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Methods

Valuing ecosystem services on the basis of service-providing units: A potential approach to address the 'endpoint problem' and improve stated preference methods

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ABSTRACT

Standardized methods are required to measure ecosystem services in order to value them. In this paper, we argue that the service-providing unit (SPU) concept may help achieve this objective by promoting the systematic quantification of the key components of nature that provide services (e.g., population density of a key pollinator) and linking these with measurable outcomes for human well-being. We discuss and provide examples of the potential role of the SPU concept in improving economic valuation of ecosystem services. Further, we suggest the concept may contribute to addressing the endpoint problem, which can be defined simply as the inability of researchers to communicate the implications of environmental change in a way that is understood by a broad cross-section of society. The endpoint problem is of particular relevance to stated preference approaches, and we discuss the capacity of the SPU concept to refine these approaches. We argue that the concept enhances interdisciplinary collaboration, promoting more validated, well-informed valuation applications. It also has the potential to minimize 'warm glow effects' and put the notion of marginal changes in the provision of ecosystem services in a new light.

1. Introduction

This paper outlines the need for standardized methods to measure ecosystem services in order to value them. It highlights the importance of the related concepts of service-providing units (e.g., the number of dung beetles in a paddock required for decomposing animal waste) and ecosystem service providers in aiding the quantification and ultimately valuation of services (Luck et al., 2009). The significance of ecosystem services to humanity was emphasized strongly by the Millennium Ecosystem Assessment (MEA, 2005), although recognition of the value of nature to society has a long history (Krutilla, 1967; Westman, 1977; Ehrlich and Ehrlich, 1981; Mooney and Ehrlich, 1997). In general terms, ecosystem services can be defined as the benefits humans obtain from nature (Daily, 1997).The MEA (2005) classified them into the following four categories: provisioning services (e.g., food and water); regulatory services (e.g., water regulation); cultural services (e.g., recreation); and supporting services needed for the production of all other services (e.g., nutrient cycling). Fisher et al. (2008) argued that this typology does not facilitate easily the economic valuation of services. They proposed that ecosystem services should be defined as "…the aspects of ecosystems utilized (actively or passively) to produce human well-being" (Fisher et al., 2008, p. 2051; also see Boyd and Banzhaf, 2007) and suggested classifying services as intermediate and final (e.g., pest control in orchards is an intermediate service while provision of fruit is the final service; see further discussion below).

The ecosystem service concept has gained prominence in the ecological and economic literature, especially recently (Vandewalle et al., 2008). For example, Perrings (2006) identified increasing interest in the topic since publication of the MEA, finding that one fifth of all the papers published in *Ecological Economics* on ecosystem service valuation have either appeared or were due to appear in 2006. Fisher et al. (2008) identified over 1165 peer-reviewed papers that included keywords related to ecosystem services, of which more than 60% appeared after 2003.

In ecosystem service assessments, ecologists focus on the system and organism characteristics required to deliver services (e.g., Kremen, 2005; Balvanera et al., 2006; Diaz et al., 2007) while economists tend to explore various techniques to determine the value of services to humanity (Pagiola et al., 2004; Barbier, 2007; Knoche and Lupi, 2007; Swintona et al., 2007; Tong et al., 2007; Ingrahama and Foster, 2008; Tianhong, 2008). Despite the burgeoning interest in ecosystem services, there are currently no widely accepted methods to include services in conservation assessments (Turner and Daily, 2008).

To help society make informed decisions about the appropriate use of natural resources, we need a framework that links the quantification of ecosystem services to societies' needs. By quantification we mean determining, for example, the number, type or density of organisms or the area or location of ecological systems required to provide a given

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service(s). This is a factor of complex interactions between the ecology of service-providing species and the needs of service beneficiaries — and is subject to variation through environmental or economic fluctuations, or socio-cultural change.

The quantification of ecosystem service providers has to be properly communicated to decision makers and, in the case of stated preference approaches, to respondents. With this aim, stated preference valuation techniques use a range of conceptual and visual stimuli to define and communicate changes in ecosystem service provision (Carson and Mitchell, 1993; Corso, 2001; Gail et al., 2007; Bateman et al., 2009). The quest for missing ecosystem values though has distracted attention from the equally important quest for missing ecosystem quantities. Quantification of how ecosystems provide services and the comprehension or 'evaluability' of that information is a prerequisite for economic valuation. Nevertheless, appropriate quantification is lacking due in part to the complexity of ecosystems and the 'public good' nature of services.

The challenge of developing an interdisciplinary model of the delivery and value of ecosystem services to humans is portrayed by Boyd (2007) as the 'endpoint problem'. In general, endpoints are the final outputs of scientific modeling taken one step further towards, and establishing a link with, the choice-related behavioral analyses (Simon et al., 1998; Rogers and Biggs, 1999; Suter et al., 2004). In that sense, endpoints are the channels through which 'science speaks to policy'.

In this paper, we briefly summarize the endpoint problem and the challenges it raises for adequate valuation of nature and the services it provides to humans. We then argue for the importance of a quantifiable 'unit' in improving our understanding of the relationships between ecosystem dynamics, services and their valuation. Explicit quantification of the links between service provider characteristics (e.g., dispersion) and service provision is lacking in ecosystem service valuation approaches, particularly those involving stated preferences.

To tackle this issue, we advance the ecological concept of a service-providing unit (SPU) as a potential avenue for improving the economic valuation of nature and addressing the endpoint problem. Here, we are focusing primarily on biophysical units (e.g., the area of a particular vegetation type required to regulate water flow). Finally, we argue that the SPU concept could also improve stated preference valuation methods if applied in making the link between biophysical indicators and human well-being explicit.

2. The Endpoint Problem

Boyd (2007, p. 27) defines ecological endpoints as "…concrete statements, intuitively expressed and commonly understood, about what matters in nature." He uses the analogy of health endpoints, whereby the effects of changing air quality are communicated to the general public through the common language of number of asthma attacks or variation in life expectancy rather than highly technical concepts such as, for example, oxygen transfer rates. Hence, the endpoint *problem* arises when researchers [scientists] are unable to communicate the implications of change in a way that is understood by a broad cross-section of society, potentially resulting in policy-makers ignoring the need for action.

This is nowhere more apparent than in the risk assessment and communication field; a field characterized by an endless quest for adequate endpoints in assessing and communicating risks to the public and decision makers in a policy-relevant form (Suter, 2000). Within the framework of environmental performance assessment, ecological endpoints would ideally provide us with a solid conceptual translation of ecosystem realities into welfare-related social effects. The endpoint problem arises when both biophysical and social sciences do not deliver such a conceptual translation and this is a serious barrier in the development of a consistent and policy-relevant application of non-market valuation methodologies.

Boyd (2007, p. 28) suggests ecological endpoints have the following general characteristics: i) they are purely biophysical; ii) they are concrete, tangible and measurable; and iii) they are directly connected to human well-being. An example is a 100,000 ha forest at the head of a water catchment that plays a critical role in water purification and improving water quality for the benefit of downstream users.

Boyd (2007) argues that ecological endpoints are the result of ecosystem processes and functions, rather than the functions themselves. This has an element of circularity in that the endpoint of various processes (e.g., a forest) will contribute to other processes (e.g., water filtration) leading to subsequent endpoints (e.g., healthy fish populations). The key point is to focus on and measure those components of nature that can be readily linked to human well-being (and not get bogged down in nature's complexity), match quantitative changes in these components [units] with measurable changes in well-being, and convey the implications of ecosystem change for society in easily understandable terms.

3. The Desperate Need for a 'Unit' in Economic Valuations of Nature

Paraphrasing Karl Marx,[1] the wealth of ecosystems presents itself as "an immense accumulation of ecosystem services, its unit being a single ecosystem service. Our investigation must therefore begin with the analysis of an ecosystem service." The underlying ecosystem processes giving rise to services are complex, dynamic functions of biotic and abiotic factors, not completely understood by scientists and often ignored by decision makers. It is not surprising that the reality of a complex nature is often invoked to deny the expediency of valuing ecosystem services through subjective, individual preferences (Ludwig, 2000; Farber et al., 2002; Limburg et al., 2002; Chee, 2004). In a similar vein, Gregory et al. (1993) denies the existence of well-defined and stable environmental values because of the complexity and unfamiliarity of environmental goods. Vatn and Bromley (1995) commenting on Gregory conclude: '...thus the elicitation procedure may serve as a means to construct preferences rather than merely uncover them' (p. 8). Under these circumstances, the necessity to connect quantitative changes in ecosystems with changes in human welfare remains a challenge for environmental economists.

Since the very beginning of environmental valuation in the 1960s, economic theory engaged methods and tools applied in the wider socio-economic research area in order to study human choices in some form of market-related (surrogate, hypothetical or experimental) transactions for environmental goods (Smith, 1996; Carson, 2007). Economic values reveal themselves through choice. Choices sometimes involve exchange transactions and these in turn rely on standardized units of account. Deriving credible estimates of nature's social worth in contexts where there are either no apparent markets or very specific ones remains a practical problem associated with ecosystem valuation. The aim of valuation approaches is to study how people themselves perceive and value changes in ecosystem services. In doing so, economists take for granted the analytical legitimacy of drawing very simplified pictures of the natural world when investigating market activities and the consequences of economic behavior (Skourtos, 1998).

One central merit of functioning markets is that they define the object of trade and its unit of measurement in a generally acceptable way. Trading units are part of our everyday life. Markets need units for arbitrage and decision makers need units to know exactly where and how public funds will be invested. In trade-offs, standardized units are

[1] In Capital, Vol. 1, Part One, Chapter One, Section One: The Two Factors of a Commodity: Use-Value and Value: 'The wealth of those societies in which the capitalist mode of production prevails, presents itself as "an immense accumulation of commodities," its unit being a single commodity. Our investigation must therefore begin with the analysis of a commodity'.

imperative: units tell people how to measure and why. Contrary to this, ecosystem valuation in a hypothetical market setting has to rely on various definitions of what is being traded and its units. By using biophysical units (indicators) and connecting them with service provision, nature may become familiar and tangible to people. Through appropriate physical units, the 'quintessential invisibility' of nature (Vatn and Bromley, 1995) becomes understandable to laypeople and to decision makers. While people may value the benefits of service provision (e.g., the aesthetic appeal of a forest) they should readily understand how changes in the SPU would affect this benefit (e.g., a 'forest' with only a few trees vs. one with thousands of trees). Owing to the complexity of nature, the delineation of units may be context specific, although could be generalized across similar cases studies.

Quantification (of how ecosystems provide services) is a prerequisite for economic valuation and it was unfortunately not provided systematically by ecology until recently. Sanchirico and Siikamaki (2007, p. 10) argued that: "*The need for well defined units and values for nature's services emerges both from macro- and micro-level perspectives, such as generating economy wide environmental statistics and payment programs for providing specific ecosystem services*". Carpenter et al. (1995) explained the time hysteresis of the quantification of ecosystem services as due to the fact that ecosystem-level experiments are difficult, costly and need long time horizons. According to Goulder and Kennedy (1997), evaluators often concentrate on the most easily measured impacts and ignore the difficult ones. Those researchers who have tackled the valuation of biodiversity loss (e.g., Kontogianni, 1998; Langford et al., 2001; Kontoleon and Swanson, 2003; Bandara and Tisdell, 2004; Eppink and van den Bergh, 2007) know very well the difficulty of such an endeavor (especially those attempting to value species under threat of extinction, where uncertainty prevails not only on the ecological risk factors, but the biological information for the species). In this context, the most important information required for valuation, the role of the species in the ecosystem and its contribution to ecosystem services, is often poorly known (Sanderson, 2006).

Without relevant ecological information, environmental economists tend either to overestimate or underestimate the problem at hand. An overestimation is apparent when economists deny the possibility of ever defining and delimiting appropriate, discrete units of nature. As Norgaard (1984, p. 160) puts it "…neither natural resources and environmental services as factors of production nor environmental impacts as products of economic activity come in discrete units." In a similar vein, Vatn and Bromley (1995, p. 11) discern three different problems in valuing nature: congruity, composition and cognition. The incongruity problem appears due to the moral aspect of environmental choices. The composition problem refers to the impossibility of economic methods to capture *functional,* or what Gren et al. (1994) termed *primary ('glue')* value. Of special interest to us is the position of the authors that cognitive problems are directly related to the actual units used to express and communicate ecosystem changes. Cognitive problems arise because of the *functional opaqueness* of environmental assets; therefore, individuals cannot make comparisons across scales and have difficulty converting environmental goods and services into monetized units for comparison with other goods. The authors conclude that, in marked contrast with market commodities, environmental goods and services cannot be conceived within an exchange process because '*they do not exist in discrete units*' (*our emphasis*).

Third, according to Vatn and Bromley (1995), existence values should emanate not from what people perceive as unique in nature (scenic beauty or anthropomorphic mammals under extinction), but from what scientifically is known to be indispensable for ecosystem functioning. The key argument here in describing the cognitive and composition problems is related to the lack of attention applied to quantifying discrete units in nature.

An underestimation of the issue, we reason, is due to the fact that the bulk of published ecosystem valuation papers by economists are up to now concerned with testing the internal consistency and potential biases inherent in the economic methodologies. It is only natural that by following this path, economists downplay any issue related to the appropriateness of the respective actual units for valuation. Concerning the physical entities used to quantify the change in the provision of ecosystem services, most economists use some biotic or abiotic indicator (Lamb et al., 2009), preferably some species or land coverage (Polasky et al., 2008). As a result, there is often no clear connection of ecosystem functions to human services; economic valuation is therefore by necessity directed more towards the valuation of natural assets than towards services. Valuation of assets in most cases can do without an appropriate ecological modeling background, ecosystem service valuation cannot.

4. Defining Service-providing Units and their Potential for Improving Valuation of Nature

Advances by ecologists in defining service delivery through the concepts of SPUs (Luck et al., 2003) and ecosystem service providers (ESPs) (Kremen, 2005), and more recently through the unification of these concepts as the SPU-ESP continuum (Luck et al., 2009), provide a framework for quantifying complex ecosystem processes and resulting services, and thus better integration of ecological concepts into social sciences generally. If ecologists are successful in decoding the functions of nature and consequently in transforming the disparate elements of these 'ecological production functions' into a collection of attributes which, taken together, are responsible for the provision of discrete units of ecosystem services (and so command a certain price), then the basic condition for successful valuation will be met. Although, given the complexity of nature and spatial and temporal variations in ecosystem processes, it is likely that this valuation will be context specific (or at best generally appropriate for similar contexts) rather than broadly applicable across all circumstances.

Put simply, an SPU can be defined as the collection of individuals from a given species and their characteristics necessary to deliver an ecosystem service at the level desired by service beneficiaries (Luck et al., 2009, p. 224). SPUs can be delineated only if the human need for an ecosystem process has been identified (i.e., we know who the service beneficiaries are), the rate of delivery of the service meets beneficiary needs, and we can determine the organisms and their characteristics providing the service. It's crucial that quantitative links are made between organism characteristics (e.g., population density) and service delivery to define the unit and allow suitable valuation.

In the original expression of the concept, Luck et al. (2003) focused on species populations as the fundamental unit contributing to ecosystem services at the local level, and introduced the notion of SPUs to capture this dynamic and link explicitly species populations with services. This approach recognized the importance of documenting changes in population diversity (e.g., size, distribution or genetic differentiation of populations) for the sake of both conservation assessments and for the provision of ecosystem services (Hughes et al., 1997; Luck et al., 2003). Conserving population diversity requires a definition of the spatial and/or temporal extent of a population and the characteristics that are used to measure diversity (e.g., genetic variation). If a population is defined through its contribution to ecosystem services, then changes in the population are more easily linked to the impact on human well-being, and population boundaries can be delineated by the extent over which the service(s) is generated.

Kremen (2005) extended this idea by emphasizing the importance of service provision by ecological organizational levels in addition to populations — for example, the functional traits and functional importance of communities, guilds and interacting networks or organisms (i.e., ESPs). Eventually, the SPU and ESP concepts were unified as the SPU-ESP continuum which promotes "…the quantification of organism, community, or habitat characteristics required to provide an ecosystem service in light of beneficiary demands and ecosystem dynamics" (Luck et al., 2009, p. 224). Occasionally below, we use the term 'SPU' as shorthand to refer to the quantification of nature's services at all levels, acknowledging that it was originally applied at the population level only, and extension of these ideas to other organizational levels was central to the work of Kremen et al. (Kremen, 2005; Luck et al., 2009).

The SPU concept, and its potential to improve economic valuation of nature, is most easily understood in its original form. For example, a population of honeybees at a given density may provide all the pollination requirements of an almond grower. We can quantify the ecological characteristics of this population to define the SPU and we can value service production (e.g., crop yield) in economic terms. Once an SPU has been defined, attention can be given to how changes in this SPU might affect service production and some measure of value (e.g., financial or other). The definition of an ecological unit is a crucial step to facilitating meaningful economic valuation.

At the population level, there are various case studies in the literature that provide good examples of how the SPU concept could be applied in reality (see Luck et al., 2009 for further details and examples). Mols and Visser (2007) demonstrated how great tits (*Parus major*) provided a pest control service in apple orchards by reducing caterpillar damage to the crop. Caterpillar damage was reduced by up to 50% when the density of breeding pairs of birds equaled 1–6 per 2 ha. Quantifying the density of breeding pairs is pivotal since caterpillars are an important food item for the bird during the breeding season. In this example, the SPU is at least one breeding pair every 2 ha, although the authors did not explicitly quantify the level of need for this service by the service beneficiaries. Such a designation is important to allow an assessment of the trade-offs (economic, social and conservation) between ecosystem service provision and human-derived alternatives (e.g., pesticides).

Hougner et al. (2006) provided another example by quantifying and valuing (in dollar terms) the seed dispersal service provided by Eurasian jays (*Garrulus glandarius*) in oak forest in the National Urban Park of Stockholm, Sweden. The authors argued that the oak forest makes a substantial contribution to the cultural, recreational and biodiversity values of the park. Jays are intimately linked to the persistence of the forest because the foraging and dispersal behavior of the species facilitates acorn germination to an extent much greater than other animal species in the park. Hougner et al. (2006) estimated that a minimum of about 24 jays (or 12 pairs) was required to ensure forest maintenance by facilitating (through seed dispersal and handling) the establishment of an average of 33,148 oak saplings per year (over a 14-year period). The jay population estimate is a bare minimum and does not incorporate the need to buffer jay populations against environmental change (i.e., provide an insurance policy, or in ecological terminology, ecosystem 'resilience' — see below). The SPU is a minimum of 12 resident jay pairs present each year for 14 years, and Hougner et al. (2006) valued the replacement costs for the seed dispersal service at US$ 4900 (for direct seeding of oaks by humans) or US$ 22,500 (for planting) per pair of jays.

We can extend this idea to different organization levels through the SPU-ESP continuum (Luck et al., 2009). For example, at the level of ecological communities, Guo et al. (2000) demonstrated how quantitative variation in key characteristics of terrestrial vegetation communities (e.g., soil type, vegetation type and area) impacted on water flow regulation and the downstream production of hydro-electricity in the Yangtze River watershed in China. This relationship has developed to the point whereby up-stream landholders are now paid to conserve particular vegetation communities on their land to ensure appropriate water regulation for continued electricity production (Guo et al., 2007).

In presenting these examples, we are not implying that other species or communities could not provide these services (indeed, an examination of the utility of different species in providing the same service is a fruitful area for further investigation) or that interactions between the SPU and other organisms (or abiotic components of the environment) are not crucial to service provision. The implications of species interactions, functional traits, and functional relationships among species for ecosystem service provision are described in detail by Luck et al. (2009). Moreover, the contribution of SPUs to human well-being may be context specific and more research is required to determine how applicable given SPU characteristics are in delivering the same service in a different context.

Nevertheless, we argue that the SPU concept offers distinct advantages for economic valuation of nature. Identifying and quantifying SPUs can help address the important issue of marginality in economic valuation of ecosystem services. Focusing at the margins, where small changes in service provision lead to concomitant changes in economic value or human well-being is important for linking ecosystem service research with practical policy making (Fisher et al., 2008). For example, if we know the density of honeybees required to pollinate an entire almond crop on an individual farm, we can better assess how marginal changes in bee density will impact on local almond production (and the trade-offs this entails). Moreover, if we know that *x* bee populations (SPUs) are required to pollinate all crops within a region, we can assess the impact of a marginal change in the number of populations. Hence, marginality can apply both within an SPU and across SPUs. Further, Fisher et al. (2008) argued that marginal analysis is best applied at smaller scales (e.g., 'landscapes'), which completely aligns with the contention by Luck et al. (2003) that SPUs are most relevant to service provision at the local level.

The other important area where the SPU concept could be applied is in setting minimum benchmarks to ensure sustainable service provision. Fisher et al. (2008, p. 2053) refer to this as the 'safe minimum standard' defined as "…the minimum quantity of ecosystem structure and process…required to maintain a well-functioning ecosystem capable of supplying services." This idea is analogous to the ecological/conservation concept of minimum viable populations, whereby a given population size is considered the bare minimum to ensure the persistence of a species for a suitably long time frame (e.g., 100 years; Shaffer, 1981). Hence, an SPU could be considered as the minimum amount of a particular ecosystem quantity (e.g., population size, forest area or functional diversity) required to ensure the delivery of an ecosystem service(s) for a set amount of time at a level needed by service beneficiaries.

There are at least three crucial caveats to the above idea. First, any minimum quantity must incorporate the need for ecosystems or their components to be buffered against possible future environmental change and recognize the level of uncertainty that exists in ensuring ecosystem conservation. That is, an 'insurance' amount must be built into the quantity to maximize the probability of the service providers persisting for a suitably long time given predicted environmental variation. Second, a suitable minimum quantity must also consider possible future market fluctuations or socio-cultural change that might impact on the demand for the service. For example, an appropriate minimum quantity at one time step might not be suitable at future time steps if the demand for the ecosystem service increases. This compounds the level of complexity that must be considered when setting minimum quantities in ecosystem service research. Finally, it is not appropriate to use marginal analysis to assess situations that invoke minimum quantities, because a small variation from above to below the minimum quantity could breach a threshold resulting in major ecosystem change (see Lindenmayer and Luck, 2005 for further discussion). Moreover, economic analyses may also wish to consider a maximum quantity of ecosystem structure and process, above which ecosystem components become detrimental to ecosystem functioning or human well-being (e.g., exotic plants that contribute to carbon storage, but become so abundant as to reduce the overall diversity of an ecosystem).

In sum, we argue that the SPU concept could play an important role in future economic valuation of nature through emphasizing the need to quantify the ecological units that provide services at the level required by service beneficiaries, focusing attention on the implications of marginal change in the characteristics of service providers for service provision, and setting suitable minimum quantities (with built-in insurance) to ensure the continued delivery of services.

5. The Potential of the SPU Concept to Address the Endpoint Problem and Improve Stated Preference Approaches

Returning to the endpoint problem, we believe the SPU concept has the potential to at least contribute to addressing this problem because its central tenets align with the requirements of ecological endpoints defined by Boyd (2007; see above). First, SPUs are biophysical. Boyd uses the example of a fish population in a lake that provides food as an ecological endpoint. We would define this as an SPU. Second, the SPU concept also promotes the idea of 'concrete, tangible, and measurable' ecological units by relentlessly emphasizing the need to quantify the components of nature that provide services — and, finally, through this association with ecosystem services the concept is squarely focused on the links between ecosystems and human well-being.

It is less obvious how the SPU concept may improve communication about the changing state of nature to a general audience, but as an example we return to the research of Mols and Visser (2007) showing how the bird species *Parus major* can provide a pest control service in apple orchards (see above). We believe that focusing on the link between bird population density and crop management and yield represents a good opportunity to formulate endpoints that are broadly understandable. This could take the form of how changes in bird density impact crop yield (e.g., number of apples), fruit quality (e.g., lack of insect damage) or even health benefits (e.g., reduced pesticide use). Hence, the endpoints communicated to broader society are change in apple availability (likely impacting on price), the quality of fruit and integrity of fruit production as a result of the contribution of the SPU.

Consideration of the SPU concept may also improve stated preference approaches where the endpoint problem is crucial. Viewing the endpoint problem from this angle translates it to a question of defining the 'object of trade' as a necessary step before determining the 'terms of trade'. Evolution of within-market transactions has established standardized physical units as acceptable and universally understandable metrics of commodity exchange *vis-à-vis* money. As development/conservation trade-offs are increasingly rationalized and quantified, new, standardized physical units of ecosystem services *vis-à-vis* non-market transactions need to be established. The potential usefulness of the SPU concept in stated preference valuation approaches centers around the following three areas.

First, the SPU concept could enhance understanding of the objects being valued and accordingly reduce the potential bias due to heuristic devises (judgmental rules of thumb) used by respondents in stated preference surveys (Kahneman et al., 1982). The problem has been succinctly phrased by Freeman (1986, p. 160): "On the basis of the familiarity and experience arguments, it appears that the CVM [Contingent Valuation Method] is likely to work best for those kinds of problems where we need it least; that is where respondents' experience with changes in the level of environmental good have left a record of trade-offs, substitutions, and so forth which can be the basis of econometric estimates of value. But for those problems for which we need something like the CVM most, that is, where individuals have little or no experience with different levels of the environmental good, CVM appears to be least reliable."

The SPU concept specifically (and the ecosystem service concept generally) answers the argument of 'constructed preferences' due to the quintessential invisibility of nature by translating purely biophysical environmental processes into processes providing services to humans. The emphasis here is on the connection between nature and humans through the provided service. The SPU gains a direct communicative advantage by expressing this relationship through the quantification of a relatively simple unit and how changes in the characteristics of this unit impact on human well-being (e.g., via changes in financial return). We believe that people should be able to readily understand the implications of quantitative changes in service providers for the benefits they may receive or the costs that may need to be incurred.

For example, if Hougner et al. (2006) were to apply a contingent valuation instead of a replacement cost approach, it would be relatively straightforward for respondents to understand that 12 pairs of jays can ensure the persistence of an oak-tree forest in an urban park used extensively by city residents, and express accordingly their willingness to pay to preserve the relevant SPU. The same holds for service beneficiaries of great tits, who, within a contingent valuation context should easily understand that in order to reduce insect damage to the apple crop by 50%, you need to conserve at least one breeding pair of great tits every 2 ha (Mols and Visser, 2007). It is not necessary for beneficiaries to understand the complexities of the various interactions and relationships that lead to the persistence of great tits (although such knowledge is vital for ecologists and those wishing to inform land managers). For the valuation procedure, it is enough to establish simply a quantified link between the service provider and the benefit to humans. Quantifying the unit of service provision facilitates an understanding of the important attributes of the service provider. The interrelated functions of nature, either isolated or not, might be better understood by respondents during the valuation process. The 'veil of ignorance' in the formation of human preferences is to a great degree lifted and respondents are presented with key components and processes of complex ecological relationships in simple terms.

The potential use of SPUs in stated preferences approaches is best visualized within a choice experimental setting. Here, the quantitative description of attributes is often presented in biophysical units, and the actual choice questions from which valuations are derived are almost always presented as a series of numeric levels for each of the attributes which define the good. To illustrate this point, Bateman et al. (2009) present examples of attributes and their levels used in recent choice experiment studies, asserting that 'many respondents find these numeric levels difficult to comprehend'. (p. 2) In order to understand how the SPU concept could help us in addressing the cognitive problems caused by the numeric levels used in choice experimental settings, we turn our attention to Barkmann et al. (2008), a choice experiment application with the explicit aim of investigating the unfamiliarity problem caused by the complexity of environmental functions in choice modeling. Barkmann et al. (2008) attempted to value a spatially delimited hydrological ecosystem function in rural Indonesia using a choice experiment. In Table 1, we have summarized the attributes used by the authors and the corresponding levels (first three columns).

We have also attempted to translate the traditional, numeric levels used by Barkmann et al. into what we term 'SPU-translated attributes' the corresponding 'hypothetical SPUs' and the 'hypothetical SPU-based levels' (last three columns). For example, the attribute 'rattan' could be quantified in terms of the area of rattan ecosystem preserved. An (hypothetical) SPU could be defined by the minimum area of rattan ecosystem needed to sustain the (annual) average demand for rattan and its levels as deviations above or below the status quo SPU (e.g., the SPU corresponding to the status quo demand). In an analogous way we could translate the rest of the attributes to SPU-based attributes.

Defining SPUs usually makes things simpler and in the case of ecosystem services it can establish the link between the obscure (to laypeople) natural functions of ecosystems and the resulting benefits. Hence, the desired level of common understanding among respondents might be better achieved through the SPU concept. During the hypothetical valuation exercise, people should have the same feature in mind and they should value the same service, which is now represented by the SPU. This enhances the validity of a stated preference application since the ultimate criterion for validity is that the method should clearly measure only what it is supposed to

Table 1
Attributes and attribute levels of the Central Sulawesi choice experiment.
Adapted from Barkmann et al. (2008).

Attribute	Description	Levels	SPU-translated attributes	Hypothetical SPUs	Hypothetical SPU-based levels
Rattan	Availability of rattan (*Calamus* spp) expressed in distance from villages.	5, 10, 15, 20 [km]	Area of rattan ecosystems preserved [km^2] within different distances of villages.	Minimum area of rattan ecosystems required to sustain average demand for rattan in the long term.	Changes in area of rattan ecosystems with consequent changes in rattan yields.
Water	Availability of irrigation water for wet rice cultivation.	0, 1, 2, 3, [number of months with water shortage].	Structural/functional attributes of ecosystems that influence water availability and quality (e.g., area of wetlands or capacity of fringing vegetation to reduce evaporation).	Minimum structural or functional attributes needed to meet irrigation demands.	Changes in attributes with consequent changes in rice yields.
Cocoa	Preponderance of cocoa plantation differing along a shade gradient.	5, 35, 65, 95 [% under shade]	Area of shaded cocoa plantations under different levels of shade.	Minimum area of shaded cocoa plantations under different levels of shade required to sustain cocoa production.	Changes in area of shaded cocoa plantations with consequent changes in cocoa yields.
Anoa	Population size of the endemic dwarf buffalo anoa (*Bubalus depressicornis*)	10, 180, 350, 520, [no. of animals]	Number of animals	Minimum population size of anoa necessary to ensure the persistence of the species given possible future environmental variation.	Changes in anoa population size with consequent changes in the probability of extinction.

measure (Gregory et al., 1993). An important caveat though is that the SPU concept is most readily applied when there is comprehensive knowledge about the relationships between ecosystem structure and function, and resulting implications for service provision. When such information is lacking, general 'rules of thumb' may be employed — for example, protecting the habitat of a key service-providing species (see Luck et al. 2009 for further discussion).

A second area of usefulness is that the SPU concept helps to establish a clear divide between use and non-use values. A corollary of respondents' unfamiliarity with ecosystem services is what Kahneman and Knetsch (1992) termed 'the warm glow effect'. They argue that such values are typically not specific to the goods under valuation but reflect the 'warm glow of moral satisfaction' associated with supporting any worthy cause. The warm glow effect undermines seriously the presence of 'existence' values, the most prolific member of the non-use class of ecosystem values. The question then arises as to the credibility of empirical findings indicating that existence values dominate the value of some non-unique resource (Bateman et al., 2008).

This became familiar to one of the authors during the Contingent Valuation (CV) of the highly endangered Mediterranean monk seal *Monachus monachus* (Kontogianni, 1998). The survey ended with a 63.5% existence value as part of the Total Economic Value given for the protection of the species. In the absence of a concrete link between *M. monachus* and an ecosystem service, moral, ethical and cultural values prevailed in explaining the value of the species. Would this be the same if the seal provided a service or the seal population could be designated as an SPU? In order to test this hypothesis, the authors initiated a CV survey for the protection of Mediterranean monk seal, adapting the former valuation scenario to an SPU-valuation version. Using the same questionnaire, we introduced to the valuation scenario the information that the presence of a specific density of seals in a regionally specified marine environment (e.g., the northern–eastern Aegean Sea) controls the jellyfish outbreaks in the same area. In the status quo, the population density of seals is lower than the one needed to supply the service. A change is proposed to protect the species and raise its density to levels adequate for supplying the service. A specific monk seal SPU is accordingly quantified and the corresponding service to humans (jellyfish-free bathing beaches) valued. We expect that the respondents will emphasize the use-value aspect rather than the existence-value aspect, which prevailed in the previous CV survey.

Although aesthetics (cultural services, MEA, 2005) can form a serious component of value and should not be disregarded, the SPU concept focuses on the systemic/functional aspect of valuation by making all ecosystem components commensurate on the basis of other service(s) they deliver. By other services we mean here regulating, supporting or provisioning services (MEA, 2005).

Finally, SPUs offer a better framework for understanding the sensitivity of value estimates *vis-à-vis* changes in quantities valued. Contrary to the logical prerequisites of economic valuation, most ecosystem valuation studies to date have not valued marginal changes in the provision of the specific ecosystem service under consideration (Turner et al., 2003; Fisher et al., 2008; see further discussion above). That might be explained, inter alia, by the lack of a clear case-to-case understanding of how service provision reacts *vis-à-vis* changes in the service providers.

Discontinuities here might explain why marginal changes in ecosystem services can now be viewed as discrete changes in the underlying service providers. To illustrate, let us assume that the 100,000 inhabitants of a near-by city use a 100-ha forest as a recreation site with no close substitutes available. On average, 1000 visits from the city to the forest are undertaken annually. A policy maker contemplates the clearing of 10 ha of the forest in order to construct a new motorway. With respect to the fulfilment of the social demand for recreation, that could mean two things: either that 1000 visits could be still realized annually as before, accommodated now in 90 ha, or that under these conditions fewer visits (e.g., 900) are feasible. In the first case, the 10 ha that have been cleared are proved to be de facto redundant: their absence does not obstruct the provision of the recreation service demanded (e.g., 1000 visits) and consequently their value is 'insensitive to scope'. This represents a stepwise supply curve indicating that in a specific range (e.g., 90–100 ha) of the service provider (e.g., the forest) no relevant change in the service provided is detected. The corresponding SPU of forest is estimated accordingly at 90 ha. In the second case, the service provided is diminished and this fact represents a real loss to be valued. Here the service provision is characterized by a rather smooth supply curve exhibiting a continuum of SPUs. Therefore, and assuming a stepwise form of ecosystem service supply curves (as implied e.g., in McConkey and Drake, 2006), valuing changes in service provision through SPUs prompts the researcher to leave the realm of marginal and enter the realm of non-marginal, discrete changes in ecosystem service provision.

Putting SPUs at the forefront of assessing the implications of ecological change might make it easier for people to express their views about if and how much they are interested in conserving the necessary units for service provision. The SPU concept could contribute to the operational framework for societal management decisions, and provide individuals with reliable information and experience with changes in the level of an environmental good or service.

6. Natural Resource Damage Assessment: A Special Case

Market-based valuation approaches, such as those referred to above, are not rare in ecosystem service assessments. Some of them are based on engineering cost assessment of preventive or restoration technologies and use the resulting cost estimates as proxies for value estimates (e.g., Hougner et al., 2006; Losey and Vaughan, 2006; Ming et al., 2007; Sandhu et al., 2008). Other studies calculate the productivity change in a market sector arising from a deterioration of an ecosystem function (e.g., Ninan and Sathyapalan, 2005; Nunez et al., 2006; Gallai et al., 2009). As such, they do not encounter any sort of endpoint problem since cost estimates are habitually market generated, not relying on subjective value assessment. Though attractive due to data and expertise availability, such proxies are often considered by economists as gross misrepresentations of the true welfare impacts of changes in ecosystem service provision. Implementing responses to ecosystem degradation without taking behavioral, and therefore welfare theoretic implications into account is apparent in a major field of USA sustainability assessment: natural resource damage assessment.

Damage assessment arises when parties cause injuries to a natural asset, altering its flow of services. In applying restoration and mitigation measures against ecosystem damages, federal agencies (the Department of Interior and the National Oceanic and Atmospheric Administration) rely on a service-to-service approach, that is, restoration measures of damaged sites are scaled and new replacement measures are planned on a functionally equivalent habitat-to-habitat basis (known as Resource Equivalency Analysis). By restoring damaged habitats and creating new, replacement habitats, the trustee agencies aim at restoring both ecosystem service losses and human welfare losses and thus '*making the public whole*' (for a general review on the subject, see REMEDE at www.envliability.eu). Logical as it may seem, such an engineering approach misses some important welfare theoretic conditions that are crucial if the biophysical restoration metric used in the damage assessment and scaling exercises is going to be equivalent to a human welfare metric. Both Flores and Thacher (2002) and Dunford et al. (2004) note that the manner in which traditional Resource Equivalency Analysis handles value, makes significant *a priori* assumptions[2] that simplify the linkage between *in natura* and *ad valorem* principles of compensation.[3] We are not surprised by these findings, for underlying the quest for resource equivalency is the assumption of one-to-one correspondence between physical objects before and after the damage. In contrast, we hold that resource equivalency is intimately tied to the specifics of both ecosystem functioning *and* social demand. We believe that the recently introduced SPU concept represents a sound, new welfare-related metric that can provide an improved basis to resource equivalency.

[2] That is, homogeneity of preferences and temporal stability of the habitat value.

7. Conclusion

Irrespective of the valuation approach that is implemented, quantification of services must meet the following objectives:

- enhance interdisciplinary collaboration and understanding between ecologists and economists and promote more validated, well-informed valuation applications;
- apply equally well to use and non-use values;
- offer a framework for understanding sensitivity of value estimates *vis-à-vis* changes in quantities valued;
- enhance understanding of the objects being valued and accordingly reduce the potential bias due to heuristic devises used by respondents in stated preference surveys; and
- address dynamic issues of value estimation.

During the last 40 years, environmental economists have gone a long way in addressing the issue of non-market ecosystem valuation. Proliferation of applied studies, theoretical refinements and policy guidelines aside, the fact remains that progress in economic valuation methods is substantially dependent on the advancement of standardized methods to measure ecosystem services. In this paper, we have tried to re-orient the physical basis of ecosystem valuation by suggesting ways in which the SPU concept could contribute to an ecologically solid and policy-relevant base for valuing ecosystem services.

We argue that the concept offers potential advances in the economic valuation of ecosystem services by enhancing interdisciplinary collaboration and understanding between ecologists and economists, therefore promoting more validated, well-informed valuation applications. By creating a better cognitive environment in stated preference surveys, SPUs could foster a sound delimitation of use and non-use values, and by recognizing and quantifying discrete changes in service providers it substantiates the meaning of changes in ecosystem service provision.

These observations suggest that there are opportunities to develop better valuation scenarios for biodiversity conservation. Scenarios of this type emphasize thresholds and discontinuities in ecosystem service provision as the major threats to humanity caused by biodiversity loss. Ventures into modeling of payments for ecosystem services, Resource Damage Assessment in the USA, and European Environmental Liability Directive 2004/35, appear to be fruitful application areas. Moreover, the increased ecological realism of the resulting valuation scenarios based on SPUs might enhance their policy relevance. The latter point underscores the necessity of designing a 'science and economics framework' in order to frame future valuation exercises. Pavan Sukhdev, the study leader of TEEB (*The Economics of Ecosystems and Biodiversity*, http://ec.europa.eu/environment/nature/biodiversity/economics/) urged the appearance of a new compass that could guide the measurement of ecosystems and biodiversity scientifically as well as

[3] Boyd and Wainger (2003) show why ecosystem compensation and exchange programs in the USA require benefit analysis in order to guarantee that compensation or trades preserve the social benefits lost when ecosystems are destroyed or degraded. Zafonte and Hampton (2007) offer an indication of the magnitude of such discrepancies between biophysical and value compensation metrics and conclude that under fair general conditions they are not substantial. McConnell and Bockstael (2005) assert though that "some of the worst mistakes in environmental valuation are made by attempting to measure the social cost of environmental degradation as the cost of remediating the damage" (p. 647).

economically. The present paper supports the idea that the new compass may come in the form of an SPU.

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