers affecting ecosystems (TEEB reports for business and citizens), and the policy changes necessary to ensure that decisions taken at various governmental levels (TEEB 2009 and TEEB for administrators), do not lead to greater degradation of ecosystems and even improve their condition (see section 3.6).

An important step towards the conservation and sustainable use of biodiversity and ecosystem services lies in accounting for the positive and negative externalities associated with human activities. Rewarding the benefits of conservation through *payments for environmental services* (e.g., Landell-Mills and Porras 2002; Wunder 2005) or ecological fiscal transfers (Ring 2008) is as important as the realignment of perverse subsidies that all too often incentivize unsustainable behaviors (TEEB 2009, chapters 5 and 6).

A growing societal awareness of the need for research and development, and for changes in policy, practice and law, can help us pursue sustainable ecosystem management and resource use, and engage in eco-regional planning and large-scale restoration and rehabilitation of renewable and cultivated natural capital (Aronson et al. 2007).

3.5 Scenarios and drivers of change

Efforts aimed at changing behavior towards, and impact on ecosystems and biodiversity must take into account that ecosystems have always been dynamic, both internally and in response to changing environments.

The importance of using scenarios in ecosystem service assessments is beginning to be realized as early assessments presented a static picture in a rapidly changing world. The necessity of providing counter-factuals is now being demanded of conservation research (Ferraro and Pattanayak 2006) and should become the norm in ecosystem service research as well. The generation of scenarios is particularly important for monetary valuation, since scenarios enable analysis of changes in service delivery which are required to obtain marginal values. Making an analysis in incremental terms avoids (or at least reduces) the methodological difficulties, which vary depending on the magnitude of the changes. Such difficulties arise when attempting to estimate total values, related to the non-constancy of marginal values associated with the complete loss of an ecosystem service. Such approaches are also in general more relevant for decision-making in real-life circumstances.

In the TEEB context, comparing the outputs under several scenarios will inform decision makers of the welfare gains and losses of alternative possible futures and different associated policy packages. This is also important for non-monetary valuation changes, but more from a social understanding aspect than for analytical robustness. For each scenario to be elaborated, we must analyze the likely consequences of drivers that directly affect the status, current management and future trajectories of ecosystems and biodiversity (and thus of the services and values they represent).

Indirect drivers of ecosystem change include demographic shifts, technology innovations, economic development, legal and institutional frameworks, including policy instruments, the steady loss of traditional knowledge and cultural diversity and many other factors that influence our collective decisions (OECD 2003; MA 2005b; OECD 2008). These (indirect) drivers affect the way people directly use and manage ecosystems and their services.

Direct drivers can be organized in negative, neutral and positive categories. *Negative drivers* include, among others, habitat destruction, over-use of resources such as largely unrestrained overfishing of the oceans of the world and pollution (leading among others to climate change). Examples of *neutral drivers* would be land use change (which can have positive or negative consequences for ecosystems and biodiversity, depending on the context and management regime). Increasing intensification and industrialization of agriculture and animal husbandry should also be placed in a broader context: intensification (provided it is done in a sustainable manner), can provide extra space for natural habitat. Finally, *positive drivers* for enhancing natural capital would include ecosystem conservation and restoration, development of sustainable management regimes and use of environmental-friendly technologies, aimed at reducing human pressure on ecosystems and biodiversity (e.g. organic farming, eco-tourism, renewable energy, etc). Clearly, even 'positive drivers' can have negative impacts on ecosystems and biodiversity, when applied in the wrong place or context, so the effects of any direct driver on ecosystems need to be carefully analyzed through the TEEB framework.

3.6 Linking ecosystem service values to decision-making: the TEEB guidance reports

TEEB brings together state-of-the art research on assessing and valuing ecosystem services to help policy makers, local authorities, companies and individuals in making decisions with respect to their responsibilities in safeguarding biodiversity. Decision-makers at different organizational levels, both public and private, affect drivers of ecosystem change such as demographic, economic, socio-political, scientific and technological as well as cultural and religious drivers, which in turn affect ecosystem services and human wellbeing. Building on a more refined valuation framework and methodology that is more suitable for capturing economic values and policy-relevant information, TEEB will develop specific guidance documents or "deliverables" addressing decision-making at different levels in different contexts by different actors.

The first guidance document addresses *policy makers* (TEEB 2009). It explores the consequences of international and national policies on biodiversity and ecosystems and presents a TEEB policy toolkit for decision-makers at various governmental levels. By demonstrating the value attached to ecosystem services and considering them in concrete policies, instruments and measures (e.g., subsidies and incentives, environmental liability, market creation, national income accounting standards, trading rules, reporting requirements, eco-labelling), it aims to enhance biodiversity and ecosystem protection as a prerequisite for maintaining natural service levels.

Local administrators are addressed by the second TEEB deliverable. It incorporates values of ecosystem services in location-specific, cost-benefit and cost-effectiveness analysis, and their use in methods and guidelines for implementing payments for ecosystem services, as well as equitable access and benefit-sharing arrangements for genetic resources and protected areas.

The third TEEB deliverable focuses on the *business* end-user. It aims to provide a framework for assessing the business impacts on biodiversity and ecosystems, both for measuring and managing risks and identifying and grasping new market opportunities for private enterprises.

Last, but not least, *individuals and consumer organizations* are addressed by the fourth TEEB deliverable. It covers how to reduce their impacts on wild nature while influencing producers through private purchasing decisions. This will include steps to improve consumer information on the land, water and energy resources used in producing foods and consumer goods.

---

[i] To avoid having to use both the terms ecosystems and biodiversity simultaneously all the time, the term 'ecosystem' is used to include 'biodiversity' throughout the chapter unless indicated otherwise (see Glossary for further explanation of these terms, and chapter 2 for a more in-depth discussion).

[ii] All key terms used in TEEB are included in the Glossary, usually indicated in italics in the text.

[iii] Acknowledging that it is quite impossible to mention all who contributed to the development of the concept of ecosystem services, some key authors and initiatives are listed in Annex 5 in the "Scoping the Science" report by Balmford et al. (2008).

[iv] Note that water purification is also listed as a regulating service in Appendix 2, in case the benefit is related to waste treatment. As mentioned at the beginning of section 2.3 a fully unambiguous classification system probably does not exist because the mix of ecosystem structure – process – function that provides the service changes depending on the benefit pursued.

[v] It should also be realized that many of these disservices are the result of bad planning or management and thus often man-made. For example "normalizing" rivers (leading to floods), cutting forest on hill slopes (causing erosion and landslides), and disturbing natural food webs (leading to outbreaks of pests).

[vi] In this context the ecosystem can be seen as the 'factory' providing (a bundle of) services. It is normal that, for example, car factories include the costs of maintaining the machines and buildings in the price of the car but for

timber or fish coming from a forest or lake we usually exclude the maintenance costs of the natural capital (stock) providing the service is usually excluded.

References

Ando, A., J. Camm, S. Polasky and A. Solow, 1998. Species distributions, land values, and efficient conservation. *Science* 279: 2126–2128.

Anthoff, D., Hepburn, C. and Tol, R.S.J., 2009. Equity weighting and the marginal damage costs of climate change. *Ecological Economics* 68(3): 836–849.

Aronson, J., S.J. Milton and J.N. Blignaut (Eds.) 2007. Restoring Natural Capital: The Science, Business, and Practice. Island Press, Washington D.C.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B.O. Jansson, S. Levin, K.-G. Maler, C. Perrings & D. Pimentel. 1995. Economic growth, carrying capacity, and the environment. *Science* 268: 520–521.

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. Green, M. Jenkins, P. Jefferiss, V. Jessamay, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and R.K. Turner, 2002. Economic reasons for conserving wild nature. *Science* 297: 950–953.

Balmford, A., K.J. Gaston, S. Blyth, A. James, V. Kapos, 2003. Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. *PNAS* 100(3): 1046–1050.

Balmford, A., Rodrigues, A., Walpole, M. J., ten Brink, P., Kettunen, M., Braat, L., & de Groot, R., 2008. Review of the Economics of Biodiversity Loss: Scoping the Science. European Commission, Brussels.

Barbier, E. B., 1994. Natural Capital and the Economics of Environment and Development. In: Jansson, A.-M., Hammer, M., Folke, C. and R. Costanza (Eds.). Investing in Natural Capital. Island Press, Washington D.C. 505 pp.

Barbier, E.B., E.W. Koch, B.R. Silliman, S. D. Hacker, E. Wolanski, J. Primavera, E. F. Granek, S. Polasky, S. Aswani, L.A. Cramer, D. Stoms, C.J. Kennedy, D.Bael, C.V. Kappel, G.M.E. Perillo and D.J. Reed, 2008. Coastal ecosystem-based management with non-linear ecological functions and values. *Science* 319: 321–323.

Bartelmus, P., 2009. The cost of natural capital consumption: Accounting for a sustainable world economy. *Ecological Economics* 68(6): 1850–1857.

Bateman, I.J., A.P. Jones, A.A. Lovett, I.R. Lake, and B.H. Day, 2002. Applying Geographical Information Systems (GIS) to Environmental and Resource Economics. *Environmental and Resource Economics* 22(1): 219–269.

Bockstael N., A.M. Freeman III, R.J. Kopp. P.R. Portney and V.K. Smith, 2000. On measuring economic values for nature. *Environmental Science and Technology* 34: 1384–1389.

Boyd, J. and Banzhaf, S., 2007. What Are Ecosystem Services? The Need for Standardized Environmental Accounting Units. *Ecological Economics 63*(2-3): 616–626.

Braat L., and P. ten Brink (Eds.) with J. Bakkes, K. Bolt, I. Braeuer, B. ten Brink, A. Chiabai, H. Ding, H. Gerdes, M. Jeuken, M. Kettunen, U. Kirchholtes, C. Klok, A. Markandya, P. Nunes, M. van Oorschot, N. Peralta-Bezerra, M. Rayment, C. Travisi, and M. Walpole, (2008). The Cost of Policy Inaction (COPI): The Case of not Meeting the 2010 Biodiversity Target. European Commission, Brussels.

Burgess, N.D., T.M. Butynski, N.J. Cordeiro, N.H. Doggart, J. Fjeldsa, K.M. Howell, F.B. Kilahama, S.P. Loader, J.C. Lovett, B. Mbilinyi, M. Menegon, D.C. Moyer, E. Nashanda, A. Perkin, F. Rovero, W.T. Stanley and S.N. Stuart (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation* 134: 209–231.

Carson, R., 1962. Silent Spring. Fawcett Publications, Greenwich Connecticut.

Chevassus-au-Louis, B., J.-M. Salles, J.-L. Pujol, 2009. Approche économique de la biodiversité et des services liés aux écosystèmes. Contribution à la décision publique. Report to the Prime Minister. April 2009. Centre d’analyse stratégique, Paris.

Christie, M., Hanley, N., Warren, J., Murphy, K., Wright, R., and Hyde, T., 2006. Valuing the Diversity of Biodiversity. *Ecological Economic, 58*(2): 304–317.

Common M. and C. Perrings, 1992. Towards an ecological economics of sustainability. *Ecological Economics* 6: 7–34.

Costanza, R., 2008. Ecosystem services: Multiple classification systems are needed. *Biological Conservation* 141: 350–352.

Costanza, R., Daly, H., 1992. Natural Capital and Sustainable Development. *Conservation Biology* 6: 37–46.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, M., B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt, 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253–259.

Daily, G., (Ed.), 1997. Nature’s Services. Societal Dependence on Natural Ecosystems. Island Press. Washington D.C.

Daily, G., S. Polasky, J. Goldstein, P.M. Kareiva, H.A. Mooney, L.Pejchar, T.H. Ricketts, J. Salzman and R. Shallenberger, 2009. Ecosystem services in decision-making: time to deliver. *Frontiers in Ecology and the Environment* 7(1): 21–28.

Daly, H., 1996. Introduction to Essays toward a Steady-State Economy. In: Daly, H. and Townsend, K.N. (Eds.). Valuing the Earth: Economics, Ecology, Ethics. The MIT Press, Cambridge, Massachusetts, p. 11–47.

Daly, H., Farley, J., 2004. Ecological Economics: Principles and Applications. Island Press, Washington D.C., 488pp.

Dasgupta, P., S. Levin & J. Lubchenko, 2000. Economic pathways to ecological sustainability. *BioScience* 50: 339–345.

De Groot, R.S., 1987. Environmental Functions as a Unifying Concept for Ecology and Economics. *The Environmentalist* 7(2): 105–109.

De Groot, R.S., 1992. Functions of Nature: evaluation of nature in environmental planning, management and decision-making. Wolters Noordhoff BV, Groningen, 345 pp.

De Groot, R.S., M.A.Wilson & R.M.J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41: 393–408.

Ellis, E.C., and N. Ramankutty, 2008. Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment* 6(8): 439–447.

EEA (European Environment Agency), 2009. Ecosystem accounting for the costs of biodiversity losses: framework and case study for coastal Mediterranean wetlands. Copenhagen: European Environment Agency. Available at http://ec.europa.eu/environment/nature/biodiversity/economics/pdf/medwetlands_report.zip.

Ehrlich, P.R. and A.H. Ehrlich, 1981. Extinction: the causes and consequences of the disappearance of species. 1st edition. Random House, New York. xiv, 305 pp.

Ehrlich, P.R. and H.A. Mooney, 1983. Extinction, substitution, and ecosystem services. *Bioscience* 33: 248–254.

EPA-SAB (U.S. Environmental Protection Agency – Science Advisory Board), 2009. Valuing the protection of ecological systems and services. U.S. Environmental Protection Agency, Washington D.C.

Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. In: the dynamics and value of ecosystem services: integrating economic and ecological perspectives. *Ecological Economics* (41): 375–392.

Ferraro, P.J. and S.K. Pattanayak, 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *Plos Biology* 4: 482–488.

Fisher, B. and R.K. Turner, 2008. Ecosystem Services: classification for valuation. *Biological Conservation* 141: 1167–1169.

Fisher B., R.K. Turner, M. Zylstra, R. Brouwer, R.S. de Groot, S. Farber P.J. Ferraro R.E. Green, D. Hadley, J. Harlow, P. Jefferiss, C. Kirkby, P. Morling, S. Mowatt, R. Naidoo, J. Paavola, B. Strassburg, D. Yu, and A. Balmford, 2008. Ecosystem services and economic theory: integration for policy-relevant research. *Ecological Applications* 18(8): 2050–2067.

Fisher, B., R.K. Turner and P. Morling, 2009. Defining and Classifying Ecosystem Services for Decision Making. *Ecological Economics* 68: 643–653.

Folke, C., M. Hammer and A.M. Jansson, 1991. Life-support value of ecosystems: a case study of the Baltic region. *Ecological Economics* 3(2): 123–137.

Granek, E.F., S. Polasky, C.V. Kappel, D.J. Reed, D.M. Stoms, E.W. Koch, C.J. Kennedy, L.A. Cramer, S.D. Hacker, E.B. Barbier, S. Aswani, M. Ruckelshaus, G.M.E. Perillo, B.R. Silliman, N. Muthiga, D. Bael, and E. Wolanski. 2009. Ecosystem services as a common language for coastal ecosystem-based management. *Conservation Biology*, Vol. 24, No 1:207-216

Haines-Young, R. and M. Potschin, 2010. The links between biodiversity, ecosystem services and human well-being. Ch6 in: Raffaelli, D. and C. Frid (Eds.): Ecosystem Ecology: a new synthesis. BES ecological reviews series, Cambridge University Press, Cambridge (31 pp)

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E.., Fujita, R., Heinmenann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Sellig, E.R., Spalding, M., Steneck, R. and R. Watson, 2008. A Global Map of Human Impact on Marine Ecosystems. *Science* 319: 948–952 and www.sciencemag.org/cgi/content/full/319/5865/948/DC1

Halpern, B.S., Ebert, C.M., Kappel, C.V., Madin, E.M.P., Micheli, F., Perry, M., Selkoe, K.A. and S. Walbridge, 2009. Global priority areas for incorporating land-sea connections in marine conservation. *Conservation Letters* 2(2009): 189–196.

Hein, L., K. van Koppen, R.S. de Groot and E.C. van Ierland, 2006. Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics* 57: 209–228.

Hueting, R., 1980. New scarcity and economic growth, more welfare through less production? North Holland Publ. Co., Amsterdam/New York, Oxford, 269 pp.

ICSU-UNESCO-UNU, 2008. Ecosystem Change and Human Well-being: Research and Monitoring Priorities Based on the Millennium Ecosystem Assessment. International Council for Science, Paris.

Jansson, A-M. et al., 1994. Investing in Natural Capital: The Ecological Economics Approach to Sustainability. Island Press, Washington, D.C., 504 pp.

Johnson, D.G., 2000. Population, food, and knowledge. *American Economic Review* 90(1): 1–14.

Kareiva, P., S. Watts, R. McDonald and T. Boucher, 2007. Domesticated nature: Shaping landscapes and ecosystems for human welfare. *Science* 316: 1866–1869.

Krutilla, J. and A.C. Fisher, 1975. The Economics of Natural Environments. Resources for the Future, Johns Hopkins University Press, Washington D.C.

Landell-Mills, N., I. Porras, 2002. “Silver bullet or fools’ gold? A global review of markets for forest environmental services and their impact on the poor”. Instruments for sustainable private sector forestry series. International Institute for Environment and Development, London.

Leopold, A., 1949. A Sand County Almanac and Sketches Here and There. Oxford University Press, Oxford. 226 pp.

Limburg, K.E., R.V. O’Neil, R. Costanza and S. Farber, 2002. Complex systems and valuation. *Ecological Economics* 41: 409–420.

MA (Millennium Ecosystem Assessment), 2003. Ecosystems and Human Well-being: a framework for assessment. Island Press, 245 pp.

MA (Millennium Ecosystem Assemssment), 2005a. Ecosystems and Human Well-being: Synthesis. Island Press, Washington D.C.

MA (Millennium Ecosystem Assessment), 2005b. Ecosystems and Human Well-being: Current State and Trends, Volume 1, Island Press, Washington D.C.

Mäler, K.G., S. Aniyar and A. Jansson, 2008. Accounting for ecosystem services as a way to understand the requirements for sustainable development. Proceedings of the National Academy of Sciences of the United States of America 105: 9501–9506.

Maltby, E. (ed.), 2009. Functional Assessment of Wetlands. Towards Evaluation of Ecosystem Services. Woodhead Publ., Abington, Cambridge.

Marsh, G. F. (1874). The Earth as Modified by Human Action. Arno, New York.

Mwakalila, S., Burgess, N, Ricketts, T, Olwero, N., Swetnam, R., Mbilinyi, B., Marchant,R., Mtalo,F., White,S., Munishi,P., Malimbwi,R., Smith,C., Jambiya,G., Marshall, A., Madoffe, S., Fisher, B., Kajembe,G., Morse-Jones, S., Kulindwa, K., Green, R., Turner,R.K., Green, J., and Balmford, A., 2009. Valuing the Arc: Linking Science with Stakeholders to Sustain Natural Capital. *The Arc Journal* 23: 25–30.

Naidoo, R., A. Balmford, P.J. Ferraro, S. Polasky, T.H. Ricketts, and M. Rouget, 2006. Integrating economic cost into conservation planning. *Trends in Ecology and Evolution* 21(12): 681–687.

Naidoo, R., A. Balmford, R. Costanza, B. Fisher, R.E. Green, B. Lehner, M. T.R. and T.H. Ricketts, 2008. Global mapping of ecosystem services and conservation priorities. *PNAS* 105(28): 9495–9500.

Naidoo, R. and T.H. Ricketts, 2006. Mapping the economic costs and benefits of conservation. *Plos Biology* 4: 2153–2164.

NRC (National Research Council), 2005. Valuing Ecosystem Services: Towards Better Environmental Decision-making. National Academies Press, Washington, D.C.

Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D.R. Cameron, K.M.A. Chan, G. Daily, J. Goldstein, P. Kareiva, E. Lonsdorf, R. Naidoo, T.H. Ricketts and M. R. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and trade-offs at landscape scales. *Frontiers in Ecology and the Environment* 7(1): 4–11.

Norgaard, R. B., C. Bode with the Values Reading Group, 1998. Next, the Value of God, and Other Reactions (A response to The Value of the World's Ecosystem Services and Natural Capital by Costanza et al.). *Ecological Economics* 25(1): 37–39.

Odum, E.P., 1989. Ecology and our Endangered Life-Support Systems. Sinauer Ass., North Scituate, MA, USA (283 pp).

OECD, 2003. OECD Environmental indicators: Development, measurement and use. OECD, Paris.

OECD, 2008. Environmental Outlook to 2030. OECD, Paris.

Pearce, D., A. Markandya, and E.B. Barbier, 1989. Blueprint for a green economy, Earthscan, London.

Pezzey, J., 1992. Sustainable Development Concepts; An Economic Analysis. The World Bank Environment Paper, No. 2. The World Bank, Washington D.C.

Polasky, S., E. Nelson, J. Camm, B. Csuti, P. Fackler, E. Lonsdorf, C. Montgomery, D. White, J. Arthur, B. Garber-Yonts, R. Haight, J. Kagan, A. Starfield, and C. Tobalske, 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biological Conservation* 141(6): 1505–1524.

Prugh, T., with R. Costanza, J.H. Cumberland, H.E. Daly, R. Goodland, and R.B. Norgaard, 1999. Natural Capital and Human Economic Survival. Lewis Publishers, Boca Raton, FL.

Ring, I., 2008. Integrating local ecological services into intergovernmental fiscal transfers: the case of the ecological ICMS in Brazil. *Land use policy* 25(4): 485–497.

Sen, A., 1993. Capability and well-being. In: Nussbaum M.C. and A. Sen (Eds.). The Quality of Life. Oxford University Press, Oxford, pp. 30–53.

Srinivasan, U.T., S.P. Carey, E. Hallstein, P.A.T. Higgins, A.C. Kerr, L.E. Koteen, A.B. Smith, R. Watson, J. Harte and R.B. Norgaard, 2008. The debt of nations and the distribution of ecological impacts from human activities. *Proceedings of the National Academy of Sciences of the United States of America* 105**:** 1768–1773.

TEEB, 2008. The Economics of Ecosystems and Biodiversity: An Interim report. Available online at www.teebweb.org, accessed 2 March 2010.

TEEB, 2009. The Economics of Ecosystems and Biodiversity for National and International Policy Makers. Available online at www.teebweb.org, accessed 2 March 2010.

Turner, R.K., J. Paavola, P. Cooper, S. Farber, V. Jessamy and S. Georgiou, 2003. Valuing nature: lessons learned and future research directions. *Ecological Economics* 46: 493–510.

van Wilgen, B.W., R.M. Cowling and C.J. Burgers, 1996. Valuation of ecosystem services. *Bioscience* 46: 184–189.

Wallace, K.J., 2008. Classification of ecosystem services: Problems and solutions. *Biological Conservation* 139: 235–246.

Westman, W., 1977. How much are nature's services worth. *Science* 197: 960–964.

White, R., 2001. Evacuation of sediments from reservoirs. Thomas Telford, London.

Wilson, M.A. and Howarth, R.B., 2002. Valuation techniques for achieving social fairness in the distribution of ecosystem services. *Ecological Economics* 41: 431–443.

Wunder, S., 2005. Payments for Environmental Services: Some Nuts and Bolts. CIFOR Occasional Paper No. 42, Center for International Forestry Research, Jakarta.

Appendices

1. Classification of ecosystems used in TEEB

2. Ecosystem service classification: brief literature survey and TEEB classification

3. How the TEEB framework can be applied: the Amazon case

Appendix 1: Classification of ecosystems used in TEEB

	LEVEL 1 (Biomes)		**LEVEL 2 (ecosystems)**
1	**Marine / Open ocean**	**1.0**	**Marine / Open ocean**
		1.1	Open ocean
		1.2	Coral reefs (*, (#
2	**Coastal systems**	**2.0**	**Coastal systems (excluding wetlands)**
		2.1	- Seagrass/algae beds
		2.2	- Shelf sea
		2.3	- Estuaries
		2.3	- Shores (rocky & beaches)
3	**Wetlands**	**3.0**	**Wetlands – general (coastal & inland)**
			(coastal wetlands)
		3.1	- Tidal Marsh (coastal wetlands)
		3.2	- Mangroves (#
			(Inland wetlands)
		3.3	- Floodplains (incl. swamps/marsh)
		3.4	- Peat-wetlands (bogs, fens, etc.)
4	**Lakes/Rivers**	**4.0**	**Lakes/Rivers**
		4.1	- Lakes
		4.2	- Rivers
5	**Forests**	**5.0**	**Forests – all**
			(Tropical Forest)
		5.1	- Tropical rain forest (#
		5.2	- Tropical dry forest
			(Temperate forests)
		5.3	- Temperate rain/Evergreen
		5.4	- Temperate deciduous forests
		5.5	- Boreal/Coniferous forest
6	**Woodland & shrubland**	**6.0**	**Woodland & shrubland** (“dryland”)
		6.1	- Heathland
		6.2	- Mediterranean scrub
		6.3	- Various scrubland
7	**Grass/Rangeland**	**7.0**	**Grass/Rangeland**
		7.1	- Savanna etc
8	**Desert**	**8.0**	**Desert**
		8.1	- Semi-desert
		8.2	- True desert (sand/rock)
9	**Tundra**	**9.0**	**Tundra**
10	**Ice/Rock/Polar**	**10.0**	**Ice/Rock/Polar**
11	**Cultivated**	**11.0**	**Cultivated**
		11.1	Cropland (arable land, pastures, etc.)
		11.2	Plantations / orchards / agro-forestry, etc.
		11.3	Aquaculture / rice paddies, etc.
12	**Urban**	**12.0**	**Urban**

Source: Based on mix of classifications, mainly MA (2005a) and Costanza et al. (1997) which in turn are based on classifications from US Geol. Survey, IUCN, WWF, UNEP and FAO.
*) usually placed under “coastal” but it is proposed to put this under “marine”.
#) These three ecosystems are dealt with separately in the monetary valuation (chapter 7).

Appendix 2: Ecosystem service classification: brief literature survey and TEEB classification

Various sources (1	Millennium Ecosystem Assessment (2005a)	Daily et al. (2008)		**TEEB classification**
PROVISIONING	PROVISIONING			**PROVISIONING**
Food (fish, game, fruit)	Food	Seafood, game	1	Food
Water availability [RS] (2	Fresh water		2	Water (2
Raw materials (e.g. wood)	Fibre	Timber, fibers	3	Raw materials
Fuel & energy (fuel-wood, organic matter, etc.)	,, ?	Biomass fuels		
Fodder & fertilizer	,, ?	Forage		
Useful genetic material,	Genetic resources	- industrial products	4	Genetic resources
Drugs & pharmaceutical	Biochemicals	Pharmaceuticals	5	Medicinal resources
Models & test organisms	- ?	- industrial products		
Resources for fashion, handicraft, decorative, etc.	Ornamental resources	- ?	6	Ornamental resources
REGULATING	REGULATING			**REGULATING**
Gas regulation/air quality	Air quality regulation	Air purification	7	Air purification
Favorable climate (incl. C-sequestration)	Climate regulation	Climate stabilization	8	Climate regulation (incl. C-sequestration)
Storm protection	- ?	Moder. of extremes	9	Disturbance prevention or moderation
Flood prevention	Water regulation	Flood mitigation		
Drainage & natural irrigation (drought prevent.)	‘’	Drought mitigation	10	Regulation of water flows
Clean water (waste treatment)	‘’	Water purification	11	Waste treatment (esp. water purification)
Erosion prevention	Erosion regulation	Erosion protection	12	Erosion prevention
Maintenance of productive and "clean" soils	Soil formation [supporting service]	Soil generation and preservation	13	Maintaining soil fertility
Pollination	Pollination	Pollination	14	Pollination
(biol. control)		Seed dispersal	15	Biological control
Pest & disease control	Pest regulation	Pest control		
	Human disease regulat.			
HABITAT/SUPPORT	**SUPPORTING**	*(3*		**HABITAT**
Nursery-service	e.g. Photosynthesis, primary production, nutrient cycling		16	Lifecycle maintenance
Maintenance of biodiversity		Maintenance of biodiversity	17	Gene pool protection
CULTURAL (& Amenit.)	**CULTURAL**			**CULTURAL** & Amenity
Appreciated scenery (incl. tranquility)	Aesthetic values	Aesthetic beauty	18	Aesthetic information
Recreation & tourism	Recreat. & eco-tourism		19	Recreation & tourism
Inspiration for art etc.	- ?		20	Inspiration for culture, art and design
Cultural heritage	Cultural diversity			
Spiritual & religious use	Spirit. & religious val.		21	Spiritual experience
Use in science & education	Knowledge systems Educational values	Intellectual stimulation	22	Information for cognitive development

1) Mainly based on/adapted from Costanza et al. (1997) and De Groot et al. (2002).
2) Water is often placed under Regulating Services [RS] but in TEEB the consumptive use of water is placed under provisioning services.
3) Daily et al. (2008) do not use main categories and also included detoxification and decomposition of waste, nutrient cycling, and UVb-protection as services.