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Essay

Valuing Ecosystem Services in Terms of Ecological Risks and Returns

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Abstract: *The economic valuation of ecosystem services is a key policy tool in stemming losses of biological diversity. It is proposed that the loss of ecosystem function and the biological resources within ecosystems is due in part to the failure of markets to recognize the benefits humans derive from ecosystems. Placing monetary values on ecosystem services is often suggested as a necessary step in correcting such market failures. We consider the effects of valuing different types of ecosystem services within an economic framework. We argue that provisioning and regulating ecosystem services are generally produced and consumed in ways that make them amenable to economic valuation. The values associated with cultural ecosystem services lie outside the domain of economic valuation, but their worth may be expressed through noneconomic, deliberative forms of valuation. We argue that supporting ecosystem services are not of direct value and that the losses of such services can be expressed in terms of the effects of their loss on the risk to the provision of the directly valued ecosystem services they support. We propose a heuristic framework that considers the relations between ecological risks and returns in the provision of ecosystem services. The proposed ecosystem-service valuation framework, which allows the expression of the value of all types of ecosystem services, calls for a shift from static, purely monetary valuation toward the consideration of trade-offs between the current flow of benefits from ecosystems and the ability of those ecosystems to provide future flows.*

Keywords: conservation policy, ecological risk, economic valuation, ecosystem services, value theory

Valoración de los Servicios del Ecosistema en Términos de Riesgos y Beneficios Ecológicos

Resumen: *La valoración económica de los servicios del ecosistema es una herramienta política clave para detener la pérdida de diversidad biológica. Se propone que la pérdida de la función del ecosistema y de los recursos biológicos en los ecosistemas se debe en parte al fracaso de los mercados para reconocer los beneficios que los humanos obtienen de los ecosistemas. La asignación de valores monetarios a los servicios del ecosistema a menudo es recomendada como un paso necesario para la corrección de tales fallas del mercado. Consideramos los efectos de la valoración de los diferentes tipos de servicios del ecosistema en un contexto económico. Sostenemos que el aprovisionamiento y la regulación de los servicios del ecosistema generalmente son producidos y consumidos de modo que los hace sensibles a la valoración económica. Los valores asociados con los servicios culturales del ecosistema se encuentran fuera del dominio de la valoración económica, pero su precio puede ser expresado por medio de formas de valoración ponderativa, no económica. Argumentamos que los servicios de soporte del ecosistema no tienen valor directo y que las pérdidas de tales servicios se pueden expresar en términos de los efectos de su pérdida sobre el riesgo para el aprovisionamiento de los servicios valorados del ecosistema que soportan. Proponemos un marco heurístico que considera las relaciones entre riesgos y beneficios ecológicos en el aprovisionamiento de servicios del ecosistema. El marco propuesto para la valoración de los servicios del ecosistema, que permite la expresión del valor de todos los tipos de servicios del ecosistema, requiere un cambio de la valoración estática, puramente monetaria, hacia*

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la consideración de los pros y contras del flujo de beneficios que proporcionan los ecosistemas y la habilidad de esos ecosistemas para proporcionar flujos en el futuro.

Palabras Clave: política de conservación, riesgo ecológico, servicios del ecosistema, teoría del valor, valoración económica

Introduction

Some ecosystem services, such as the provision of food, fuel, and fiber, have long been valued through markets. Nevertheless, until the 1960s the nonmarket benefits derived from ecosystems were not valued explicitly. Early valuations were derived from revealed-preference methods (e.g., Krutilla 1967), in which the prices of market goods consumed in conjunction with the nonmarket good are used to reveal the value of the resources of an unknown price (e.g., Clawson & Knetsch 1966; Smith 1975). In the 1970s the direct questioning of an individual's willingness to pay for some good, known as stated-preference methods, began to be developed (e.g., Randall et al. 1974; Bennett 1984). The development of the concept of "total economic value" in the 1980s (e.g., Randall 1987; Pearce & Moran 1994) provided a framework for including indirect use and nonuse values when valuing nature (Dziegielewska 2009) and therefore provided a framework for identifying all the types of utilitarian value associated with ecosystems.

The introduction of the concept of ecosystem services, as the conditions and processes through which ecosystems benefit humanity (MEA 2003), in the 1990s provided a means of conceptualizing the relations between ecosystem structures and functions and the benefits humans derive from them (e.g., Ehrlich & Ehrlich 1992; Daily 1997) and hence a means of systematically assessing the sources of value provided by ecosystems. The Millennium Ecosystem Assessment (MEA 2003) identified these relations at a global scale, which helped move valuation from the assessment of individual aspects of nature—for example, the value of deer for recreation—to understanding the various ways ecosystems maintain and improve human well-being.

The MEA conceptual framework is now being used to place monetary unit values on ecosystems (e.g., TEEB 2008) because it allows for the multiple benefits highlighted in the MEA to be aggregated under a single metric. Aggregating ecosystem service values to estimate the "total value" of an ecosystem is appealing because it simplifies the ability of conservation professionals to inform decisions about management of ecosystems (Ehrenfeld 1988). Nevertheless, the application of the economic framings of value developed for the valuation of individual aspects of nature to multiple interconnected ecosystem services is fraught with difficulties.

The theoretical assumptions inherent in these economic framings of value are challenged by the potential incomparability of the different values associated with ecosystems (e.g., O'Neill 1993; Ludwig 2000) and the application of economic models to complex, dynamic ecosystems (e.g., Chee 2004; Norton & Noonan 2007; Farley 2008). It is therefore important to consider where such economic framings may be inappropriate when applied to the unique characteristics of ecosystem services. In this context the primary objective for ecosystem-service valuation is to quantify the values associated with particular sets of ecosystem structures and processes. If the theoretical assumptions inherent in the framings of economic value (developed for market goods and services) result in valuations of nonmarket ecosystem services that do not reflect the values humans associate with those services, then the primary objective of the valuation process cannot be met and the valuation process cannot be considered appropriate.

Assumptions of Economic Valuation

The transition from valuing specific aspects of nature to the comprehensive valuation of ecosystems in terms of the services they provide has required increasingly interdisciplinary work (Norton & Noonan 2007). Nevertheless, a framing of the value of ecosystems (and the assumptions underlying the framing) that is understood and accepted by both conservation professionals and economists has not been developed. For example, economic theory assumes that if an activity increases human welfare—the sense of pleasure or well-being (Bockstael et al. 2000)—then it is of value. From this utilitarian perspective ecosystems are deemed valuable because they provide environmental goods and services to humans (Costanza et al. 1997). Unlike deep ecology and Kantian ethics, a utilitarian framework does not accommodate the concept of intrinsic value—that an object has value for its own sake (Zimmerman 2001; O'Neill 2003). Yet the concept of intrinsic value has long been the focus of philosophical arguments for conservation (Vilkka 1997).

As well as a utilitarian framing of value, economic valuation includes three key assumptions about the meaning of *value* and the assignment of value to goods and services: value can be ascribed, value should be measured at the margin, and value can be expressed in terms of exchange. Although these assumptions are generally well founded in the context of market goods, they do not necessarily hold true when applied to nonmarket ecosystem services.

Values Can Be Ascribed

Brown (1984), building on the work of Rescher (1969), categorized values as functional, held, or ascribed. Functional values are nonpreference-based values derived from a quantification of the biological or physical relation of one entity to another, for example, the value of nesting habitats for birds. Such values are free from human preferences and as such are outside the realm of valuation. Held values are deeply held first-order preferences that influence subsequent, second-order preferences. First-order preferences form the conceptual basis for decision making, and second-order preferences are the real-world choices that flow from those first-order preferences. For example, the idea of sustainability (a first-order preference) may affect consumption choices (a second-order preference). As such, first-order preferences exist in the conceptual realm of ideas and ideals, whereas second-order preferences exist in the objective realm of choice and action.

Held values, such as ideas of justice, identity, and freedom, are difficult for individuals to quantify. Attempts to do so tend to result in valuations that lack legitimacy in the eyes of the public (Vatn & Bromley 1994). Ascribed (or assigned) values are second-order preferences, generally associated with goods or services that individuals are prepared to ascribe relative values to and make trade-offs between (Brown 1984).

Humans attach held and ascribed values to ecosystems, but the economic framing of value requires a shift in perspective away from held values, which are exemplified by Leopold's land ethic (Leopold 1949), to an entirely ascribed valuation framework, regardless of whether individuals are willing to ascribe economic value to particular ecosystem services. Moreover, the ascription of economic values requires individuals to quantify the benefits they derive from ecosystem services. In this context a distinction can be made between ecosystem services that provide direct benefits to humans (e.g., provision of clean water) and those that are indirectly beneficial in that they create conditions that allow the provision of the directly used services (e.g., role of nutrient cycling in food production). The ascription of value to indirectly useful services can be problematic because it is not always obvious to individuals what the benefits of those indirect services are.

Valuation Is Undertaken at the Margin

Marginal utility is the additional satisfaction gained from consuming an additional unit of a given good or service. It recognizes the role of scarcity in setting exchange value (Barnett 1963). For example, diamonds command a higher market price than water. The first units of water consumed are of very high value, being necessary for survival. Because water is abundant, however, additional units are used for activities with less marginal utility and are therefore of less value. The marginal utility of the next unit of abundant water is thus lower than the marginal utility of relatively scarce goods such as diamonds (Samuelson & Nordhaus 1989).

Many ecosystem-services valuations are not undertaken at the margin; that is, it is not the value of the next unit of the service to be consumed that is valued. Where marginal value is used to value an ecosystem service, the most common approach is to calculate value on a unit-by-unit basis. Aggregating per unit (e.g., hectare) values to estimate total value is difficult because the marginal value depends on the relative scarcity of the service (Daly 1998). For example, allowing access for recreationists in a forest for the first time may diminish the recreational value of nearby forests because the sites will be competing for visitors. Therefore, although spatially explicit valuation of ecosystem services is useful, it is insufficient if the values do not reflect how spatial dependence and scarcity affect marginal value. Moreover, despite the importance of marginality in economics, not all ecosystem services can be valued at the margin. Some services cannot easily be split into discrete units of consumption (e.g., cultural services providing spiritual value) and are more appropriately valued in some form of aggregate (Sagoff 2008).

Value Is Measured in Terms of Exchange

Exchange value represents the quantity of other goods or services that a given good or service can be exchanged for, if traded in the market. It provides a common unit to express the trade-offs between different factors that contribute to human welfare (Brown et al. 2007). Nevertheless, not all the values associated with ecosystems can be captured with a single metric (Farley 2008).

Economic valuations are expressions of either hypothetical or real market values and imply potential for substitution (Ludwig 2000), under the assumption that the values of services "in use" and "in exchange" are equivalent. This holds true for market goods and services. In fact, the use value of some goods (such as cut diamonds) depends largely on the ability to exchange them for something useful (such as water). These assumptions of equivalency and substitution, however, fail when valuing irreplaceable ecosystem services.

Other ecosystem services also should not be valued in exchange. Exchange value implies private ownership (the right to exchange) and requires the valued good or service to exist in some form of scarcity (Lauderdale 1819). Many ecosystem services (such as climate regulation) are public goods with value in use irrespective of whether scarcity makes them valuable in exchange. Increased scarcity of a previously abundant ecosystem service may diminish its value in use, while increasing its marginal exchange value (Day et al. 2009). In such cases there is a divergence between exchange and use values and exchange valuations may be misleading in relating ecosystem service provision to human well-being.

The livelihoods of the rural poor are particularly dependent on the provision of ecosystem services (Landell-Mills & Porras 2002). Yet aggregate exchange valuation cannot easily account for the uneven distribution of costs and benefits relating to the provision of ecosystem services (Howarth & Farber 2002; Corbera et al. 2007). Additionally, exchange value does not differentiate between those services that meet wants (e.g., the provision of space for recreation) and those that meet needs (e.g., provision of food or survival). Hence, exchange value is not necessarily always an appropriate metric for expressing the linkages between ecosystems and human well-being.

Expressing the Values of Ecosystems

Before an ecosystem services valuation is undertaken, a process is required to define the values being sought and the appropriate means by which these values will be expressed. For example, Howarth and Farber (2002) argue for the use of discourse-based valuation methods to capture aspects of value that are not easily expressed through individual preferences, whereas Wallace (2007) notes that ecosystem services are hierarchical and direct trade-offs are not always possible among sets of ecosystem services. Building on these debates, we examined whether it is appropriate to apply the assumptions of economic valuation: that values are ascribed, measured at the margin, and expressed in terms of exchange to different types of ecosystem services. We used the MEA ecosystem services typology of *cultural*, *provisioning*, *regulating*, and *supporting* services (MEA 2003). As with any such typology it draws artificial boundaries between services. Food, for example, serves both provisioning and cultural needs and wants. Nevertheless, these classifications are useful in distinguishing clusters of service types with broadly shared characteristics. We suggest means of expressing the value of these different types of ecosystem services and emphasize the dependence of cultural, provisioning, and regulating services on the supporting ecosystem services that enable them.

Cultural Services

Cultural services provide nonmaterial benefits through spiritual enrichment, cognitive development, and aesthetic experience (MEA 2003). The framing of cultural value is based on nonconsumptive and intangible human values, such as identity (Ioras et al. 2009), aesthetics, inspiration (Sodhi et al. 2010), spirituality, and sense of place (Raymond et al. 2009). Thus, we suggest that cultural services represent conceptual, first-order, held values rather than second-order, object-oriented, ascribed values that are associated with economic preferences.

Whereas recreational activities—classified as cultural services in the MEA—may often be nonconsumptive and have cultural significance, the dominant recreational service provided by ecosystems is the material provision of spaces and resources for active use. Moreover, the values associated with recreation are generally second-order, objective preferences. For example, individuals are willing to make trade-offs between the recreational amenities provided by different spaces and the expense involved in accessing them. For these reasons, we classify recreation as a provisioning rather than cultural service.

Cultural services cannot easily be split into the discrete units required for marginal valuation (Trainor 2006). This is to some extent reflected in the development of valuation approaches to estimate preferences for conservation of ecological or cultural assets. Increasingly, such work seeks to identify the value of conservation programs defined in terms of expected conservation outcomes, such as the degree of protection provided by the program, potential visitor restrictions, and the financial implications of implementing the program, rather than directly estimating unit values of marginal changes in the asset (e.g., Horton et al. 2003). Such economic valuations of changes to cultural ecosystem services can provide useful information (e.g., to evaluate sets of competing conservation strategies). Nevertheless, original surveys are often not available for each policy or management decision, and applying these economic values outside the context in which they were expressed to aggregate cultural value with the marginal valuations of other ecosystem services is problematic.

Moreover, cultural values are not primarily expressed in terms of their exchange value. For example, the Burra Charter, which defines the basic principles and procedures to be followed in the conservation of heritage sites, proposes a typology of cultural value based on aesthetic, historical, scientific, and social values (ICOMOS 1999). Deliberative, noneconomic valuation methods (Wilson & Howarth 2002; Spash 2007) may therefore be more appropriate for expressing the value of cultural ecosystem services than context-free, marginal, economic valuations. We suggest that the expression of cultural values, including conservation value, in these noneconomic terms would complement the purely ascribed, utilitarian values expressed through the economic valuation of ecosystems.

Provisioning Services

Provisioning services are directly used goods and services, including genetic resources, food, fiber, freshwater, and space for recreation (MEA 2003). Individuals can ascribe values to provisioning services, and the services are generally amenable to marginal economic measurements. Many of the goods that flow from these services already have or can be ascribed market prices. Although existing market prices may not accurately reflect all the costs and benefits associated with the consumption of those goods, they do represent aggregate, second-order ascribed preferences consistent with the theoretical assumptions of economic valuation.

Nevertheless, there may be situations in which a high marginal value of a provisioning ecosystem service does not necessarily result in incentives for conservation. For example, bioprospecting—the mining of genetic information for pharmaceutical or other industrial uses—is seen as an important source of value provided by ecosystems (Rausser & Small 2000). Yet it is not clear that this potentially valuable service has led to greater levels of biological conservation in ecosystems in which bioprospecting occurs (Burtis 2007). The economic value of the first hectare within which the genetic information is found is, in theory, very high (Farnsworth & Soejarto 1985). Once the genetic information has been captured, however, subsequent lands containing the same genetic information have effectively zero bioprospecting value. So, although the provisioning of genetic information provides significant potential-use values for societies, bioprospecting is unlikely to provide much practical impetus for large-scale conservation efforts.

Regulating Services

Regulating services are ecosystem processes, including the regulation of climate, water, and the spread of diseases (MEA 2003). Individuals are generally willing to ascribe values to such services and to express them in exchange terms, although the benefits they provide are often not obvious and are therefore difficult to ascribe value to. For example, the regulation of diseases by ecosystems may only become apparent once that service has been lost. Some regulating services, such as pollination and the regulation of water, may be characterized as being of indirect use because they provide the conditions (e.g., pollinated crops and the absence of unwanted flooding, respectively) that allow other directly used ecosystem services (e.g., provision of food) to exist. Nevertheless, it is often useful to place market values on these indirect services. For example, the economic value of pollination in agricultural systems (e.g., Allsopp et al. 2008) might inform decisions about conservation of rapidly declining pollinator populations.

Even when it is relatively easy to ascribe economic values to regulating services, it may be inadvisable, from a conservation perspective, to value them in isolation. Some regulating services of high economic value are not dependent on the maintenance of diverse ecosystems (Redford & Adams 2009). For example, a dense monoculture of fast-growing trees may absorb more carbon dioxide (regulation of climate) and therefore be more economically valuable than a plantation of trees of different species that are less densely planted. On the basis of current economic criteria, it may make sense to manage ecosystems to optimize carbon storage. It does not necessarily follow that biological diversity—all levels of biological organization, including their structures, composition and functions—will be maintained.

Moreover, there may be nonlinearities in the relations between ecosystem structures and the provision of some regulating ecosystem services under which marginal changes in ecosystem structures result in abrupt changes in ecosystem services (Limburg et al. 2002). To rely on (fixed) marginal exchange values for such services may lead to inaccurate estimation of their stability and their importance in maintaining human well-being. This is a particularly important issue where the cost of replacing regulating services, such as the storm protection provided by mangroves, may be so high as to make the ecosystem effectively irreplaceable. In such cases, we argue that it is more appropriate to classify and value regulating services as supporting services.

Supporting Services

Supporting services are defined as the services necessary for the production of other types of ecosystem services (MEA 2003). Examples of supporting services include the production of atmospheric oxygen, soil formation, nutrient cycling, and ecosystem resilience (i.e., the capacity of a system to withstand disturbances without a qualitatively change in system state [Gunderson & Holling 2002]). Supporting services are not generally associated with held values. Rather they are associated with ascribed values that are difficult to express in economic terms.

Supporting services are of indirect use. They support the services that directly affect human well-being and cannot be valued independently. For example, the value of crop production (provisioning service) to a farmer can be defined as the profit derived from the sale of the crop. This profit is in part dependent on the "free" nutrient cycle (supporting service). The value of the nutrient cycle is therefore included in the value of the provisioning service. Due to double counting—an accounting error whereby a cost or benefit is counted more than once—the economic values of indirectly used services cannot be aggregated with the economic values of the directly used services that they enable (Fisher & Turner 2008).

Small changes in ecosystem structure may lead to substantial changes in supporting services and the services they in turn enable (Limburg et al. 2002; Chee 2004). This complexity calls into question the appropriateness of attempting to value such services at the margin. Moreover, some supporting services, such as soil formation, are poorly understood by the public, which creates a cognitive gap between marginal changes in the service and an individual's ability to identify and value the effects of those changes (Vatn & Bromley 1994).

This cognitive gap often leads to the use of replacement cost—the market price of providing an equivalent service—to value supporting services. For example, in one study over half of the estimated value of global ecosystems services (US$17 trillion/year) was derived from the replacement cost of nutrient cycling (Costanza et al. 1997). If, as is the case for nutrient cycling, there exists no replacement service at the global scale, then it is inappropriate to value the existing ecosystem service at this extent in terms of exchange value.

A Risks and Returns Framework for Valuing Ecosystem Services

Consider, for example, that there is a choice between the retention of a mangrove stand and its removal to provide space for shrimp farming. The retention (i.e., conservation) option is likely to generate relatively low risks and relatively low returns for the owners. The shrimp-farming option provides higher returns for the owners, but increases the risk of human fatalities in a storm and storm damage to property and livelihoods of people living in the area. These kinds of risk and return trade-offs are inherent in real-world decision-making, but are not reflected in current approaches to ecosystem-service valuation.

Recently there have been attempts to use insurance value—the value derived from the reduction of risk to which an individual is exposed—as a measure of ecosystem resilience (Baumgartner 2007; Vergano & Nunes 2007). We contend that changes in any supporting ecosystem service can be expressed in terms of ecological risk—the likelihood of a decrease in the provision in directly used ecosystem services as a function of changes in the provision of the supporting service. This approach acknowledges that the value of supporting services depends on the value of the other ecosystem services that they enable.

Risk has a prescriptive component that describes the causal relations between the level of potential damage to a system (the hazard) and the likelihood of that damage (the exposure) occurring (Chicken & Posner 1998). In the context of ecosystem-service provision the hazard is determined by the value of the cultural, provisioning, and regulating services enabled by the supporting ecosystem services. Exposure can be expressed in terms of the likelihood that changes in the provision of supporting services will reduce the provision of other valued ecosystem services.

Nevertheless, risk is also socially constructed in that it depends on human preferences toward risk taking. Therefore, although scientists can describe the hazards and exposure there is still a need for individuals and societies to express their preferences for different levels of risks and returns in the management of ecosystem services. Judgments about individual and societal risks may be disconnected (Tyler & Cook 1984) and require different spatial and temporal frames. Therefore, the quantification of societal risk requires a more sophisticated approach than the simple aggregation of individual preferences for, and perceptions of, risk. This represents an opportunity to move away from the assumption inherent in purely economic valuation that societal preferences are simply the sum of individual preferences.

Quantifying the exposure aspect of ecological risk is difficult for many of the same reasons (e.g., cognitive gaps, complexity, thresholds) associated with assigning economic values to supporting services. Nevertheless, exposure can be expressed as a range of probabilities over a given time period that the level of a service will decrease. Although this may result in a qualitative rather than quantitative description of risk, we suggest it is essential to emphasize the interdependence of ecosystem services in the further development of methods to value supporting services.

Quality of Provision and Risk

In a sense, application of a risks and returns framework expresses the quantity or flow of ecosystem services as the economic and cultural returns from directly used services and the quality or stock of the ecosystem as the ability of the ecosystem to provide those returns into the future. In contrast, per-unit valuation of ecosystems leads to either stock valuations (value per unit area) or flow valuations (value per unit area per year).

Fixed stock or flow valuations that do not reflect the spatial context and quality of the site and relative abundance of such sites are, in isolation, of limited use to inform decision making. For example, placing a monetary value per unit area on wetlands provides no information regarding the monetary value of potential management changes to the wetland. Fixed, per-area valuations may unintentionally imply a binary choice between the existence of an area of the valued wetland and some alternative ecosystem state that has, effectively, been ascribed no value. In practice, ecosystem structures are often purposefully altered—rather than disappearing unit by unit—to increase the economic value the ecosystem provides (e.g., agricultural intensification in agricultural ecosystems). The value of such changes cannot be captured with a single monetary valuation of an area.

Changes to ecosystem structures intended to enhance provisioning services may also alter supporting ecosystem services and may decrease the probability of future provision of directly valued services. A risks and returns valuation framework allows for the expression of this increased risk and acknowledges that directly valued ecosystem services depend on the continued provision of

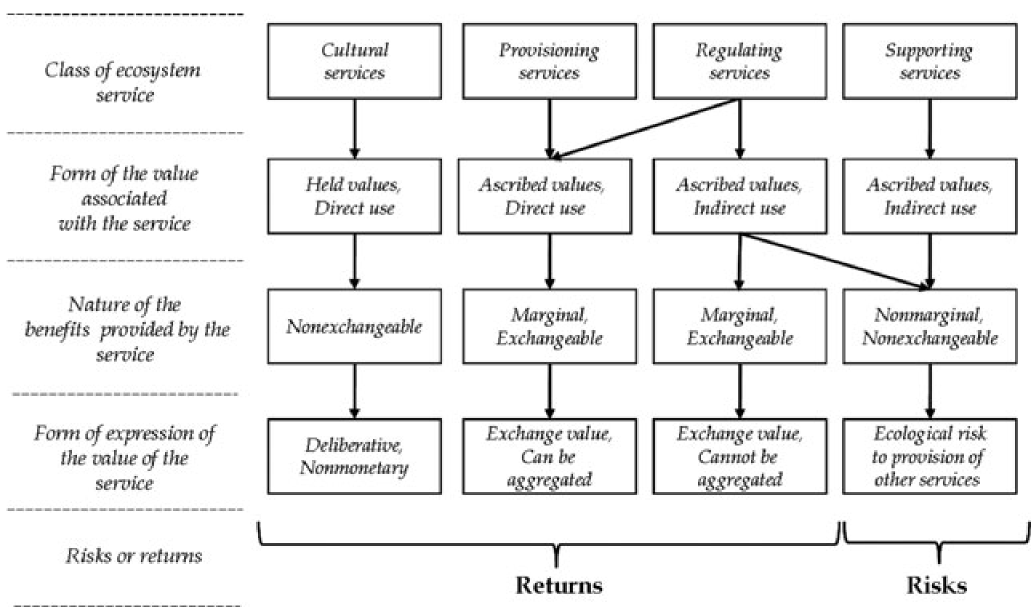

Figure 1. A heuristic framework for expressing ecosystem-service values.

supporting services. Most economic valuations are static and do not capture either the dynamic nature of ecosystems or the potential cascade of biological and social consequences that may result from changes to ecosystem structures. In contrast, a risks and returns framework does allow consideration of the dynamic consequences of changing ecosystem structures (on dependent ecosystem services) at a range of temporal scales (Landis 2003).

Results of recent studies suggest that potential trade-offs between the conservation of biological diversity and the management of ecosystems for ecosystem services provision may be relatively small (Chan et al. 2006; Nelson et al. 2009). The extent to which these potential trade-offs might be exacerbated by a narrow focus on the management of the directly valuable ecosystem services is not well understood. A risks and returns valuation framework that allows for all types of ecosystem services to be valued within a single consistent framework may help avoid the management of only those ecosystem services most amenable to traditional economic valuation.

Our simple heuristic framework can be used to consider the appropriate expression of the value of multiple, interdependence ecosystem services on the basis of characteristics and forms of value associated with each type of service (Fig. 1). This framework is based on consideration of four factors. First, whether the values associated with the service are held or ascribed. Second, whether the service is directly or indirectly used. Third, whether the benefits derived from the service are amenable to marginal valuation and, fourth, whether the benefits derived from the service are exchangeable. We suggest that the value of ecosystem services can be expressed either in deliberative nonmonetary terms, as economic exchange values that can or cannot be aggregated or in terms of ecological risk.

Conclusion

The economic rationale for valuing ecosystems is to maximize the benefits societies derive from interactions with ecosystems through the efficient allocation of scarce natural resources between competing, potentially beneficial uses. Nevertheless, the assumptions inherent in economic valuations may not be appropriate when applied to ecosystem services. We suggest that valuations of ecosystems should reflect both the economic and cultural benefits derived from human–ecosystem interactions and provide an indication of the ability of the ecosystem to provide these benefit flows into the future.

Only valuing provisioning and regulating services—the types of ecosystem services amenable to economic value—may lead to the management of ecosystems to optimize the delivery of those economically valued services. Placing more emphasis on the concept of ecological risk—expressed in terms of the likelihood that losses of supporting services will result in losses of economically and culturally valued ecosystem services—may help clarify trade-offs between the drive for short-term economic gains and the desire for long-term conservation of ecosystems and the services they provide.

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