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METHODS

Defining and classifying ecosystem services for decision making

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ABSTRACT

The concept of ecosystems services has become an important model for linking the functioning of ecosystems to human welfare. Understanding this link is critical for a wide-range of decision-making contexts. While there have been several attempts to come up with a classification scheme for ecosystem services, there has not been an agreed upon, meaningful and consistent definition for ecosystem services. In this paper we offer a definition of ecosystem services that is likely to be operational for ecosystem service research and several classification schemes. We argue that any attempt at classifying ecosystem services should be based on both the characteristics of the ecosystems of interest and a decision context for which the concept of ecosystem services is being mobilized. Because of this there is not one classification scheme that will be adequate for the many contexts in which ecosystem service research may be utilized. We discuss several examples of how classification schemes will be a function of both ecosystem and ecosystem service characteristics and the decision-making context.

1. Introduction

Ecosystem services research has become an important area of investigation over the past decade. The number of papers addressing ecosystems services is rising exponentially (Fig. 1). The significance of the concept is witnessed by the publication of the Millennium Ecosystem Assessment (MA), a monumental work involving over 1300 scientists. One of the key results of the MA was the finding that globally 15 of the 24 ecosystem services investigated are in a state of decline (MA, 2005), and this is likely to have a large and negative impact on future human welfare. One of the clarion calls of the MA was for increased and concerted research on measuring, modeling and mapping ecosystem services, and assessing changes in their delivery with respect to human welfare (MA, 2005; Carpenter et al., 2006; Sachs and Reid, 2006).

The 1300-plus scientists have moved ecosystem services science considerably forward. One of the key MA documents subtitled “A Framework for Assessment,” clearly indicates that it is not intended to be a static document. Additionally, several lead authors have acknowledged the need to keep this as an evolving concept (see Carpenter et al., 2006; Sachs and Reid, 2006). To do this, the scientific community needs to frequently check the validity of early concepts, including how ecosystem services are defined, and how the concept can be utilized by a wide range of stakeholders including scientists, economists, practitioners, policy makers, land managers and environmental educators.

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This requires a clear and consistent definition of what ecosystem services are and a wider understanding of key characteristics of ecosystems and the services they provide.

The MA opened a wider understanding and use of ecosystem services and offered an excellent heuristic and classification system. Despite its recent publication date, the MA classification of *supporting*, *regulating*, *provisioning* and *cultural* services is one of the most widely used. This classification is understandably not meant to fit all purposes, and this has been pointed out for contexts regarding environmental accounting, landscape management and valuation, for which alternative classifications have been proposed (Boyd and Banzhaf, 2007; Wallace, 2007; Fisher and Turner, 2008).

However, underlying the multiple ways in which ecosystem services can be packaged or classified, we suggest that there needs to be a clear, consistent and operational definition of what ecosystem services are. This is because a functional definition, widely agreed upon, would allow for meaningful comparisons across different projects, policy contexts, time and space (Boyd, 2007; Barbier, 2007). Such a definition would also provide us with boundaries for the characteristics we are interested in. For example, if we use the MA definition, i.e. benefits people obtain from ecosystems, then the characteristics of import include things outside of ecological systems such as imputed cultural meanings, recreation, and spiritual fulfillment.

However, if ecosystem services are defined as ecological phenomena, as below or as in Boyd and Banzhaf (2007), then the first role of science, to deliver information to society, becomes much more clear. In this vein, the first duty is to understand and relate the behaviors and characteristics of ecological systems. Some of the identified characteristics, along with the decision context or motivations for mobilizing ecosystem services, will inform an appropriate classification system for use, or rather a meaningful and transparent way to organize ecosystem services for use.

This paper argues that a classification system should be informed by 1) a clear and robust definition 2) the characteristics of the ecosystem or ecosystem services under investigation and 3) the decision context or motivation for which ecosystem services are being considered.

Fig. 2 demonstrates how we suggest that these various issues connect. First and foremost we suggest that clearly defining what ecosystem services are is important, at the very least so that (as stated above) meaningful comparisons and synergies can be made across projects, researchers etc. As pointed out by Boyd and Banzhaf (2007), GDP accounting was slow to deliver a consistent set of definitions and accounting methods, and to this day we still talk about production within national boundaries (GDP), and production by nationals of a country regardless of where it happens in political space (GNP). This type of evolution is likely to be the case with the ecosystem services concept.

Once we define ecosystem services then we can consider their characteristics and the characteristics of the systems from which they derive that are important for understanding their link with human welfare. Fig. 2 also suggests that we need to know something about the decision context or motivations for mobilizing ecosystem services research (e.g. spreading awareness, accounting systems, landscape management…). A brief example following Fig. 2 is such: we define ecosystem services to be about ecological phenomena (e.g. not cultural services which we see as very valuable benefits derived from ecosystems and services); we know that some ecosystems and functions can behave nonlinearly (characteristic); we are trying to decide how much upland forest to convert to a ski resort (decision context); we can classify our ecosystem services based on any (un)certainty about their functional response to this land conversion. Perhaps, at certain initial levels, a list of services that will behave in as linear response include genetic storage, pollination, carbon sequestration. A list of services that may change nonlinearly could include soil retention and water regulation. By classifying services in this way they can feed back into the decision process and perhaps suggest a precautionary approach or management strategy for soil retention and water regulation. The rest of this paper is used to flesh out Fig. 2 and expand its implications.

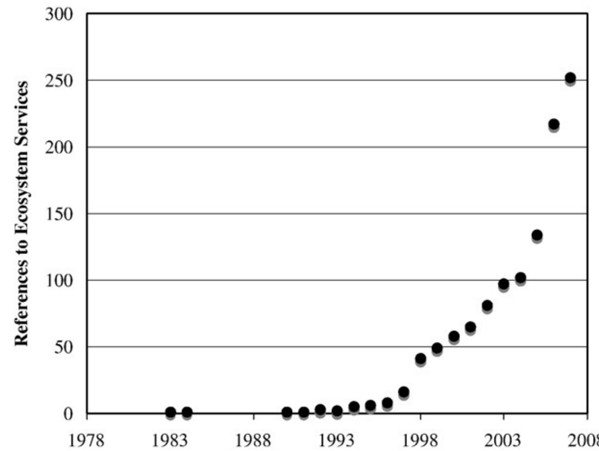

Fig. 1 – Number of papers using the term "ecosystem services" or "ecological services" in an ISI Web of Science search through 2007. "Environmental services" as a search term, was left out as it returned publications related to hospital environments. Therefore, the graph is indicative but clearly an underestimate.

First we suggest a broad, yet operational, definition of ecosystem services (Section 2); identify some of the characteristics of ecosystems and the services they provide that might be important for classification schemes (Section 3); and provide examples of decision-making contexts which illustrate how any classification scheme needs to fit the end use for an investigation into ecosystem services (Section 4). We then offer some concluding thoughts on the future of ecosystem service research.

2. Defining ecosystem services

Humanity's reliance upon nature for welfare and survival is complete. The history of civilization is, at its most basic, a story of people trying to access resources and seek protection from the elements. Around 10,000 years ago when we began to domesticate nature, the story changed a bit. Through husbandry and agriculture we were managing nature's services more directly in order to increase productivity. In this

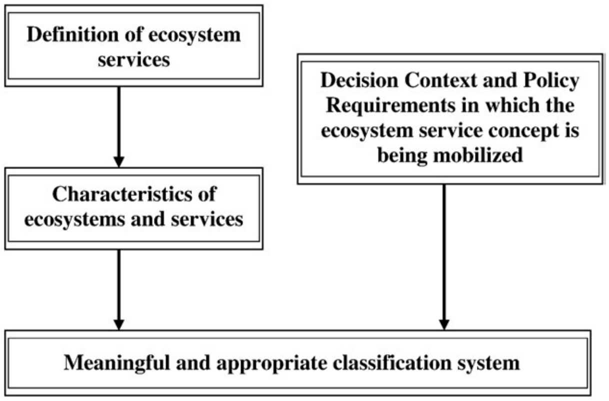

Fig. 2 – Classifying or packaging ecosystem services for meaningful and appropriate use will require a clear definition of what ecosystem services are; an understanding of the key characteristics or behaviors of these ecosystems and their services; and an understanding of the decision context in which the ecosystem services concept will be used.

way humans have always recognized the importance of what we now call ecosystem services. The ancient Greeks knew the importance of soil retention, a knowledge predicated by deforestation related soil thinning. The classic, oft-cited example is the Easter Island society whose cultural beliefs led them to completely deforest their island leading to loss of soils, and no raw materials for building sea vessels (see Ponting, 1993). Jared Diamond's Collapse: How Societies Choose to Fail or Succeed (2005) documents societies throughout history that have ignored the importance of well-functioning ecosystems to their ultimate demise. He emphasizes habitat loss, soil retention, biomass production and water regulation among others as the key services lost with the result of societal collapse.

Researching these links between welfare and ecologies under a concept like 'ecosystem services' has increasingly been fleshed out over the past few decades. In 1977, Westman (1977) suggested that the social value of the benefits that ecosystems provide could potentially be enumerated so that society can make more informed policy and management decisions. He termed these social benefits 'nature's services.' Now we commonly refer to Westman's services as 'ecosystem services' — a term first used by Ehrlich and Ehrlich (1981). Mooney and Ehrlich (1997) offer a history of the concept starting from George Perkins Marsh's *Man and Nature* in 1864 through Leopold's idea of a land ethic, and right up to experimental ecology and the role of biodiversity in ecosystem functioning.

Despite the history of the concept, the literature does little to distinguish exactly how ecosystem services should be defined (Boyd, 2007; Barbier, 2007). Three definitions commonly cited are:

- the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life (Daily, 1997a).
- the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al., 1997).
- the benefits people obtain from ecosystems (MA, 2005).

These definitions suggest that while there is broad agreement on the general idea of ecosystem services, important differences can be highlighted. In Daily (1997a,b) ecosystem services are the "conditions and processes," as well as the "actual life-support functions." In Costanza et al. (1997) *ecosystem services* represent the goods and services derived from the functions and utilized by humanity. In the MA, services are benefits, writ large.

The language surrounding this issue has taken many forms, as illustrated above. Table 1 identifies other related terms in the literature, and is one way to look at the various terms and their meanings. In this typology, the word *organization* represents the physical constitution of ecosystems; the word *operation* represents what authors have been referring to as the processes or functioning of ecosystems; and the word *outcome* for the link to human wellbeing. These are only offered as a way to systematize the various terms used in the literature. The semantics are so nuanced that there is even debate over the difference between ecosystem *function*, which has been argued to imply anthropocentrism (because *function* implies a goal), and ecosystem *functioning*, which does not (de Groot et al., 2002; Jax, 2005).

Boyd and Banzhaf (2007) offer an alternative definition to the ones above. In their definition, ecosystem services are not the *benefits* humans obtain from ecosystems, but rather, the ecological components directly consumed or enjoyed to produce human well-being. For Boyd and Banzhaf services are directly consumed components (structure included), meaning indirect processes and functions are not ecosystem services. An important distinction that Boyd and Banzhaf (2007) elucidate is that services and benefits are not identical. Recreation, often called an ecosystem service, is actually a benefit of multiple inputs; often human, social and built capital inputs are necessary for recreation (Boyd and Banzhaf, 2007) — the ecosystem services that may help produce a recreational benefit could be a number of ecological components including a forest, meadow, or a vista.

Drawing largely on Boyd and Banzhaf (2007) we propose that *ecosystem services are the aspects of ecosystems utilized (actively or passively) to produce human well-being*. The key points are that 1) services must be ecological phenomena and 2) that they do not have to be directly utilized. Defined this way, ecosystem services include ecosystem organization or structure as well as process and/or functions if they are consumed or utilized by humanity either directly or indirectly. (*Boyd and Bazhaf see services as only the directly consumable end points*). The functions or processes become services if there are humans that benefit from them. Without human beneficiaries they are not services.

Table 1 – Various terms used in the literature regarding ecosystems and ecosystem services in recognition of the clear links among ecosystem organization, the operation of ecosystems, and the outcomes that provide human benefits

Organization	Operation	Outcome
Stock	Flows	Services
Structure	Function(ing)	Goods
Infrastructure	Services	Benefits
Pattern	Process	
Capital		Income

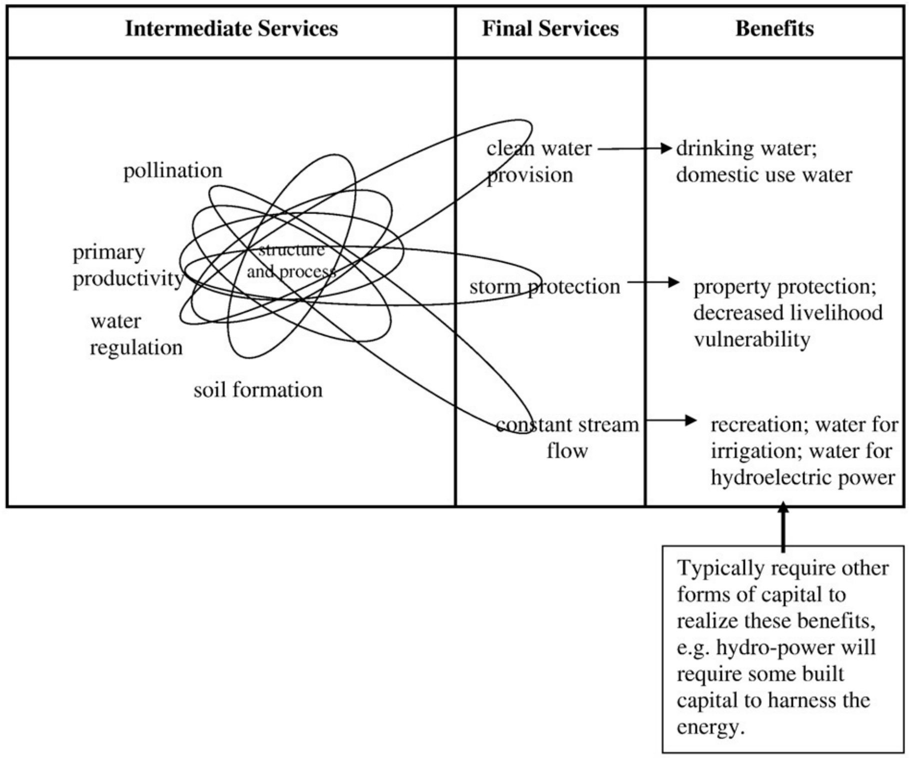

Fig. 3 – Conceptual relationship between intermediate and final services, also showing how joint products (benefits) can stem from individual services. Intermediate services can stem from complex interactions between ecosystem structure and processes and lead to final services, which in combination with other forms of capital provide human welfare benefits.

Ecosystem structure (called *component* in Boyd and Banzhaf, 2007) is a *service* to the extent that it provides the platform from which ecosystem processes occur. How much structure and process is required to provide a diversity of ecosystem services in a given ecosystem is still an active research question (Turner et al., 1998; Kremen, 2005). Clearly some minimum configuration of structure and process is required for 'healthy' functioning and service provision. This 'infrastructure' has value in the sense that its prior existence and maintenance is necessary for service provision, and is therefore a service in itself (Turner, 1999).

This does not mean that structure, function, and services are identical or synonymous. Ecosystem structure and function have been identified and studied for years with no reference to the services to humans, which they also provide. So, while most ecosystem structures and processes do provide services they are not the same thing. One can best see this distinction with a simple thought experiment. What if there was an Earth-like planet with no humans? It could have a wide array of ecosystem structures and processes, but no services.

For example, nutrient cycling is a process in which one outcome is clean water. Nutrient cycling is a service that humans utilize, but indirectly. Clean water provision is also a service that humans utilize, but directly. Clean water, when consumed for drinking, is a benefit of ecosystem services. The benefit being the point at which human welfare is directly affected and the point where other forms of capital (built, human, social) are likely needed to realize the gain in welfare. Here, clean water provision is a service and clean water for consumption — requiring extraction tools or knowledge — is a benefit. Pollination is another ecosystem service that humans utilize, although not directly. Pollination is the service, the benefit may be eating almonds. Fig. 3 is one such conceptual model of these types of connections between ecosystem structure, processes, services and benefits.

3. Characteristics of ecosystems and ecosystem services

Once we have clearly defined ecosystem services, we can consider their characteristics, and the characteristics of the ecosystems that produce them. By understanding key characteristics we can better manage, maintain, restore or evaluate ecosystem services. For example by knowing that there are seasonal fluctuations in stream flows needed for irrigation we can prepare for this variability though water collection or better irrigation management. Below we discuss a few broad characteristics that can aid in classifying ecosystem services for various decision-making contexts. These are illustrative and certainly not exhaustive, but they are important when trying to understand the ecology–society link of ecosystem services. Therefore they are likely to be important for decision-making and general motivations behind utilizing the ecosystem services concept. All of these characteristics are related to each other and interact in some way. We deliberately limit the discussion of these interactions since we are using them not to show complexities and interdependence, but rather to highlight important aspects of ecosystems and their services to consider in various decision contexts.

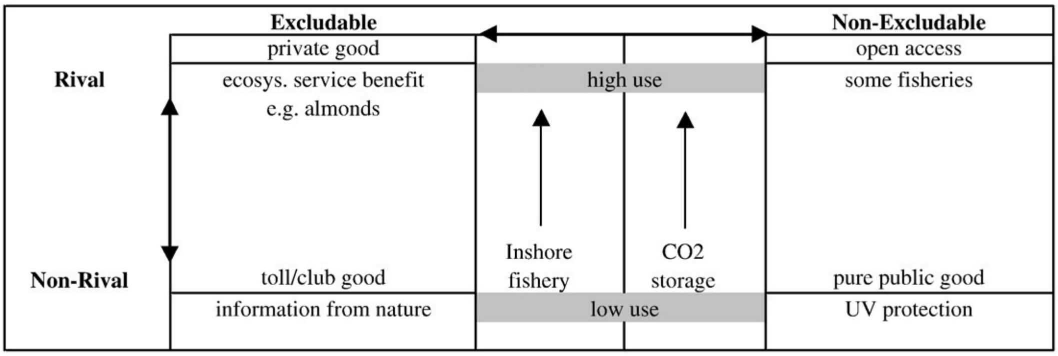

Fig. 4 – Goods and services can be characterized along a continuum from rival to non-rival and from excludable to non-excludable. Some goods that are non-rival at low use levels (fisheries and CO_2 storage) can move towards becoming rival goods with high use.

3.1. *Public–private good aspect*

Goods that we typically buy in markets have two characteristics that make them appropriate for the market. Economists use the terms *rival* and *excludable* to describe these characteristics. To be *rival* means that if I use this good, there is less of it for you to use. To be *excludable* means that I can keep you from using this good. For example, if I buy a chicken in the market, my use of it precludes your use (rival) and I can keep you from using it by say locking it up, or eating it (excludable). Ecosystem services do provide benefits that are rival and excludable goods, like timber, fish, and medicines.

Obviously not all goods are rival and excludable. In fact there is a spectrum from rival to non-rival and from excludable to non-excludable. Fig. 4 sets out to demonstrate how ecosystem services fit into these characteristic spectrums. Again, ecosystem services provide benefits that are both rival and excludable. For example, pollination services and primary production services provide the benefit (along with other capital inputs like labor) of almonds. These can be traded in conventional markets and are typically considered *private* or *market goods*. Other ecosystem services fall into a category often known as *toll* or *club goods*. This type of good is one that is non-rival, but excludable. For example, information we gain from nature (e.g. insights from bio-mimicry) is non-rival in that if I use this information, there is not less information for you to use, i.e. the good does not degrade or transform. However, I can keep you from using this information by say, patenting it. Another set of goods are those that are rival, but non-excludable. These are often called *open access* or *common pool resources*. Deep-sea fisheries are an example since my use of the fishery leaves less for you (rival), but I cannot prevent you from using it (non-excludable). Finally, there are pure-public goods, which are neither rival nor excludable. For example, the ability of the atmosphere (with its biotic and abiotic interactions) to protect people from harmful UV radiation is often considered an ecosystem service. My use of this service does not leave less of it for you, nor can I keep you from using it.

These four types of goods are stylized examples. There are grades of goods in between these categories, e.g. goods where it gets more difficult to exclude use. In Fig. 4, this is signified by the arrows between excludable and non-excludable goods. For example, we used deep-sea fisheries as an example of a non-excludable good, but we can imagine a system of barriers and monitoring to keep people from using such fisheries. However, this exclusion would be a very difficult and costly endeavor. It is a similar case with rivalness. Some goods may be non-rival at low use levels. Inshore fisheries at low or sustainable use levels could be considered non-rival since — my use does not preclude your use. However, as we increase our use or extraction of the fishery benefits (e.g. fish) they move towards being rival goods. At unsustainable levels my use of the fishery does leave less for you. Fig. 4 demonstrates this process, sometimes known as congestibility (Farley and Daly, 2004). An example in this vein of a more difficult to exclude good is the carbon storage capacity of the atmosphere. 300 years ago, using the atmosphere as a carbon sink was non-rival. The sink was big compared to the emissions. However, we are now in a situation where the use of the atmosphere as a carbon sink by one country leaves less of it for others (if climate stability is a societal goal). This previously non-rival sink is becoming congested.

There is an additional complexity here with regards to biodiversity. The utility someone derives from the nonuse of biodiversity (e.g. warm glow, bequest value, existence value) could be considered a public good. Likewise, the role of increased species numbers as insurance to the stable functioning of ecosystems over time and space (Hooper et al., 2005) has public good aspects. Therefore, the stability (Macarthur, 1955; Tilman 1996; Naeem and Li 1997; Ives et al., 1999), resilience (Nystrom and Folke 2001; Petchey et al., 1999) and resistance (Allison 2004; Hughes and Stachowicz, 2004) roles of biodiversity for ecosystem functioning and therefore service provision are also characteristics that relay some non-excludability and non-rivalness to society.

Additionally, the complexity of understanding how ecosystem services and their benefits fit into the public–private goods space, is not just a function of the ecosystem dynamics, but also in the social systems that interface with these goods and services. Governance systems, markets, informal land use and others are employed to utilize and benefit from ecological systems. These in themselves are complex and dynamic, and will interact with the different categories of goods by requiring different social solutions for each type.

3.2. *Spatial and temporal dynamism*

Another important characteristic of ecosystems and the services they provide is that they are not homogenous across landscapes or seascapes, nor are they static phenomena. They are heterogeneous in space and evolve through time. This spatio-temporal dynamic is a characteristic that can help in understanding and classifying ecosystem services. For example some ecosystems provide services that are utilized *in-situ*. Soil formation is an example of a service that can be used in the same place as it was made — providing a benefit of say an agricultural product. Another example is when a service is provided in one location at one time, but the benefit is realized in another location at another time. For example, water regulation provided by mountain top forest will provide benefits downslope overtime in the form of regulated and extended water provision. These characteristics are described in more detail below where we use them to derive a classification scheme.

3.3. Joint production

Just as discrete ecosystems can deliver several ecosystem services, ecosystem services can provide multiple benefits for human welfare. In both cases, these are considered “joint products” (see Daily, 1997b for chapters regarding multiple services produced by individual systems and biomes). In Fig. 3 we can see that the interactions among several intermediate services produce final services such as clean water provision and storm protection. These final services can provide joint products, or multiple benefits, as in the case that having a regulated stream flow provides humanity with recreation opportunities, water for irrigation and water for hydroelectric power. Joint production is a characteristic of ecosystem services that could be important for deriving accounting and classifications schemes in certain decision-making contexts.

3.4. Complexity

Discerning the complex interactions between structure, process and service is further complicated by the fact that ecosystems are not linear phenomenon, but rather “complex systems” with feedbacks, time lags, and nested phenomena (Limburg et al., 2002). This complexity is somewhat responsible for the categories of goods in Section 3.1, especially with rival to non-rival continuum as that is driven by biophysical characteristics, i.e. does the good degrade or transform with use. Our knowledge of the ecological dynamics responsible for ecosystem services (i.e. production functions) is still in early days (Daily et al., 2000; Kremen, 2005). In line with this there are some services we may not be able to measure or monitor directly. For example, it may be possible to measure net primary productivity for a given area from models and remote sensing, but it may be problematic to measure the waste absorption service provided by a landscape with a certain level of productivity. This measurement problem is visible in payments schemes for ecosystem services like the PSA program in Costa Rica. Here landowners are paid for providing services like carbon sequestration, but this service is not measured directly, but rather by proxy — the number of hectares forested.

As mentioned above, our understanding of the role of biodiversity in the production of ecosystem services is another area where complexity and uncertainty reign. The term itself is used in different ways by different people. We know that some systems and processes are initially insensitive to species loss (Hooper et al., 2005), but after a certain threshold an ecosystem may abruptly change. Other systems, may respond quickly to the loss of a single species, like the collapse of kelp systems as a result of sea otter decline and subsequent release of sea urchin populations (Estes et al., 1998).

The complexity of the system is a characteristic that can help with classifying ecosystem services. For instance, we might not have knowledge of all the interactions and dependencies between ecosystem components and processes, so delineating between intermediate services, final services and benefits might be the best we can do, and might be enough for a desired outcome e.g. green accounting. This classification may aid in developing financial or market mechanisms for managing ecosystems, i.e. mechanisms with outcomes that can be clearly monitored.

3.5. Benefit dependence

Services are often benefit dependent (Boyd and Banzhaf, 2007), meaning the benefits you are interested in will dictate what you understand as an ecosystem service. For example, water regulation services are an intermediate input to the final service of clean water provision. One benefit is better water quality. But if one was interested in the final service of fish production, then water provision would move from being a final service to an intermediate one, i.e. whether the service is considered final or intermediate will change depending on what is being valued, monitored or measured, as well as who are the beneficiaries (see Boyd, 2007 for a full treatment of benefit dependence).

Since different stakeholders (or even individuals) perceive different benefits from the same ecosystem processes they can at times be conflicting (Turner et al., 2003; Hein et al., 2006). For example, to global stakeholders the carbon sequestration service of tropical rain forests may be valued for climate regulation, but locally the forest may be valued as fuel wood. In economic terms these services are rival. Further complications stem from the fact that many intermediate and final ecosystem services are valuable, providing benefits to humans, even if the stakeholders themselves do not perceive the service. Climate regulation is an example of a vital service for human wellbeing that is probably not perceived by a large portion of the earth’s population.

3.6. Characteristics and interactions

The discussion of the above characteristics was limited and stylized as the goal of this section is to illustrate how certain characteristics will be important for certain decision contexts. Clearly all of the characteristics above interact in significant ways. For example, the public good provision of climate regulation from carbon storage and sequestration occurs on a global scale. The beneficiaries are also a global distribution. This formerly non-rival good of the atmosphere as a carbon sink is becoming congested and therefore rival. In light of the nature of this good a supranational organization, or international agreement, like Reduced Emissions from Deforestation and Degradation (REDD) or Kyoto will be necessary (Sandler, 1998). This intervention response is different than would be needed for a congestible public good provided at local scale. For example, a recreational beach might require access fees. These interacting characteristics: the public good, spatial scale, benefit dependence and complexity (through congestibility as a function of social systems and biophysical properties), all combine together with the specific decision context to condition an appropriate classification system. A myriad of responses for decision making in these two examples may include access fees, change in property rights, taxes, subsidies, tradable permits, regulation, or devices to change individual or group incentives (Turner, 1999). These responses will be informed by some of the key characteristics discussed above. The nature of these interactions among characteristics, decision contexts and ecosystem service classification is the focus of the following section.

4. Classifications, decision contexts and motivations

There have been several efforts to classify ecosystem services (e.g. de Groot et al., 2002; MA 2005; Wallace, 2007). The dynamic complexity of ecosystem processes and the innate characteristics of ecosystem services (some noted above) should have us thinking about several different types of classification schemes (Costanza, 2008). Any attempt to come up with a single or fundamental classification system should be approached with caution. Also, ecosystem services are innately linked to social systems and social decisions and therefore, the decision context for utilizing ecosystem services research is also crucial for mobilizing the ecosystem services concept. Here we use the term *decision context* to mean the broad spectrum of processes which lead to social choices. Decision context therefore signifies aspects of social choice from information gathering and communication processes, through analyses, implementation and ex-post appraisal. Here we suggest how the decision context linked to the characteristics discussed above can help to decide which classification scheme is most appropriate for use (Fig. 2). We provide several examples below.

4.1. *Understanding and education*

One decision context for utilizing the concept of ecosystem services might be to promote understanding and to educate a larger public about the services and benefits that well functioning ecosystems provide to humans. This was one major focus of the MA and its classification scheme was fit for purpose. The MA divided ecosystem services into a few very understandable categories — supporting services, regulating services, provisioning services and cultural services. This classification utilized the complexity characteristic of ecosystems and the public–private good dynamic to draw distinct boundaries of different ecosystem services. For example, by acknowledging the many interconnections among ecosystem components and processes the MA classification placed *supporting services* as an underpinning to the other service categories. This in turn makes their classification readily accessible as a heuristic — one of the key goals of the MA.

4.2. *Cost–benefit analysis as an aid to environmental decision-making*

If the goal or decision context utilizes economic valuation of ecosystem services then the MA classification is not appropriate and some other scheme should be utilized. This is due to the fact that the MA classification could lead to double counting the value of some ecosystem services. For example, in the MA, nutrient cycling is a supporting service, water flow regulation is a regulating service, and recreation is a cultural service. However, if you were a decision maker contemplating the conversion of a wetland and utilized a cost–benefit analysis including these three services, you would commit the error of double counting. This is because nutrient cycling and water regulation both help to provide the same service under consideration, providing usable water, and the MA's recreation service is actually a human benefit of that water provision.

For valuation purposes a classification scheme that divides ecosystem services into intermediate services, final services, and benefits would be more appropriate. With this definition, ecosystem processes and structure are ecosystem services, but they can be considered as *intermediate* or as *final* services, depending on their degree of connection to human welfare (see Aylward and Barbier (1992) for an early example of this). The same service can also be both intermediate and final depending on the benefit of interest. This classification scheme recognizes that ecosystems are complex, and rather than understanding all of the complexity we just have to be clear about some final services and benefits with which we are concerned. In doing so it also appreciates the benefit dependence characteristic. This classification avoids any potential double counting problem because you would only value the final benefits, and hence is fit for purpose in a valuation context. For example Ricketts et al. (2004) estimate the importance of wild pollination by pollinators (service) by enumerating the yield benefit and associated economic returns due to pollinator populations of coffee beans (benefit) in Costa Rica.

Despite the fact that environmental valuation is an important tool for evaluating non-market goods (see Fig. 3), it is not useful in all cases of environmental decision-making, nor is it unproblematic. First, the complexity of ecological systems and the services they generate inhibits both our social understanding of the benefits as well as our ability to place a monetary value on them. For example, economic valuation works on marginal changes, i.e. how will a small change in quantity *X* affect its value (often realized by market price). Exactly what constitutes a marginal change in regards to ecosystem processes and services is not always clear (Turner et al., 1998; Daily et al., 2000), and price changes (for example for water used for irrigation) will likely not reflect the "ecological quantities" important for the delivery of that benefit (Gowdy and Erickson, 2005).

Also, the values people place on environmental goods and services, through stated preferences techniques, are susceptible to a range of inconsistencies. For instance, studies of willingness to pay (WTP) have shown that the values elicited are often reference dependent (Bateman et al., 1997a); show a part–whole bias where the parts are valued more than the whole (Bateman et al., 1997b); and are highly malleable in response to (mis)

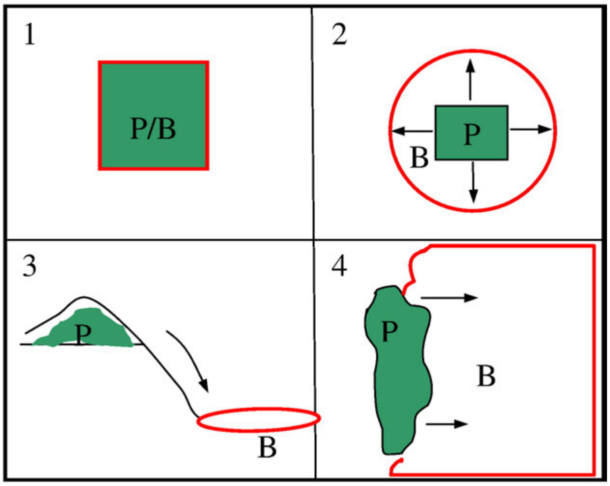

Fig. 5 – Possible spatial relationships between service production areas (P) and service benefit areas (B). In panel 1, both the service provision and benefit occur at the same location (e.g. soil formation, provision of raw materials). In panel 2 the service is provided omni-directionally and benefits the surrounding landscape (e.g. pollination, carbon sequestration). Panels 3 and 4 demonstrate services that have specific directional benefits. In panel 3, down slope units benefit from services provided in uphill areas, for example water regulation services provided by forested slopes. In panel 4, the service provision unit could be coastal wetlands providing storm and flood protection to a coastline.

information provided (MacMillan et al., 2006). There is also the problem of incommensurability (see Aldred, 2002) i.e. can we meaningfully encompass the values of goods that fall outside the private goods box in Fig. 4? For example, would it be appropriate to add values elicited from people regarding biodiversity existence to market-based values for timber provision?

Despite these limitations, there is a legitimate and meaningful role for market transactions (and values) and related human behavior in the environmental domain. All policy choices are made by humans, and therefore some conception of "preferences" and their human motivations lie behind any environmental policy and its relative values. The classification system described here forces one to link complex ecosystem processes and services to benefits perceived to be important by the specific users of an ecosystem services evaluation. From the list of final benefits generated under this classification, users will have to decide for which benefits it is appropriate and meaningful to use economic valuation. For example, processes occurring in a sacred forest may contribute benefits to a local population such as drinking water and spiritual fulfillment, but we might not want to enumerate a value for the latter, let alone add it to the former.

4.3. *Landscape management*

Another way to classify ecosystem services would be to use their spatial characteristics. This might be appropriate if the decision context was how to manage a given landscape for the provision of ecosystem services across scales. Looking at species patterns, Polasky et al. (2005) found that by understanding the spatial patterns of biodiversity, thoughtful land-use planning can achieve conservation successes outside of reserves with little effect on potential or realized economic uses of a landscape. In a similar vein, it will be important for managers to know what other services are provided on the landscape and how these services flow across that landscape. The European Union's Habitats and Water Framework Directives is taking such a tack by incorporating spatio-temporal characteristics of natural systems into policy solutions. Utilizing the spatial characteristics a classification scheme might involve categories that describe relationships between service production and where the benefits are realized (Fig. 5). Such a classification might include categories such as:

- *in situ* — where the services are provided and the benefits are realized in the same location
- *omni-directional* — where the services are provided in one location, but benefit the surrounding landscape without directional bias
- *directional* — where the service provision benefits a specific location due to the flow direction.

A classification scheme as such could also use scale qualifiers, such as local omni-directional (e.g. pollination), and regional directional (flood protection). Understanding the distribution of services and benefits across a landscape (or seascape) as well as, knowing where the services are provided informs where management interventions should be concentrated (Chan et al., 2006; Naidoo and Ricketts, 2006). Classifying ecosystem services in this way recognizes such characteristics as the spatio-temporal dynamics of ecosystems, public–private good aspects, and benefit dependence of services. This distributional classification can also highlight the possibility of cases where beneficiaries might compensate providers such as in *payments for environmental services* schemes, an example being payments for forest carbon storage to cover the opportunity costs of marginalized poor (see Pfaff et al., 2007) or as often the case, absentee landowners (Pagiola et al., 2005). Another example is where downstream water users compensate upslope landowners for leaving their property forested for water regulation purposes.

4.4. *Public policy and equity in human welfare*

Through the economic concept of an externality — where the action of one agent brings about an inadvertent gain or loss to another without payment or compensation — economists have been long interested in the effects that changes in environmental quality can have on welfare. The work of Alfred Marshall and A.C. Pigou in the late 19th and early 20th centuries on externalities and common property problems, laid early foundations for the future of environmental economics (Laffont, 1987). With regards to ecosystem services, one person's harvesting of timber may preclude another person's benefit of bush meat due to declining habitat. The linked effect that the human economy has on the environment and that the environment has on the human economy is difficult to assess since the externalities reverberate throughout these complex social and ecological systems (Crocker and Tschirhart, 1992). Dynamic modeling of complex systems can help to identify unintended consequences and their patterns of distribution across these linked systems (Boumans et al., 2002; Finnoff and Tschirhart, 2003).

In light of externalities and distribution issues, one possibly important classification scheme considers the decision context of how ecosystem services relate to equity in the provision of human welfare. This is important as it is now generally accepted that diminishing environmental quality disproportionately affects people more marginalized by the market economy (Dasgupta, 2002). The decision context might be a government interested in measuring how the natural environment distributes and provides services and consequent benefits across their constituents. This is made complex by the fact that stakeholders at different spatial scales have different interests in ecosystem services (Hein et al., 2006). For example, the benefits people receive from existence values of biodiversity might conflict with benefits impoverished people receive from converting biologically diverse habitats, where poverty and species diversity have been shown to be highly correlated (MA, 2005; Fisher and Christopher, 2007). In this decision context several characteristics are important for consideration including — public–private goods aspect, spatio-temporal dynamic and how services are benefit specific. Linking these characteristics to the decision context (i.e. fulfilling human needs and wants) can be set out in a hierarchical classification as found in Wallace (2007). Here an ecosystem service classification starts with basic needs — which Wallace labels *adequate resources*. Other categories include *protection from predators, disease, parasites*; *benign physical and chemical environment*; and *socio-cultural fulfillment*. Dividing services in this way can provide decision-makers with information about what level of people's needs are being met in a given landscape by ecosystems and their services.

4.5. *Meeting multiple objectives*

Decision makers are often trying to meet multiple objectives, or to get an 'acceptable' balance if objectives conflict. In this context, for example, the decision of a nation to gazette a new national park could require decision makers to 1) educate the public about the benefits of this decision, 2) attempt to ensure the equitable distribution of benefits 3) impute an economic valuation of the services provided by the park and 4) consider landscape management issues inside of and adjacent to the park. The different policy requirements may all be informed by an agreed upon definition of ecosystem services, and some of the key characteristics of the system of interest (e.g. what types of goods will be provided). Given multiple objectives some form of multi-criteria assessment will be required which will be anchored to the component analysis and their tailored approach.

Appropriately classifying or packaging ecosystem services is not difficult, but it must be consistent with the end use. One slight difficulty with classification is due to the confusion and imprecision currently surrounding the ecosystem services concept (Boyd, 2007; Barbier, 2007). Referring back to Fig. 2 and two papers in the literature, Boyd and Banzhaf (2007) and Wallace (2007), we see that these steps make intuitive sense. Both papers key in on a precise definition[1], and use their particular decision context (green GDP and landscape management, respectively) to package ecosystem services that are appropriate and meaningful in light of these contexts. They of course take into account the complex characteristics of the service provision to help in this classification. Boyd and Banzhafs' interest is in a green GDP index that is comparable to conventional GDP. The things that need to be counted in green GDP are the 'end products' of natural systems which directly affect welfare — Boyd's definition of services (Boyd, 2007). Taken together, this definition and decision context — green GDP for tracking a nation's environmental state — set up a classification for what should and should not be considered as ecosystem services. One of many key characteristics taken into account here is the benefit dependence of the services, so that a wetland is not counted for producing quality water, (as the wetland is not an end product), but is counted for flood attenuation (Boyd and Banzhaf, 2007). Another classification scheme would have been inappropriate given Boyd's definition and decision context.

5. Conclusions

Ecosystem services research is a rapidly evolving field, and while the term itself may be relatively new, an understanding that nature provides services for human welfare goes back to the myth of Eden. In some respects it is still early days for concerted scientific research into ecosystem services. However, consistent and robust means of measuring, mapping, modeling, and valuing ecosystem services are beginning to emerge (Ricketts et al., 2004; Naidoo and Ricketts, 2006; Chan et al., 2006; Naidoo et al., 2008). In this paper we argue that, as a first step, having a consistent, and ecologically based definition of ecosystem services in important. Since the concept of ecosystem services has become a major topic of study and a critical criterion for conservation assessments (Egoh et al., 2007) it is important that it is clearly defined allowing meaningful comparisons across time and space (Boyd, 2007; Boyd and Banzhaf, 2007; Wallace, 2007). While a single definition is important, attempts to create a single classification scheme for ecosystem services is unlikely to be helpful. Ecosystem services are a function of complex interactions among species and their abiotic environment; complex use and utilization patterns; and various perceptions by beneficiaries. Since linked ecological–economic systems are complex and evolving, a 'fit-for-purpose' approach should be considered in creating clear classifications. Considering all the parts to ecological system of interest is crucial, but so to is considering the social and political contexts within which ecosystem services are being investigated or utilized.

Utilizing an inappropriate classification can lead to problems for meaningful and robust research results. We have seen problems with double counting in the published literature, submitted manuscripts and government documents due to the misuse of the MA classification system. In fact, in a forthcoming review of ecosystem service studies only one of 34 studies examined explicitly acknowledged the double counting problem in environmental valuation of ecosystem services (Fisher et al., in press). A similar problem would arise if we tried to utilize a classification based on the spatial–temporal aspects of ecosystem services for educating a broad range of stakeholders, from decision-makers to the lay public.

[1] These two papers use different definitions but use them consistently within their purpose.

It would likely prove to be more involved than necessary and not foster buy in, where the MA classification, for example, is well suited for the communication of this type of complex information.

In conclusion, decisions that necessitate the understanding of ecosystem services are often social decisions, or at least have public consequences. Science, writ large, can tell us what ecosystem services are; how to monitor; measure; and value such things. Social processes tell us what issues and perspectives are important in the short term, and what information is actually utilized by decision makers. There are often times where society does not have the scientific information to make appropriate long-term decisions. There are also times where the scientific information may not be all that important for social decisions (e.g. GM foods in Europe). This communication–information dynamic will be true for ecosystem services research as well. There is an obvious need for scientists to more clearly communicate findings to the public and decision makers. To effectively use the ecosystem services concept in decision-making will require a clear understanding of the concept (definition and characteristics). Doing this in a transparent and appropriate way (classifications) should enable us to expose entry points for science to inform, rebut, and debate society's understanding of the issue, and conversely it should provide scientists with information about what is deemed important by the public and decision makers.

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