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Challenges in framing the economics of ecosystems and biodiversity: the TEEB initiative

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The Economics of Ecosystems and Biodiversity (TEEB) study is a major international initiative to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation and to draw together expertise from the fields of science, economics and policy to enable practical actions moving forward. TEEB seeks to show that economics can be a powerful instrument in biodiversity policy, both by supporting decision processes and by forging discourses between science, economics and governing structures. The legitimate and effective use of economic instruments in biodiversity conservation depends on applying and interpreting them appropriately, taking into account the ecological, economic and political challenges associated with valuing biodiversity and nature's services to society.

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Introduction

The ongoing degradation of ecosystems and loss of biodiversity is a well-documented reality. The Millennium Ecosystem Assessment (MA) used a new conceptual framework for analysing and understanding the effects of environmental change on ecosystems and human well-being, putting the ecosystem services concept centre stage [1]. Although the MA did a thorough job of assessing the effects of policies on ecosystem services and human well-being [2], we still lack certain basic information about the dynamics of social–ecological systems and the interrelationship between ecosystem services and human well-being [3••].

A major reason for the decline of ecosystem services is that their true values are not taken into consideration in economic decision making [4]. The root causes of biodiversity loss lie in the ways human beings relate to nature, and in the effects of our dominant economic model. Although there are many exceptions, our dominant economic model promotes and rewards more versus better consumption, private versus public wealth creation, man-made capital versus natural capital. This is the 'triple-whammy' of self-reinforcing biases that leads us to uphold and promote an economic model in which we tend to extract without fear of limits, consume without an awareness of consequences, and produce without responsibility for third-party costs, the so-called 'externalities' of business.

The genesis of TEEB, a global study on the economics of ecosystems and biodiversity, lies in climate change. The G8 + 5 meeting of environment ministers held in Potsdam in 2007 proposed that a study be conducted to assess the economic impact of the global loss of biodiversity, in order to present a convincing economic case for conservation [5•]. Their inspiration was the Stern Review [6], which had presented a powerful economic case for timely action on climate change, building on the science of the IPCC. Environmental economists have argued that ''the impact of economists on environmental policy to date has been modest'' [7]. Yet economists are set to play an increasingly important role in shaping environmental policies in the future, provided they attend more to problems than to tools, become more comfortable with the idea of being advocates for policies in which they believe and institutionalise their power in certain policy settings in order to have a voice in the policy process [7].

TEEB calls for a change to the current economic paradigm; at the same time it acknowledges the persuasive power of economic reasoning in contemporary societies [8]. TEEB aims at drawing attention to the global economic benefits of biodiversity and highlighting the growing costs of biodiversity loss and ecosystem degradation. The TEEB initiative does not seek to develop new methods and techniques; rather, it attempts to synthesise the current state of knowledge in order to provide a basis for evaluating the stock of natural capital and the flow of ecosystem services, and to address the complexities entailed in applying economic valuation in situations characterised by thresholds, non-linear changes and ecosystem resilience. In doing this, TEEB draws together expertise from the fields of environmental science, economics and policy to facilitate progress in practical arenas.

The TEEB Interim Report, which set out the general framework for the project, was presented by study leader Pavan Sukhdev at CBD COP9 in May 2008 and attracted widespread attention [5•]. The second phase of TEEB (2008-10) will generate several end-user reports aimed at national and international policy makers [9••,10••,11•], regional administrators, businesses and citizens at large. These reports will outline the specific challenges and opportunities these groups are likely to encounter as they enhance their role in safeguarding biodiversity. A scientific report on the ecological and economic foundations of the economics of ecosystems and biodiversity – developed, written and reviewed by renowned experts from all relevant disciplines – will provide the basis for these end-user reports.

The goals of the present article are twofold: first, to understand better the scientific challenges involved in framing the economics of ecosystems and biodiversity, from both an ecological and an economic perspective; and second, to highlight the practical challenges entailed by biodiversity policies: How can economic reasoning support the choice and design of policy instruments? And how can policy makers take better account of the value of biodiversity and ecosystem services in international and national policy making?

Ecological challenges

In order to frame the economics of ecosystems and biodiversity, it is necessary first to address the challenges related to the natural science underpinning it. Although ecological research on the relationship between biodiversity, ecosystem functioning and the provision of ecosystem services has increased substantially in recent years and some of these linkages have been elucidated for specific systems, we are still far from having a comprehensive picture of these relationships [12]. Almost all the benefits that people derive from ecosystems depend to some extent on biodiversity, but its precise role is variable and often context-dependent. We have considerable knowledge of the role of biodiversity in some ecosystem services, and know that biodiversity plays a key role in ecosystem functioning, but many questions remain unanswered concerning the precise (or even approximate) roles of most species. In its report on the ecological and economic foundations, TEEB provides up-to-date evidence for the links between biodiversity, ecosystem functions and ecosystem services, synthesising the current state of knowledge in relation to 22 ecosystem services [13].

In the following sections, we will concentrate on ecological challenges of special relevance to economic analysis and societal decision making. In particular we focus on two issues of that we still have insufficient knowledge and that affect our ability to value ecosystem services and manage them in a sustainable way in the face of uncertainty and change (for further details, see [13]): The first issue is potential trade-offs among services and the fact that there are multiple interactions and linkages among services; this means that management aimed at providing a single service (e.g. food, fibre, water) often reduces biodiversity and the provision of other services. The other issue is that of thresholds and the fact that ecosystems vary in their ability to adapt to change; they may pass thresholds and thus enter different (and often less desirable) ecological states or trajectories.

Trade-offs among ecosystem services

Functioning ecosystems provide multiple services and these interact in complex ways. Different services are interlinked or 'bundled' together, and are therefore affected negatively or positively as one service such as food production as a provisioning service is increased. Most studies so far have focused on one or a few services such as pollination, or on food versus water quality and quantity. The task of characterising multiple ecosystem services and biodiversity across the same region has only recently emerged as a field of study (e.g. [14]), and the little quantitative evidence available to date has led to mixed conclusions (e.g. [15]). The spatial concordance among different services varies widely [16••]. Finding ways of assessing how multiple ecosystem services are interconnected and linked to each other in 'bundles' is one of the major research gaps identified by the MA with regard to ecosystem services [3••]. Some ecosystem services co-vary positively (more of one means more of another): for example, maintaining soil quality may promote nutrient cycling and primary production, enhance carbon storage and hence climate regulation, help regulate water flows and water quality and improve most provisioning services, notably food, fibre and other chemicals. Other services co-vary negatively (more of one means less of another): an increase in provisioning services may reduce many regulating services. For example, the provision of agricultural crops may reduce biodiversity.

Furthermore, finding ways to target and implement payments for bundling biodiversity conservation with 'bundles' of ecosystem services, for example carbon and water services, is also a major priority [17•]. In the context of climate mitigation policies, the potential trade-offs between biodiversity conservation and carbon sequestration by forests have recently attracted increased attention

[18–20], especially owing to the proposed financial schemes to reduce emissions from deforestation and forest degradation (REDD) [21,22].

The types of interactions and whether there are positive or negative feedbacks will have very different implications for the design and management of landscapes. For example, it has been suggested that major ecosystem degradation tends to occur as a result of simultaneous failures in multiple ecosystem services [23]. The dry lands of sub-Saharan Africa provide one of the clearest examples of these multiple failures, which have given rise to a combination of failing crops and deteriorating grazing conditions, declining quality and quantity of fresh water, and loss of tree cover. However, an evaluation of over 250 projects of investment in organic agriculture in developing countries around the world (both dry lands and non-dry lands) showed that the implementation of various novel agricultural techniques and practices resulted in a reduction of ecosystem service trade-offs, even as crop yields increased [24]. There is an urgent need to deepen our scientific knowledge about these trade-offs, particularly those between regulating and provisioning services.

Other trade-offs might be handled more readily using methods of valuation and decision making among stakeholders. Such trade-offs include:

1. Temporal trade-offs: benefits now–costs later. Such trade-offs represent the central tenet of sustainable development, that it ''...meets the needs of the present generation without compromising the needs of future generations...'' [25]. The economic challenges associated with this relate to the economics and ethics of discounting, which will be addressed later [5•,26].
2. Spatial trade-offs: benefits here–costs there. These trade-offs are behind much deliberation between communities and countries (especially on the matter of transboundary waters) and also occur between ecosystems and production landscapes. An example of a landscape level trade-off is that between improved water productivity (evapotranspiration used per tonne of grain) upstream and consequential downstream problems with deteriorating water quality associated with the use of agricultural inputs. Spatial trade-offs are well-known in economics and are closely linked to the assessment of spatial externalities (regional spillovers), for example in terms of the local costs and global benefits of biodiversity conservation [27,28].
3. Interpersonal trade-offs: some win–others lose. Such trade-offs are real, but there is a possibility of moving towards 'winning more and losing less'. This might be achieved by improving access to information about ecosystem services and their valuation, by framing and using appropriate incentives and/or markets, and by clarifying and strengthening the rights of local people over their resources. Nevertheless, the distributional dimension of ecosystem services provision and livelihood dependence upon them need to be properly addressed, requiring improved instruments for measuring economic welfare [5•].

Thresholds in ecosystem dynamics

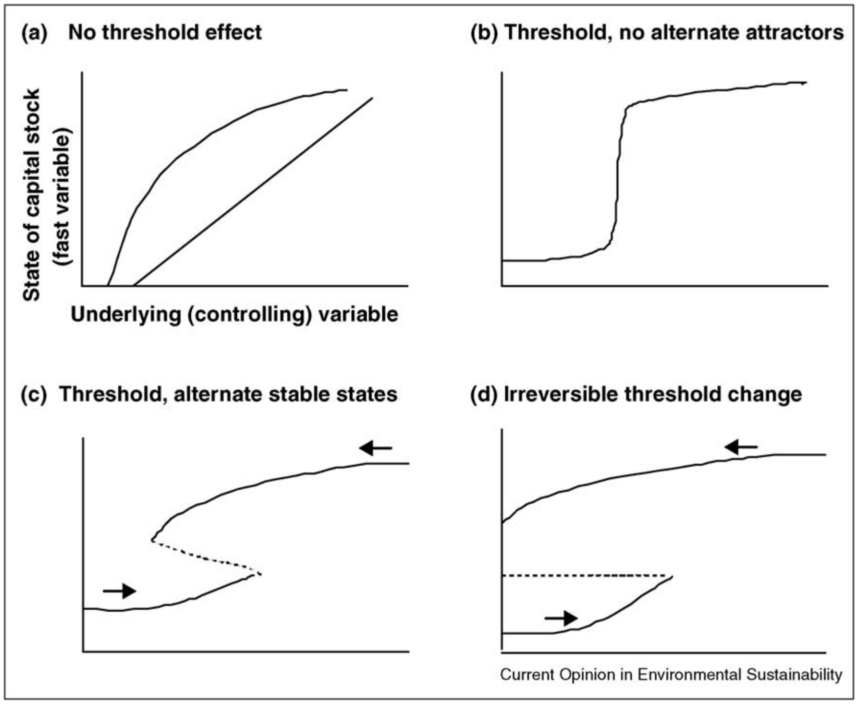
The capacity of an ecosystem to withstand perturbations without losing any of its functional properties is often referred to as ecosystem resilience. In practice, minor disturbances to ecosystem stability can serve to increase resilience overall because they impose the necessity for flexibility on species interactions [29]—hence Holling's original definition of the term [30] as ''the capacity of a system to absorb and utilise or even benefit from perturbations and changes that attain it, and so to persist without a qualitative change in the system''.

Where environmental or socio-economic drivers are persistent or strong, ecosystems may cross a threshold and undergo sudden and catastrophic structural change [31–33]. This can shift the ecosystem into an alternative state [30,34,35], which is sometimes also termed a 'regime shift' [36]. Such regime shifts can produce large, unexpected changes in ecosystem services. Examples at local and regional levels include eutrophication of lakes, degradation of rangelands, shifts in fish stocks, breakdown of coral reefs and extinctions due to persistent drought [36].

Four different types of non-linear relations are possible [37] (Figure 1 and Box 1). (a) represents a system with no threshold effect, where changes in the controlling variables are reversible. Such a system is relatively easy to handle using current methods of valuing services and management. (b) represents a system with a threshold, where a small change in a controlling variable has a large effect on system attributes and where passing the threshold is reversible. Again, this system may also be handled using current valuation and management methods. (c) represents a system with a threshold, where there is a hysteresis effect, that is it is possible to reverse the passing of a threshold only if changes in the controlling variables are very large, that is at significantly different values than when the threshold was passed. These systems are currently difficult to handle using existing valuation and management methods. (d) represents the truly irreversible crossing of a threshold that should be avoided at all costs, particularly if this relates to large-scale systems like continental-scale interactions and feedbacks among the biosphere, atmosphere and oceans.

The concept of regime shifts and non-linear ecosystem change has important consequences for ecosystem management and conservation [3••,43•], especially when our ability to control global-scale environmental change is limited and reactive. The present framework challenges those models and policies that are based on assumptions of linear dynamics, and focus on optimal solutions. If a

Figure 1



Different thresholds and 'tipping points'. Source: [37]

system is discontinuous the basic theorems of welfare economics are not valid and the outcome of resource allocation may be very far from the optimum, even if existing property rights are well-defined [44]. This has major implications for production, consumption and international trade, as well as for economic policy. Management based on optimal economic solutions will often be extremely difficult to put into practice owing to the complex dynamics involved.

Economic challenges

In theory, markets should enable human choices to be expressed through adjusted market prices, and if the worsening condition of the Earth and its living fabric were not desirable outcomes, then prices and market forces should have engineered a reversal of fortunes. But of course, there are no markets for the largely public goods and services that flow from ecosystems and biodiversity, and no prices on them either [45,46]. The traditional term for this is 'market failure'. In their study on land conversion and degradation of remaining natural habitats, Balmford *et al.* [4] find that the major benefits associated with keeping ecosystems intact are non-marketed externalities, accruing to society at local and global scales. These benefits are often considerably larger than the immediate private benefits derived from land-use change. But as long as the full range of direct uses (e.g. food, water for human consumption), indirect uses (e.g. ecosystem functions providing services for humans) and non-uses (e.g. the existence of a rare species) as well as values to society at large are not properly valued or factored into decision making through policy instruments, the loss of biodiversity and valuable ecosystems will continue [47,48•]. Thus the economic challenge is to apply suitable valuation methods for estimating biodiversity benefits and to highlight appropriate instruments to deal with the challenges.

Neglecting nature's values in economic analyses and political decision making is closely related to the three trade-offs mentioned above. In economics, *temporal trade-offs* are usually addressed by discounting future costs and benefits to the present, and the choice of discount rate may ultimately determine whether or not a project or business is realised. However, discounting biodiversity losses and the loss of vital ecosystem services needs to be critically reassessed, especially if irreversible changes are likely to occur. In this case, we face an ethical decision rather than a purely economic one [5•]. It is also necessary to adopt an ethical perspective with regard to the vital significance of ecosystem services and their contribution to livelihood and well-being for the poor: poor people are often hit hardest by the misuse of environmental resources, as they depend on them most heavily [8]. This requires (1) being very cautious in using discount rates and not transferring market-type considerations of

Box 1 How the TEEB framework can be applied: The Amazon case

The Amazon forest provides a good case for exemplifying the role of ecosystems and ecosystem services at various spatial scales. TEEB uses the Amazon case to demonstrate the benefits provided by ecosystem services to human well-being from the local up to the global level. Monetary estimates of the values of various ecosystem services are presented; if these are not available or are unknown, values are described in other terms [38]. At each spatial level, regime shifts are conceivable, depending on continued pressures from deforestation and forest degradation and their respective socio-economic drivers. The point at which specific thresholds are crossed and we see potential regime shifts is not known, owing to the complex interactions and feedback mechanisms of this large-scale forest ecosystem. For example,

- at the global scale, deforestation and forest degradation of the Brazilian Amazon reduces carbon sequestration capacities with an estimated value of US$ 1.5–3 trillion (C-stock value) and contributes to the loss of biodiversity [38];
- at the continental scale, at a certain (as yet unknown) threshold level, deforestation may affect the Amazonian 'water pump' [13,39], which sustains rain-fed agriculture estimated at a value of US$ 1–3 billion per year [38] as well as other ecological systems on the Latin American continent; modelling experiments by Alcock [40] indicate that ''human-driven deforestation may shift regions of the Amazonian ecosystem to instability after 25%–30% of the forest has been permanently cleared, within two to four decades if the current practice is maintained'';
- at the regional scale, forest growth for timber harvesting, erosion prevention, water purification and nursery services for fish populations are important ecosystem services provided by the Amazon basin. For example, the value of reduced siltation in hydropower reservoirs is estimated to range between US$ 60–600 million per year [38];
- at the local scale, the Amazon forest provides food and natural resources for subsistence lifestyles estimated at US$ 500 million to 1 billion per year [38]. The boom of the Açaí palm fruit in the Amazon estuary has had many and varied local implications, but is also a good multi-scale example, with an estimated economic impact on the fruit market in the region and abroad ranging from R$ 100 to 500 million per year [41,42].

discounting indiscriminately to fields where markets do not exist; (2) choosing different discount rates in different socio-economic contexts [26]; and (3) developing appropriate measures of welfare accounting, not least in the context of GDP.

TEEB advocates the need to address the links between poverty and biodiversity in macroeconomic accounting and actively promotes the development of a 'GDP of the Poor' [5•,49]: In economies where rural and forest-dweller poverty is a significant social problem, a sectoral GDP measure should be used that is focused on and adapted to the livelihoods of the rural poor. This so-called GDP of the Poor highlights the natural resource-dependent sectors, that is agriculture and animal husbandry, forestry and fishing. It builds on registered GDP from these activities but should, in a second step, assess and add non-market benefits from these sectors and ecosystem services as well, because the rural poor are especially dependent on these services. TEEB conducted three case studies, for India, Brazil and Indonesia, to test this emerging methodology. For India, the original share of agriculture, forestry and fisheries of officially registered GDP is 16.5%. By contrast, ecosystem services and non-market goods account for about 46.6% of the total income of the poor. In the Brazilian and Indonesian case studies, the difference is even more significant, from 6.1 to 89.9% for Brazil, and from 11.4 to 74.6% for Indonesia [49–52]. This shows that the rural poor's dependency on income from non-market products and services is a critical issue that needs to be factored into policy making. Thus TEEB explicitly takes interpersonal trade-offs into account as well as the distributional dimension of ecosystem services provision and differing degrees of dependence upon them among poor and rich people respectively.

The other link between ecological challenges and economics is seen in *spatial trade-offs*. The task is to reconcile the local costs and global benefits of biodiversity conservation, because the costs of conserving ecosystems and biodiversity fall mostly on local land users and communities, whereas the beneficiaries of conservation are found not only at local levels but also far beyond, at national and global scales as well [27,28]. These spatial externalities of biodiversity conservation and the provision of ecosystem services need to be properly valued in economic terms and incorporated into appropriate policy instruments. If externalities cannot be evaluated precisely in terms of their true economic costs and benefits, a rough approximation is still preferable to not valuing them at all. The onus is on policy makers to set policy targets and to design instruments that make us move in the right direction [53] (see also below).

While the scholarly literature in conservation economics has focused to a large extent on the economic valuation of natural resources, and environmental valuation has become increasingly popular among policy makers, it has also been subject to criticism, and some have issued pleas for its cautious use [54–56,57•]. However, the fundamental aim of economic valuation of ecosystem services is not to put a '$ price tag' on the environment, or its component parts, as Turner *et al.* [47] emphasise, ''but to express the effect of a marginal change in ecosystem services provision in terms of a rate of trade-off against other things people value'' (see also [58,59]). Monetary valuation builds on marginal analysis and is most meaningful when considering small, or marginal, changes in the condition of natural assets. Thus it is a matter of the substitutability of the object to be valued. If species or ecological processes are complementary to each other and not substitutable, a key requirement for marginal economic analysis is not met from an ecological perspective [60].

Uncovering the value of ecosystem components also requires an understanding of the ways in which they contribute to the production of ecosystem services. Economists need to know the shape of the ecological production function in order to derive the value of ecosystem components and their marginal impact on the production of valued goods and services [61]. Ecological production functions capture the biophysical relationships between ecological systems and the services they provide, as well as interrelated processes and functions such as carbon sequestration, predation and nutrient recycling. In contrast to economic production functions with well-studied inputs, ecological production functions involve poorly understood complex inputs, and humans have only variable and often limited control over them [13,62••]. Although there has been some progress in defining ecological production functions for specific ecosystem services, such as pollination or carbon sequestration [62••], current understanding of most ecosystem services remains limited [1,4].

Further challenges for valuation arise from our ignorance about ecosystem thresholds and uncertainties associated with the relationship between biodiversity and ecosystem services. Ecologists suggest that thresholds should be taken seriously, especially if large-scale impacts in the form of major ecosystem collapse may occur and regardless of the low probability of such events. In the context of catastrophic climate change, Weitzmann [63] has questioned the use of cost–benefit estimates, especially where large-scale impacts with low probabilities are concerned.

In addition to these ecological limitations, socio-cultural considerations may limit the range of valid cases for marginal valuation [47]. From a social or collective choice perspective, social norms and institutions are crucial for societal decision making [64]. For example, both societies and citizens may decide to put an infinite value on certain ecological goods for cultural or religious reasons, be it a species, a sacred wood or a special cultural landscape, and not expose it to a cost–benefit calculus (e.g. [65]). Alternatives and complementary methods to monetary valuation need to be kept in mind [57•,66•,67]. In the United States, where executive orders often require economic cost–benefit analyses, the Environmental Protection Agency is now actively promoting the use of a wider range of possible valuation methods, including, among others, measures of attitudes, preferences and intentions, civic valuation, decision science approaches, ecosystem benefit indicators and biophysical ranking methods [62••]. In the same vein, TEEB aims to demonstrate the full range of values of ecosystems and biodiversity, using physical measures and indicators [68] as well as highlighting the socio-cultural context of ecosystems and biodiversity valuation [42].

Both the ecological and social considerations presented make it difficult to define conservation issues through market mechanisms alone [1,5•,45,47]. Nevertheless, in order to flesh out a broader holistic economic approach that recognises the existence and significant economic effects of natural capital, we argue that shadow prices can and should be calculated and presented, in the proper context of different biomes and differing socio-economic conditions, for a wide range of ecosystem services (such as climate regulation, water provisioning, etc.) and biodiversity benefits (such as crop pollination by bees, citizens' enjoyment from visiting national parks in excess of travel costs, profits to pharmaceutical companies from new medication discovered through bio-prospecting, etc.) [5•]. In most instances the valuation of services rewarded is an important input for an effective economic solution. Economic valuation thus aids the design of institutions that provide incentives for the conservation of life-sustaining ecological systems [69,70].

Political challenges

Even if the ecological and economic challenges of evaluating biodiversity and ecosystem services can be overcome, there remains the political challenge of transferring scientific results into practical politics. Here, TEEB can contribute significantly by raising awareness and recording concrete examples.

Currently, biodiversity and ecosystem services remain largely neglected in practical policy making [71]. Decisions are made without taking biodiversity issues into account. The reasons for this neglect are many and varied. One root cause is the fact that ecosystems and biodiversity have the characteristics of a public – and often global – good (for more detail on the following, see [72]). Their benefits take many forms and are widespread, which makes it difficult to capture value and ensure that beneficiaries pay for them properly. For example, a large forest ecosystem such as the Amazon forest (see Box 1, [38]), provides local benefits to local people (timber, food and other products); the forest ecosystem mediates water flows and provides regional climate stability; and forests are globally important because they sustain biodiversity and act as carbon sinks. Existing markets capture only some ecosystem services, for example in the field of eco-tourism or water supply. However, in many cases nothing is paid for capturing these services, and those providing the benefits often receive no due recompense. Furthermore, the costs of conservation and ecosystem protection are paid immediately, while benefits often occur in the far future and present great uncertainties for decision makers. Thus decision makers are faced with just two choices: to pursue present gains with a high degree of certainty, or to pursue highly uncertain gains that might occur in the far future. These kinds of heavily imbalanced choices constitute one of the major problems that lead to biodiversity loss and the degradation of ecosystem services.

The value of economic values

The TEEB response to this political challenge is not only to acknowledge ecological services, as is done by the

Millennium Ecosystem Assessment [1], but also to give values to ecosystem services wherever possible. This step (from acknowledgement of services to their evaluation) may be seen as a small one, but in fact it is huge. This still holds even if – owing to a lack of monetised values – values can be expressed only in semi-quantitative or qualitative terms and even if the 'true' values of ecosystems and biodiversity are much higher than estimated values [73]. If we succeed in making explicit the inherent values of biodiversity and ecosystem services, this will contribute towards increasing awareness and avoiding the loss of biodiversity and the deterioration of ecosystem services.

Economic valuation can help policy makers by shedding light on the contribution made by different ecosystem services, whether directly or indirectly, and thus serve an information function. It can help overcome the systematic bias in decision making by demonstrating the equivalence of values (between man-made capital and natural capital, present and future benefits or costs, and between different resource types). It can demonstrate that even if biodiversity benefits are multi-faceted and diffuse (as in the case of forests) they can be subsumed or aggregated within broader values. Furthermore, economic analysis can help create new markets. Twenty years ago these markets did not exist; the idea of emissions trading as a market-based instrument did not find its way out of the academic ivory tower until the beginning of the 1990s. Their introduction under real-world conditions was a radical change in environmental policies [74]. This is not to say that these markets emerged as a result of economic valuation. But it does demonstrate the powerful forces that can be created by making environmental goods marketable. Today, the market for greenhouse gases is a powerful example of what can be achieved when market-based approaches are developed for environmental goods. Furthermore, economic valuation could help make future benefits visible, rather than simply relying on today's costs. One example are option values of plants from tropical forests relevant for pharmaceutical products [75,76]. Economic values could also contribute to solving poverty and social problems by making explicit the beneficiaries and burden-carriers of policy measures.

TEEB seeks to highlight the fact that there are policies that already work well, deliver more benefits than costs and are effective and efficient. It collates examples that demonstrate how economic analysis can help existing instruments work better. For example, using assessment tools to measure and compare the efficiency and cost-effectiveness of existing policies can ensure that instruments are able to exert their maximum impact [73]. TEEB shows that economic assessment can make explicit the damage caused by harmful subsidies [77]. TEEB also gives examples of the wide range of pricing instruments already in operation, such as payments for ecosystem services in Costa Rica (e.g. [78]).

In many instances, if a particular set of services is taken into account, conservation becomes more attractive than its next best use. In those instances where we suggest the use of modelled or shadow prices as inputs to an actual policy action [5•,9••,10••], the value we select is always a 'floor value'. By that we mean that our estimates are reasoned and conservative, and might have been higher had we had a more comprehensive means of incorporating future climate change impacts or had we modelled whole systems rather than aggregating individual benefits, and so on. We argue that decision makers can and should award higher values for good conservation than any 'floor values' but certainly not any lower. Once again, the ethical and pragmatic choice is not to wait for the perfect solution but to suggest a solution that points in the right direction and corrects prevailing biases.

At the same time prices or economic values have an incentive function, serving as a compass for politicians, administrators, businesses and consumers, to help them change their behaviour and reallocate their resources according to 'true' values (including biodiversity and ecosystem services). "It can be said that we are trying to navigate uncharted and turbulent waters today with an old and defective economic compass. And this is not just a national accounting problem—it is a problem of metrics that permeates all layers of society, from government to business to the individual and affects our ability to forge a sustainable economy in harmony with nature.... No matter how challenging, if we truly want to manage our ecological security, we must measure ecosystems and biodiversity—scientifically as well as economically. The economic compass that we use today was a success when it was created, but it needs to be improved or replaced" ([5•], pages 4 and 6).

Actors balance costs and benefits and they take trade-offs into account. If, for example, city A rejects alternative X and does not include areas for building in local planning, what are the costs and what is gained? Up till now these decisions have been systematically biased towards the development alternative, because no values for nature or nature's services exist. If we succeed in making these values explicit, decisions can be based on more reliable ecological and economic foundations. The two examples in Box 2 demonstrate how economic valuation of environmental services can influence decision making [72]: In Indonesia, a valuation of watershed services led to the establishment of a watershed management committee to protect the respective watershed [79]. In Uganda, monetary valuation of wetland services resulted in the decision not to drain and reclaim a wetland that provides valuable services for Greater Kampala [80,81].

Box 2 Using valuation as part of a decision support system [72]

Indonesia: The Segah watershed (Berau District) contains some of the largest tracts of untouched lowland forest in East Kalimantan (150,000 ha) that constitute the last remaining substantial habitat of orang-utans. A 2002 valuation study concluded that water from the Segah river and the nearby Kelay river had an estimated value of more than US$ 5.5 million/year (e.g. regulation of water flow rates and sediment loads to protect infrastructure and irrigation systems). In response to these findings, the Segah Watershed Management Committee was established to protect the watershed [79].

Uganda: The Greater Kampala Metropolitan Area benefits from services provided by the Nakivubo Swamp (catchment area > 40 km^2), which cleans water polluted by industrial, urban and untreated sewage waste. A valuation study looked at the cost of replacing wetland wastewater processing services with artificial technologies (i.e. upgraded sewage treatment plant, construction of latrines to process sewage from nearby slums). It concluded that the infrastructure required to achieve a similar level of wastewater treatment to that naturally provided by the wetland would cost up to US$2 million/year compared with the costs of managing the natural wetland in such a way as to optimise its waste treatment potential and maintain its ecological integrity. On the basis of this economic argument, plans to drain and reclaim the wetland were reversed and Nakivubo was legally designated a part of the city's greenbelt zone [80,81].

Box 3 Using economic valuation to determine compensation rates in India [95]

In 2006 the Indian Supreme Court set compensation rates for conversion of different types of forested land to non-forest use. It drew on an economic valuation study of Indian forests done by the Green Indian States Trust [50]. This study estimated the value of timber, fuel wood, non-timber forest products and eco-tourism, bio-prospecting, ecological services of forests and non-use values related to the conservation of certain charismatic species, such as the Royal Bengal tiger and the Asian lion, for six different classes of forests (see Table 1). Converters pay compensation to an afforestation fund to improve national forest cover. In 2009 the Supreme Court directed Rs. 10 billion (~US$ 215 million) to be released from the fund every year towards afforestation, wildlife conservation and creating rural jobs [96].

A broad set of existing and new instruments

Successful biodiversity policies are often restricted to a small number of countries, because they are unknown or poorly understood beyond these countries. However, a broad range of instruments are available, ranging from existing instruments and applications to new instruments. They include rewarding (unrecognised) benefits of biodiversity and ecosystem services, as well as aligning today's subsidies with tomorrow's opportunities, and addressing losses through regulation and pricing.

One example for developing and applying new instruments is the REDD scheme. REDD, introduced as a key climate policy instrument in 2007, is an instrument that serves not only climate purposes [21,22,82,83] but also many other ecosystem services associated with the protection of forests. By combining environmental protection with financial aid, this instrument has stimulated broader interest in payment for ecosystem services (PES) at an international level [78,84]. At the national level, however, various forms of PES have already been implemented, and the properties of PES as market-based instruments have been the subject of intense debate [85–87]. Many lessons can be learned, for example, from the case of Costa Rica, a forerunner in establishing this type of instrument [88]. Other examples of approaches that could be used more widely include green public procurement and instruments based on the polluter pays principle, for example regulatory instruments or taxes.

In addition, new markets have been created, such as that for wetland banking in the U.S. and 'BioBanking' in Australia, or trading to reduce land consumption in Germany [89–92]. In all these cases, private actors or public authorities buy credits in order to compensate for their negative impacts on wetlands, biodiversity or land use (e.g. through agriculture or building activities). While ecologists are still discussing whether lost areas and 'newly created' areas are equivalent, these instruments are attempts to provide compensation. Economic values can be immensely helpful in implementing them efficiently and effectively.

Table 1

Compensation rates for forest conversion in India

Eco-Value Class	Forest Type	Very Dense Forest	Dense Forest	Open Forest
I	Tropical Wet Ever- and Semi Evergreen; Tropical Moist Deciduous	22,370	20,100	15,700
II	Littoral and Swamp	22,370	20,100	15,700
III	Tropical Dry Deciduous	19,000	17,200	13,400
IV	Tropical Thorn and Tropical Dry Evergreen	13,400	12,100	9,400
V	Sub-Tropical Broad Leaved Hill, Sub-Tropical Pine and Sub-Tropical Dry Evergreen	20,100	18,100	14,100
VI	Montane Wet Temperate, Himalayan Moist and Dry Temperate, Sub Alpine, Moist and Dry Alpine Scrub	21,300	19,200	15,000

All values per ha, transformed to US$ and rounded.
Sources: [50,96].

Finally, broad arrays of pricing instruments are gradually gaining more and more acceptance. They range from various forms of taxes (charges on inputs, products or emissions) through tradable permits [93] to the specific design of ecological fiscal transfers between governmental levels [94]. An economic valuation study of Indian forests was the basis for setting compensation rates for conversion of different types of forested land to non-forest use (see Box 3, [95]). Economic assessment can also make explicit the damage caused by harmful subsidies. Examples of harmful subsidies may include subsidies for housing that encourage land conversion and urban sprawl in natural areas and fisheries and agricultural subsidies that are harmful to biodiversity and ecosystems [77].

To sum up, economic analysis can help make existing instruments work better. Using assessment tools to measure and compare the efficiency and cost-effectiveness of existing policies can ensure that instruments are able to exert their full potential impact, while economic valuation of biodiversity and ecosystem services is an important step towards transferring 'values' to the policy process.

Conclusion

Society's over-reliance on markets to deliver the goods and services we need for our well-being, along with our almost total dependence on market prices to indicate value, means that society does not measure or manage the economic value that is exchanged in ways other than through markets, such as the public goods and services that comprise a large part of nature's flows to humanity. Society generally also ignores third-party effects of private exchanges (so-called 'externalities') unless they are actually declared illegal. Finally, society has not learnt to live in harmony with nature or to adopt a caring stewardship role rather than its current relatively careless role as extractor of resources.

There is ample evidence of the human and economic costs of biodiversity loss and ecosystem degradation, quite apart from the ecological costs in terms of worsening ecosystems and lost biodiversity. These costs are being felt now, and have been felt for much of the past half-century.

However, the identification and valuation of these costs are associated with ecological, economic and political challenges. The ecological challenges stem partly from a lack of knowledge about ecosystem services – in particular the relationship between biodiversity, ecosystem functions and ecosystem services – and partly also from uncertainties about ecological trade-offs and thresholds that are still poorly understood in many fields. The economic challenges comprise the development and application of adequate evaluation tools, which also includes solving difficult ethical aspects, such as discounting, or the proper inclusion of people's rights. A wide range of instruments exists for translating results into practical politics. The concrete process of putting these instruments successfully to work can help set biodiversity concerns on a broader stage. TEEB has been set up to contribute to the resolution of challenges in all three regards: identifying needs for further ecological research, contributing to the debate on suitable economic methods and discount rates and illustrating, through real-world examples, how the conservation of biodiversity and ecosystem services can help contribute more effectively towards delivering human well-being.

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