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Ecosystem services: Exploring a geographical perspective

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Abstract

The 'ecosystem service' debate has taken on many features of a classic Kuhnian paradigm. It challenges conventional wisdoms about conservation and the value of nature, and is driven as much by political agendas as scientific ones. In this paper we review some current and emerging issues arising in relation to the analysis and assessment of ecosystem services, and in particular emphasize the need for physical geographers to find new ways of characterizing the structure and dynamics of service providing units. If robust and relevant valuations are to be made of the contribution that natural capital makes to human well-being, then we need a deeper understanding of the way in which the drivers of change impact on the marginal outputs of ecosystem services. A better understanding of the trade-offs that need to be considered when dealing with multifunctional ecosystems is also required. Future developments must include methods for describing and tracking the stocks and flows that characterize natural capital. This will support valuation of the benefits estimation of the level of reinvestment that society must make in this natural capital base if it is to be sustained. We argue that if the ecosystem service concept is to be used seriously as a framework for policy and management then the biophysical sciences generally, and physical geography in particular, must go beyond the uncritical 'puzzle solving' that characterizes recent work. A geographical perspective can provide important new, critical insights into the place-based approaches to ecosystem assessment that are now emerging.

Keywords

ecosystem services, natural capital stocks, service providing units, social-ecological systems, valuation of ecosystem services

I Introduction

The idea that ecosystems provide services to people has taken on many of the features of a Kuhnian paradigm. It is both dominating current debates and is shaping research and application. The anthropocentric, utilitarian perspective offered by the paradigm also challenges conventional wisdoms, including the belief that the case for conservation is based on ethics rather than economics (see, for example, Armsworth et al., 2007; Chan et al., 2007; McCauley, 2006; Peterson et al., 2010; Salles, 2011). The trajectory of research in ecosystem services in environmental debates is also driven by forces outside the science community (Perrings et al., 2011). Much of the current interest in ecosystem services was stimulated by the Millennium Ecosystem Assessment (MA, 2005), an initiative sponsored by the United Nations, and the recently completed study on the Economics of

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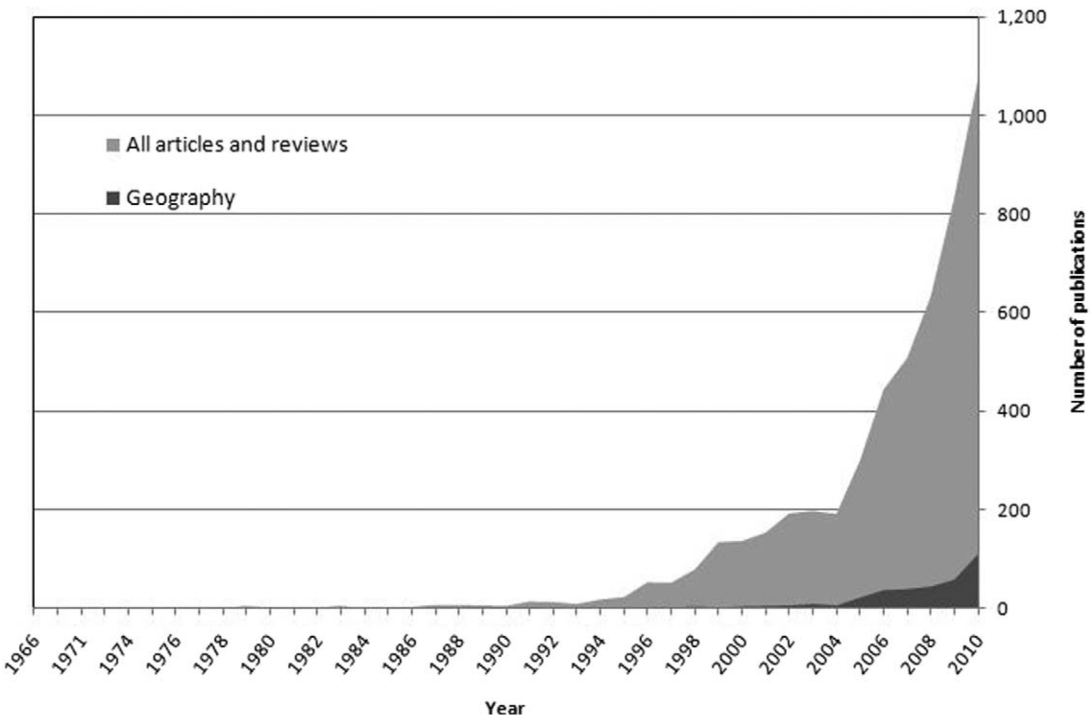

Figure 1. Number of article and review publications dealing with ecosystem services by year up to 2010, identified in the Scopus Database (as of 9 April 2011, 2011 data have not been included)

Ecosystems and Biodiversity (TEEB).[1] The latter examined the long-term costs of failing to address the problem of contemporary biodiversity loss, and arose from a proposal by the German Government to the environment ministers of the G8+5 in Potsdam in March 2007. No doubt the newly established Intergovernmental Platform on Biodiversity and Ecosystem (IPBES) lead by UNEP[2] will encourage further activity, given its aim of linking research and policy communities to 'build capacity' and 'strengthen the use of science in policy making'. Finally, the paradigmatic character of 'ecosystem services' is illustrated simply by the prospect it offers for straightforward, uncritical 'puzzle solving'. Although some publications have criticized the topic, many more have sought to apply it. The expansion of interest in the topic of ecosystem services and its growing dominance may be gauged by Figure 1, which plots the number of publications identified in Scopus[3] that made reference to the term ecosystem service(s) in the 'title, abstract and keywords' field. Between 1966 and 2010, 5136 articles and reviews were recorded (out of 7681 documents of all types) with more than 60% of them appearing since 2006.

Despite the emphasis that Geography has traditionally placed on understanding the relationships between people and the environment, an analysis of the data shown in Figure 1 suggests that the contribution of the discipline to this expanding field has been limited; only about 366 publications of all types contained variations 'geography' or 'geographical' in the affiliation field, and 436 with the same terms for 'title, abstract and keywords' criteria. The analysis is perhaps only indicative because it reflects the terminology used by geographers and the fact that geographers may be publishing under other affiliations. However, although some reference to the topic has been made in this journal,[4] it seems that it has yet to achieve significant *explicit* and general interest among geographers; the gap between the total number of publications and those contributed by geographers appears to be widening. Progress, in understanding the relationships between people and the ecosystems, it seems, is largely driven by work in other discipline areas, particularly ecology, conservation and environmental economics (cf. Egoh et al., 2007; Fisher et al., 2008; Seppelt et al., 2011). Moreover, while mapping studies are increasingly frequent in the literature, the development of mapping methodologies and spatial analyses commonly appears to be undertaken by disciplines other than Geography; less than 20% of the papers identified above included the key word 'map' or its variants in the title or abstract and had authors with affiliations related to Geography. Do other disciplines now find a spatial viewpoint more interesting than Geographers?

In the light of the relatively weak interest in ecosystem services apparently shown by Geographers, the aim of this paper is to examine more closely the putative ecosystem service paradigm and highlight the contribution that the discipline can make to this emerging field. We do this by examining some of the most challenging conceptual issues. At a time when the 'relevance' of all subjects is often questioned, it is important to identify what is distinctive and important about the geographical perspective. We take this perspective to be one which explores the spatial relationships between people and the environment and so puts 'understandings of social and physical processes within the context of places and regions'.[5] As the ecosystem service paradigm develops from the 'revolutionary' to more 'normal' phases, it is essential that we maintain a critique of what it entails and where significant problems remain; the assumptions underlying all paradigms must continually be challenged (Haines-Young and Petch, 1986). Geography has much to offer, we suggest, in terms of understanding issues of space and place.

II Conceptual challenges

1 Connecting ecosystem function and human well-being

Whether we choose to think of the ecosystem service concept as a new paradigm or not, the novel aspect of the idea is that it encourages people to re-examine the links between ecosystems and human well-being in a pragmatic way. Although it is often conflated with the more broadly based 'ecosystem approach', the so-called 'ecosystem *services* approach' (cf. Turner and Daily, 2008) is put forward as a way of developing integrated solutions to the problem of understanding the nature and scale of ecosystem degradation. In both cases, their merit rests on making explicit the direct and indirect benefits that people derive from natural capital. The maintenance and enhancement of ecosystem services is also seen as a fundamental part of any strategy for dealing with future environmental change.

We have suggested (Haines-Young and Potschin, 2010a) that the idea of a 'service cascade' can be used to summarize much of the logic that underlies the contemporary ecosystem service paradigm and key elements of the debate that has developed around it (Figure 2). The model, which has also been adapted and discussed by others (e.g. De Groot et al., 2010; Salles, 2011), attempts to capture the prevailing view that there is something of a 'production chain' linking ecological and biophysical structures and processes on the one hand and elements of human well-being on the other, and that there is potentially a series of intermediate stages between them. It also helps to frame a number of the important questions about the relationships between people and nature, including: whether there are critical levels, or stocks, of natural capital needed to sustain the flow of ecosystem services; whether that capital can be restored once damaged; what the limits to the supply of ecosystem services are in different situations; and how we value the contributions that ecosystem services make to human well-being. The

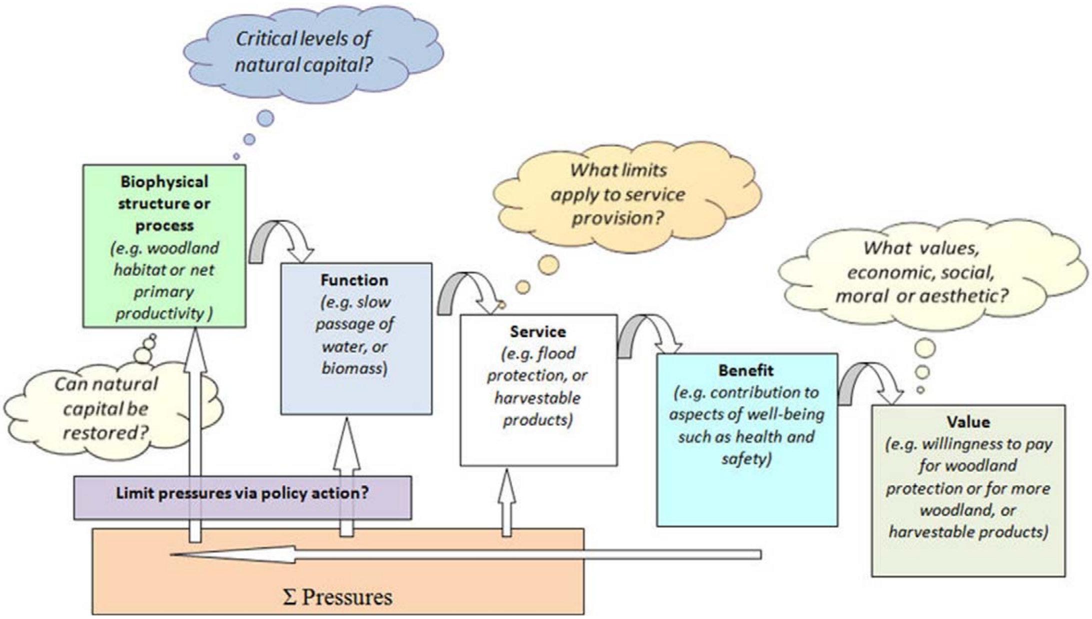

Figure 2. The ecosystem service cascade model initially proposed in Haines-Young and Potschin (2010a) modified to separate benefits and values in De Groot et al. (2010)

judgement made about the seriousness of these issues or pressures partly shapes the feedback implied in the diagram that goes through policy action. In this paper we will use the model as a framework for understanding how concepts and definitions are shifting.

The version of the cascade shown in Figure 2 reflects the refinements suggested in the review of conceptual frameworks in TEEB (see De Groot et al., 2010). Here benefits are separated from values, because it is argued that if benefits are seen as gains in welfare generated by ecosystems, then it is clear that different groups may value these gains in different ways at different times, and indeed in different places (cf. Fisher et al., 2009: their Figure 5). Despite this modification, however, the fundamental tenet of the ecosystem service paradigm remains: namely, that a service is only a service if a human beneficiary can be identified and that it is important to distinguish between the 'final services' that contribute to people's well-being and the 'intermediate ecosystem structures and functions' that give rise to them. The distinction between intermediate and final products or services is fundamental according to Boyd and Banzhaf (2007) and Fisher et al. (2009), for example, because they suggest it helps avoid the problem of 'double counting' when undertaking valuation. Valuation, they argue, should only be applied to the thing directly consumed or used by a beneficiary, and the value of the ecological structures and processes that contribute to it are already wrapped up in this estimate; or, to put it another way, the same structures and functions may also support many services and, for those interested in valuations, these should only be counted once. The extent to which this problem of 'double counting' applies to non-economic forms of valuation is, however, rarely considered.

In following the 'cascade' idea through it is important to note the particular way in which the word 'function' is being used, namely to indicate some capacity or capability of the ecosystem to do something that is potentially useful to people. This is the way commentators like De Groot (1992), De Groot et al. (2002) and others (e.g. Brown et al., 2007; Costanza et al., 1997; Daily,

1997) use it in their account of services. In his *Functions of Nature*, De Groot (1992) actually proposed a classification of functions to capture the relationships between ecosystem processes and components and goods and services, which he has subsequently revised on several occasions. However as Jax (2005, 2010) notes, the term 'function' can mean a number of other things in ecology. It can refer to something like 'capability' but it is often used more generally also to mean processes that operate within an ecosystem (like nutrient cycling or predation). Thus Wallace (2007) prefers to regard functions and processes as the same thing, to avoid confusion, and commentators like Fisher and Turner (2008) and Fisher et al. (2009) simply label all the elements on the left-hand side of the cascade diagram, that ultimately give rise to some service and benefit, as 'intermediate services'. On the basis of their work on the economic consequences of biodiversity loss, Balmford et al. (2011) suggest a threefold division between 'core ecosystem processes', 'beneficial ecosystem processes' and 'ecosystem benefits'; they then go on to rank the beneficial processes in terms of their importance to human well-being and their analytical tractability.

The key messages that seem to emerge from these debates is that, in relation to the cascade idea, whether or not it involves three, four or more steps, or how particular boxes are labelled, the fundamental task is to understand the mechanisms that link ecological systems to human well-being. The intention of the cascade idea is to highlight the essential elements that have to be considered in any full analysis of an ecosystem service and the kinds of relationships that exist between them. The challenge of the new paradigm is the assertion that *all* of them have to be considered together, as an inter- and even transdisciplinary undertaking.[6]

To emphasize the point that it might be best to think of the links between nature and people more as a cascade or sequence of transformations rather than a discrete set of steps, we can consider the further modifications of terminology surrounding exactly what is being valued that has been introduced in the conceptual framework of the UK National Ecosystem Assessment[7] (UK NEA) (Bateman et al., 2011b; Mace et al., 2011). Here a clear distinction is made between 'services' on the one hand and 'goods' on the other. The cascade model follows the MA by treating them as essentially synonymous, while recognizing that some (e.g. Brown et al., 2007) prefer to use the term goods to refer to tangible ecosystem outputs, and services to denote more intangible ones. For Bateman et al. (2011b) and Mace et al. (2011), however, the usage of these terms is quite different. They argue that from an economic perspective ecosystem services are 'contributions of the natural world which generate goods which people value' (Bateman et al., 2011b), and include all use and non-use, material and non-material outputs. For them, the notion of a good goes beyond those things that can be traded in markets and includes ecosystem outputs which have no market price; they can, in other words, have both use and non-use values. These authors also note that some goods come directly from nature without human intervention (e.g. scenic beauty) making the good and service identical, while others result from a combination of natural and human inputs (e.g. a processed food product). For the latter, any attempt at valuing 'nature's services' would have to try to disentangle the contribution that these two types of capital make to the good being considered, although clearly any such manufacture remains dependent on some natural input. The need to separate goods from benefits arises because goods can give rise to different types of benefit in different spatial and temporal contexts.

These developments suggest that, despite their paradigmatic nature, the constellation of concepts that surround the idea of ecosystem services is far from universally agreed. Whether any final agreement about terminology and conceptual frameworks will emerge remains to be seen. In its absence, a pragmatic way forward would be to recognize that it is, perhaps, most useful to treat the things called 'services' simply as thematic labels and seek to understand or articulate the production chain (cascade) that underlies them. Labels like 'benefits', 'goods', 'services', 'functions' and 'structures/processes' are clearly helpful in understanding the transformations that link humans to nature, but the precise boundaries between them might be difficult to define, unless referenced to specific situations. The proposal for a Common International Classification for Ecosystem Services (CICES; Haines-Young and Potschin, 2010b) recently made as part of the discussions surrounding the revision of the SEEA (System of Integrated Environmental and Economic Accounting; UN et al., 2003) suggests that a hierarchical approach to describing the different service themes might be helpful in taking account of the different levels of thematic generality that is apparent in recent work, and for linking service assessments to other data related to economic activity (Figure 3). What does seem clear, however, is that if we accept that there are layers of different ecological structures and processes that underpin all 'final service' outputs, then the category of 'supporting services' proposed by the MA is probably unnecessary or best used as a synonym for ecological functions and processes. The argument here is that given the biophysical complexity that underlies most of the things that we would identify as a final service for people, and the fact that any given service depends on a range of interacting and overlapping functions and processes, any attempt to seriously define the set of supporting services is likely to oversimplify matters.

If progress is to be made with the ecosystem service paradigm, then a key task is to ensure the rigour of analytical outputs and not become preoccupied with definitions. The splitting of goods and services in the UK NEA, like the other distinctions discussed above, merely emphasizes the complexity of the problem that we face in framing the notion of ecosystem service, and the need to be clear in describing how the concepts are applied. Lamarque et al. (2011) have also argued for more careful framing of the way concepts are used. From the perspective of Physical Geography, a particular conceptual challenge is to help identify what the appropriate spatial units of analysis are, and find ways of characterizing the 'significant' functions and the services they deliver, so that comprehensive assessments can be made. We need to show how the structure and dynamics of ecological systems vary with geographical location so that we can better understand the ways in which spatial context affects societal choices and values. As we will argue below, a place-based perspective is one that is becoming increasingly relevant. It is a conceptual framework that geographers could clearly help to articulate.

2 Biophysical contexts: service providing units and social-ecological systems

One criticism of the cascade analogy is that it implies that there is a simple linear analytical logic that can be applied to the assessment of ecosystem services, and that once those interested in biophysical structures and processes have 'done their work', social science in the form of economics, say, can 'take over'. Such a reading of the model is, however, misleading. Its central idea is that to be effective analytical approaches have to be inter- or even transdisciplinary, and that no individual component should be looked at in isolation. Valuation is certainly not the final outcome or only motivation for applying the idea. Indeed, it might well be that only through the identification of what people value can significant biophysical processes be recognized or problematized, and strategies for adaptive management therefore developed and executed.

Cowling et al. (2008), for example, distinguish three complementary types of assessment according to whether they focus on social, biophysical or valuation issues. Collectively such

Theme	Class	Group
Provisioning	Nutrition	Terrestrial plant and animal foodstuffs
		Freshwater plant and animal foodstuffs
		Marine plant and animal foodstuffs
		Potable water
	Materials	Biotic materials
		Abiotic materials
	Energy	Renewable biofuels
		Renewable abiotic energy sources
Regulation and Maintenance	Regulation of wastes	Bioremediation
		Dilution and sequestration
	Flow regulation	Air flow regulation
		Water flow regulation
		Mass flow regulation
	Regulation of physical environment	Atmospheric regulation
		Water quality regulation
		Pedogenesis and soil quality regulation
	Regulation of biotic environment	Lifecycle maintenance & habitat protection
		Pest and disease control
		Gene pool protection
Cultural	Symbolic	Aesthetic, Heritage
		Religious and spiritual
	Intellectual and Experiential	Recreation and community activities
		Information & knowledge

Figure 3. The proposal for a Common International Classification of Ecosystem Services (CICES) (see Haines-Young and Potschin, 2010b)

assessments allow decision makers and stakeholders to look at the opportunities and constraints available to them and the tools needed for management. They argue that social assessments are important because they provide an insight into the perspectives of the owners and beneficiaries of ecological systems that give rise to a service. In this sense, they suggest, these types of appraisal should precede any biophysical assessment; the latter aims more to generate information about the dynamics and geography of the ecological systems and the impacts of direct and indirect drives of change. Valuation assessments, they suggest, are dependent on inputs from the social and biophysical analysis. This generally, but not exclusively, seek to place a monetary value on the services being considered and provide insights into the changes in value under different conditions or assumptions.

Hein et al. (2006) have described what they consider to be the key steps needed for making a valuation of ecosystem services (see their Figure 1) and, while they emphasize how important it is to ground the analysis on an understanding of biophysical relationships, like Cowling et al. (2008) they also propose that definition of the boundary of the ecosystem to be valued is essentially a social process. Specification of the boundaries of the ecosystem involves making clear what the 'Service Providing Unit' (SPU) actually is; since it looks at nature from the perspective of the beneficiary its specification is fundamentally socially determined. The concept was originally proposed by Luck et al. (2003) and has more recently been refined and extended (see Luck et al., 2009). The discussion of Hein et al. (2006) echoes many features of the SPU concept. They argue that ecosystem units can range across all spatial scales, and that decisions about the nature of the assessment units take account both of the biophysical scales at which the services are generated and the institutional scales at which stakeholders interact and benefit from the services. They test their approach using a case study from the De Wieden wetlands in The Netherlands, and found that stakeholders can have quite different interests in the associated ecosystem services, depending on the scale of analysis. Thus a multiscale perspective may be necessary if a range of different interest groups are involved.

The SPU corresponds to what others have referred to as a 'social-ecological system (SES)'[8] (Anderies et al., 2004; Folke, 2007) which also describes how ecosystem services and human welfare are linked through some kind of demand-supply relationship. If natural scientists are to be involved in taking the ecosystem services paradigm forward, then they must become more involved in describing the dynamics of such 'socially constructed' systems, and the sensitivity of the system outputs to different drivers of change. In particular it seems to imply that they move beyond the types of process-response units, such as catchments or habitats, that they have traditionally dealt with, and begin to characterize space-place relationships in more sophisticated ways. One of the problems with applying the ecosystem service concept, for example, is the proposition that it should be applied at 'the appropriate spatial and temporal scales'.[9] In a given locality, once we start to consider how different services might relate to each other, it soon becomes clear that there may be no single scale that is appropriate, and that cross- or multiscale approaches are probably more 'appropriate'. The problem is not so much of defining the boundaries of a system at the most suitable scale, but of dealing with influences at different scales that are relevant to understanding the issues in play at a given place.

Satake et al. (2008) have looked at scale mismatches and their ecological and economic effects on landscapes from a theoretical perspective using a spatially explicit model. They considered the relationships between deforestation decisions, provision of pollination services, and the impacts of payments for carbon storage, all of which were assumed to operate at different spatial scales. They found that while Payments for Ecosystem Services (PES) schemes that encourage carbon storage can increase the average well-being, the effects of spatial heterogeneity at the landscape scale can result in greater inequalities between land-owners, depending on the mix of land-cover types on their holdings; those with larger areas of forest receive higher rewards than those with larger areas of agricultural or abandoned land. Elsewhere, Jones et al. (2009) have illustrated that to understand the factors that influence ecological functioning within a national park area in the USA, for example, broader-scale monitoring of land-cover and land-use change around the park area is vital. A more general review of cross-scale issues has been provided by Du Toit (2010), who noted that despite the widespread acknowledgement of the importance of scale in biodiversity conservation, multiscale studies are 'remarkably uncommon' in the literature. He suggests that an examination of a conservation issue at a range of spatio-temporal scales often shows that the nature of the problem or its causes are often quite different from those initially considered.

Rounsevell et al. (2010) have extended the thinking around the idea of an SPU in their proposal for a 'Framework for Ecosystem Service Provision' (FESP). Their schema seeks to extend the widely acknowledged Driver-Pressure-State-Impact-Response (DPSIR) model into the discussion of ecosystem services, by better describing how 'service providers' are embedded in the system. Like others (e.g. Potschin, 2009), they argue that new frameworks are needed to provide a more balanced or integrated treatment of supply and demand side issues, and the analyses at multiple spatial and temporal scales. It is important to note, however, that the FESP is only offered as an analytical strategy. Rounsevell et al. (2010) suggest a stepwise process for its implementation and illustrate its features by reference to a set of case

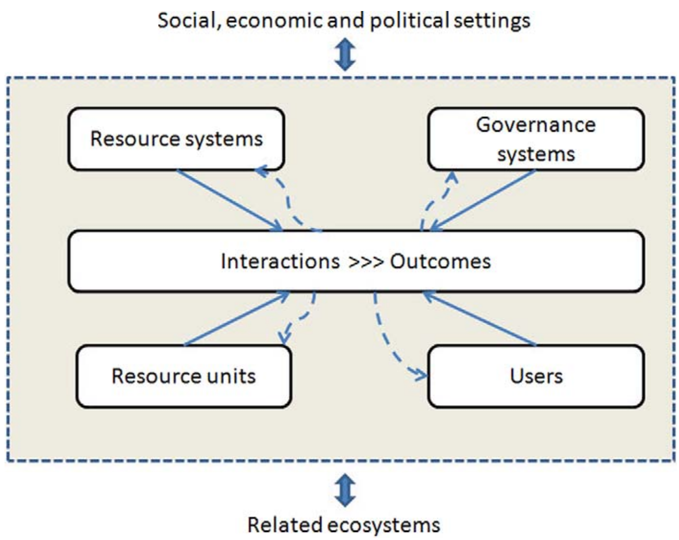

Figure 4. Ostrom's multi-tier approach for analysing social-ecological systems
Source: After Ostrom (2007)

studies that are retrospectively interpreted into its structure. Nevertheless, it does provides a picture of the kind of 'system' that the natural science community might need to consider if they are to engage with the ecosystem service paradigm. But, as these authors point out, it is a framework and not a model, and we are some way from making testable generalizations about either the biophysical or social processes that operate within such systems. As Fish (2011) has argued, one of the key challenges we face is to 'combine analytical rigour with interpretive complexity', and it is precisely in the construction of these kinds of analytical framework that the task seems to lie. Given that these systems have, in a sense, to be co-constructed by drawing on both biophysical and social understandings, we will also need to find ways in which deliberative approaches can capture and make operational different types of knowledge and associated uncertainties, by combining both quantitative and qualitative types of evidence using, for example, multicriteria methods. Smith et al. (2011) provide a wide-ranging review on the use of quantitative methods in the analysis of ecosystem services. They suggest that graphical models using a probabilistic logic, such as Bayesian Belief Networks (BBNs), stand out as a promising way of approaching both complexity and uncertainty, and dealing with the character of different kinds of 'data'. The use of BBNs as an analytical-deliberative tool for exploring social-ecological systems is explored further in this special issue (Haines-Young, 2011).

Definition of the boundary of an ecosystem is, it seems, not merely a biophysical problem. While Physical Geographers can contribute in terms of understandings they provide about the structure and function of environmental systems, they also need to be familiar with how to characterize and investigate these coupled social-ecological systems, the interactions within them as well as their emergent properties. One possible way forward has been provided by Ostrom (2007), who has described a nested multi-tier framework (Figure 4) for organizing information about the structure of SESs, in terms of a resource system, resource units, users and governance systems. She argues that such frameworks can help bridge 'the contemporary chasm separating biophysical and social science research' (Ostrom, 2007: 15186), and build the kind of interdisciplinary science needed to address problems of sustainability.

III Application challenges

1 The limits of economic valuation

There is little doubt that the ability to estimate the economic value of ecosystem services has done much to stimulate interest in ecosystem services, particularly among those concerned with policy and management issues. However, economic valuation of the benefits ecosystems provide to people is not the only goal. As the ecosystem service paradigm matures, the contexts in which economic valuation is useful are becoming clearer, and the limits and assumptions of valuation methods are being better understood. We therefore now turn to an examination of the limits of economic valuation and the need for broader ethical perspectives in relation to understanding the importance of ecosystem services. Although these issues are not usually debated in this journal, it is important that physical geographers along with other natural scientists engage with these topics because they help define some key research challenges in the biophysical arena.

The 'Total Economic Value' (TEV) framework has been widely employed to estimate both the use and non-use values that individuals and society assign to changes in ecosystem services. A feature of recent work has been the attempt to describe how different methods can be used to estimate the various components of TEV (e.g. Brown et al., 2007; Chee, 2004; De Groot et al., 2010; Farber et al., 2006; Pagiola et al., 2004) and how such data can be used to estimate the way monetary values change under different geographical conditions (say across spatial gradients, or as a result of environmental change over time). An additional feature of recent work has been a more critical reflection on economic valuation, marginality (see below) and the role of non-monetary methods of valuation. For example, Spangenberg and Settele (2010) question the assumptions on which current monetary methodologies are based, and Gómez-Baggethun et al. (2010; see also Gómez-Baggethun and Ruiz Pérez, 2011) look at the ideological issues that attend recent trends to commodity nature. Fish (2011) has provided a discussion of the role of analytical and deliberative assessment methods.

In reviewing such debates it is important to note that reference to 'Total' in TEV is often misunderstood because the goal is not to calculate the complete value of the ecosystem in any absolute sense, but to understand how economic values change 'marginally' with a unit gain or loss in some ecosystem asset (Bateman et al., 2011b; Fisher et al., 2009). The word total should also not be taken to imply that only economic values are relevant. The main service groups (provisioning, regulating and cultural) have different profiles in terms of the various TEV categories, and the general aim is to achieve an aggregated value for the ecosystem that can be used to compare the differences between the contrasting sets of circumstances, say as the impacts of different policies or interventions. While non-money measures of the value of a service to people can be aggregated in some kind of multicriteria assessment (cf. Hein et al., 2006), interest currently focuses most on aggregating monetary estimates.

The work of Pagiola et al. (2004) remains particularly useful in helping to define the different contexts in which such biophysical understandings of marginal economic change must be set; we have to understand the magnitude of the biophysical changes before economic estimates of a change in value can be made. The first broad context concerns attempts to determine the total value of the current flow of benefits from an ecosystem, to better estimate the contribution that ecosystems make to society. The analytical strategy suggested here is to identify all the mutually compatible services provided, to measure the quantity of each service and multiply these outputs by their marginal value. They argue that these approaches are probably mainly applicable at local scales because the question implicitly being asked is: 'how much worse off would we be without this ecosystem?' (but see section III, 2, below); thus an understanding of the 'per hectare' benefits of a natural area might be useful in demonstrating that it has value to a society. At global scales, however, they suggest this kind of question makes little sense because the value is essentially infinite as there is no alternative (cf. Heal et al., 2005).

The second area of the application identified by Pagiola et al. (2004) is in valuing the costs and benefits of interventions that modify ecosystems with the aim of deciding whether the intervention is economically worthwhile. The approach involves measuring how the quantity of each service changes as a result of the intervention compared to doing nothing. It forms the basis of traditional cost-benefit analysis which is widely used as an aid to decision making. A number of studies illustrate the power of this approach. At a local scale, for example, Luisetti et al. (2011) have compared the impact of different strategies for managed realignment along the eastern coast of England, and have shown that, for the Humber and Blackwater estuaries, set-back schemes seemed to be more economically efficient in the long term than either the 'business as usual' or 'hold the line' scenarios. However, they note the importance of using a spatially explicit approach in these types of analysis because the results may be context dependent. The body of work that has been built up around the topic of managed realignment in the East of England is particularly valuable in demonstrating how fundamental a good understanding of biophysical processes is to valuation studies. Studies such as those of Andrews et al. (2006) and Shepherd et al. (2007) have looked more closely at the economic value of nutrient storage, as alongside the cycling and storage of carbon and sediment. Jickells et al. (2000) illustrate the insights that long-term historical environmental reconstruction can bring to such debates.

At a broader scale, the approach to valuation based on the analysis of costs and benefits of interventions is illustrated by the UK NEA. Here the land-cover changes implied by the different national scenarios (Haines-Young et al., 2011) were used to compare the impacts of the different storylines on a range of ecosystem outputs that could be valued using market- and non-market-based methods (Bateman et al., 2011a); the marginal changes in value were calculated using the year 2000 as the baseline. Elsewhere, Swetnam et al. (2011) have used GIS and participatory methods to construct a scenario study of the Eastern Arc Mountains of Tanzania (see also Fisher et al., 2011), and Polasky et al. (2011) have made a similar kind of economic analysis of alternative scenario outcomes describing different land-use futures in Minnesota, USA, using the InVEST GIS toolbox (Daily et al., 2009). These kinds of study illustrate some of the strengths and limitations of economic analysis. Thus, while a comparison of the marginal differences in economic values between alternative policy options of management strategies is a powerful framework for decision making, decisions ultimately depend on what criteria are included in the analysis. So, while the scenarios developed in the UK NEA were not proposed as policy alternatives, the view that one might take of these alternative futures depends upon whether we only focus on market-priced values or also take account of non-market values in the discussion. In both the UK and US studies, the scenarios that led to the greatest expansion of marketed agricultural goods (and hence private benefits) led to the largest declines in those services that provide public or shared benefits, such as greenhouse gas emissions and carbon sequestration.

The third and fourth application areas described by Pagiola et al. (2004) further emphasize the importance of what economic analysis can and cannot achieve. They concern examining how the costs and benefits of an intervention or impact on an ecosystem are distributed across society and over time, and the kinds of financing mechanisms that might be established to better realize the public benefits that ecosystem services can provide. The examination of impacts on social equity requires the identification of the relevant stakeholder groups, the services they use, their needs and the values they attach to services, and how they would be affected by any intervention or impact. This kind of distributional analysis is now being widely applied to ensure that management interventions do not harm vulnerable groups and, in particular, to try to ensure that interventions reduce poverty (De Koning et al., 2011; see also Fisher et al., 2011). However, as a number of commentators have argued, distributional issues are not simply a matter of economic analysis, and the 'commodification' of ecosystem services is likely to lead to counterproductive outcomes for biodiversity and equity in relation to ecosystem service benefits (Gómez-Baggethun and Ruiz Pérez, 2011). By turning services into commodities, these authors argue, one potentially transforms them into things that can only be accessed by those with purchasing power. Wegner and Pascual (2011) have also provided a critique of economic cost-benefit methods, and argued that when dealing with public ecosystem services we need more pluralistic approaches to articulating the values that people hold and that, although traditional approaches have a place, we must not be locked into a 'monistic approach' based on individualistic values and ethics. These types of issue are especially apparent in the context of the new kinds of financing mechanisms for ecosystem services.

It has been argued that Payments for Ecosystem Service (PES) schemes can help realign the private and social benefits resulting from their environmental management decisions (for reviews, see Smith, 2006; Smith et al., 2006; Wunder, 2005, 2007). The approach is based on paying individuals or communities to undertake actions that increase the levels of the desired services and, in their purest form, enable those who directly benefit from a service to make contractual or conditional payments to local landholders who provide them. The market mechanism thus helps internalize environmental externalities, and potentially can change aspects of property rights.

Van Hecken and Bastiaensen (2010) have, however, looked at the political economy aspects of PES schemes, and noted that in recent debates the market efficiency aspects of such schemes have often overshadowed discussion of the distributional implications. They argue that key issues that need to be considered include how the externality is defined, whether such schemes should focus on positive or negative externalities, and what the implications of this decision might be. These kinds of issue will determine whether the user should pay for the right to enjoy the service or the provider for the right not to provide it. On the basis of their work on multiple forest uses, Corbera et al. (2007) have argued that unless legitimacy and equity issues are fully considered these new kinds of market mechanism may only reinforce existing inequalities and power structures. Given the complex relationships between ecosystem functions in different spatial and social contexts, Van Hecken and Bastiaensen (2010) emphasize how important it is to ground the design of schemes on a good biophysical understanding of the social-ecological system as well as knowledge about social and political contexts. Jack et al. (2008) make a similar point, and suggest that this is a particular issue when the marginal benefits of intervention are not constant across space and time, and when there is uncertainty about the way performance measures used to assess service output relate to the kinds of intervention or efforts made by the provider. Further biophysical complexities emerge when we consider how to deal with situations where more than one service is influenced by the decisions that land managers make, and where those services have benefits to groups at different spatial scales. It is apparent that an understanding of the values people hold about particular services, and the views they take of the trade-offs between them, can often only be achieved by an appreciation of the multifunctional character of the localities or places in which decisions are being made. Thus a place-based perspective on the structure and dynamics of social-ecological systems and the ecosystem services that are associated with them is a key area where Geography might make a distinctive contribution.

Consideration of the contexts in which economic assessments of ecosystem services are made suggests that while such research appears to be a major force in shaping ideas in the current paradigm it is clearly not unproblematic. Too great a focus on economic valuation, and the assumption of rational economic behaviour, results in an unfortunate narrowing of perspectives that tends to obscure ethical and political issues and the role that natural science can play in understanding how people and nature are linked. Better understanding the limits of economic valuation is a key application challenge if we are to preserve the broad perspective of the ecosystem service paradigm. Whether we are concerned with economic assessments or wider distributional issues, knowledge about the sensitivity of ecological structures and functions to the different drivers of change in different places is a prerequisite for making any progress, and it is precisely here where Physical Geography can provide insight.

2 Maintaining natural capital

The emphasis currently placed on the economic valuation of ecosystem services is perhaps inevitable, given the financial terminology used to express the idea that people benefit from nature. In arguing that there are limits to such work we do not suggest that efforts to make monetary estimates are not without their merits. Indeed, as Goldman et al. (2008) have found, conservation projects involving ecosystem services (e.g. carbon, water and ecotourism) appear to attract more funding than those more traditionally focused on biodiversity from a more diverse set of sources. Instead, our purpose here is to consider the ecosystem services paradigm in a more balanced way, and describe how different disciplinary expertise might be more effectively combined. Nowhere is this more vital than in the identification of critical thresholds in social-ecological systems.

It is widely acknowledged that social-ecological systems can exhibit complex dynamics, that include non-linearities, thresholds (regime shifts) and more gradual changes to external pressures. In fact, these non-linearities appear to be part of the emergent properties that coupled social-ecological systems can exhibit. The consequence is that management or policy interventions may be difficult because they can involve making decisions against a backdrop of considerable uncertainty (Rockström et al., 2009; Scheffer and Carpenter, 2003; Scheffer et al., 2001, 2003; Walker and Meyers, 2004; Walker et al., 2006). The existence of such behaviour also has implications for the way we value or assign importance to ecosystem outputs, because they undermine key assumptions on which economic valuations are made. As a number of commentators have argued (see above and, for example, Fisher et al., 2008) if economic valuation is primarily about the 'difference' something makes, then the analysis of marginal value is *only* possible when an ecosystem is far from an unstable threshold or tipping point. It is in this context that the notion of Safe Minimum Standards (SMS) arises (see also Ekins, 2011). By crossing such thresholds social-ecological systems, by definition, will exhibit quite different characteristics to those we are familiar with, and the level and mix of benefits they provide to people may be significantly changed. In these situations, arguments about whether strategic policy or management interventions are justified turn more on ethical and political considerations, or arguments about the intrinsic and instrumental

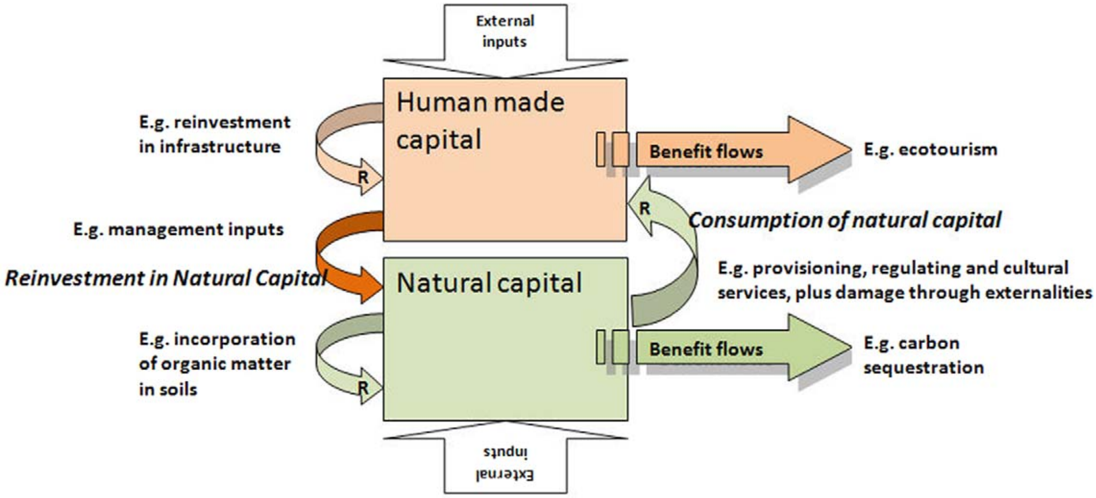

Figure 5. The relationship between natural and human-made capital, and ecosystem stocks and flows, in a social-ecological system (R = reinvestment)

values we attach to nature, rather than on economic impacts (see, for example, Justus et al., 2009). The differences are too large and significant to be regarded any longer as 'marginal'. Spangenberg and Settle (2010) argue more generally that economic analysis alone is not adequate for defining conservation objectives or policies, which rather should be set by political processes based on 'multistakeholder' and 'multicriteria' analysis. We might add that the views people take of the risks associated with system collapse are also key issues.

Discussion of what these minimum levels of natural capital might be and how we might describe, maintain and restore them, has taken many forms in the natural sciences. They have been considered implicitly in this journal by O'Keeffe (2009), for example, who considered the problem of defining sustainable flows in rivers in South Africa. He found that, while knowledge about the eco-hydraulics of the system was necessary, understanding the social-economic and political context was of overriding importance for successful implementation of management responses. Elsewhere, Physical Geographers have provided relevant case-study materials in the context of whether strategies for rewetting of peatland ecosystems can transform the prospects for water quality and carbon sequestration (Holden et al., 2011; Ramchunder et al., 2009; Wilson et al., 2011a, 2011b). While such case studies are important in their own right, it is also helpful to look at them in the context of wider debates about how we characterize natural capital stocks in general and what interventions are required to maintain their integrity.

The issue of maintaining capital stocks has been the focus of recent debates in environmental accounting (Bartelmus, 2009; Mäler et al., 2008, 2009; Walker and Pearson, 2007; see also Haines-Young, 2009; Weber, 2007). These discussions highlight the fact that, while much of the current literature dealing with the problem of valuing the benefits from natural capital has focused on the *flows* of final products or services, the importance and costs of maintaining the ecosystem structures and functions (stocks) that underpin them cannot be overlooked. Figure 5 describes how natural and human made capitals are linked and co-dependent with a social-ecological system, and suggests how both stocks and flows might be considered. In addition to valuating final services, we suggest an equally important application challenge is to understand the scale and/or value of the intermediate services consumed in the production of these final goods. In the same way in which society has to reinvest in human-made capital to take account of depreciation, we must also consider the level of reinvestment in the stock of natural capital needed to sustain the output of ecosystem services. Such 'reinvestment' in natural capital stocks arises because we judge the flow of some service or set of services to be impaired or inadequate, and may take many forms including maintenance or management, protection and restoration costs (assuming 'restoration' is possible). However, it could also include less tangible things like resilience (e.g. Deutsch et al., 2003; Vergano and Nunes, 2007) and 'use forgone'; the latter can be thought of as the stock of natural capital that must not be appropriated to ensure that ecosystems retain their capacity renew and sustain themselves. If the kind of 'stock-based' approaches to measuring sustainable development described by Bartelmus (2009) and Walker and Pearson (2007) are to be delivered, however, those interested in the structure and dynamics of social-ecological systems must devise improved physical accounting methods that describe the ways in which the quantity and quality of natural asset stocks change over time for social-ecological accounting units that are relevant in a decision-making context.

IV Conclusion

Whether we choose to view the developments around the idea of ecosystem services as a paradigm or not, it is clear that a considerable body of interest has been built up around the concept that goes beyond the science community. The debate has usefully reinvigorated discussions about the critical natural capital and sustainable development, and refocused attention of ideas about thresholds and uncertainties in coupled social-ecological systems. The promise it appears to hold for making economic arguments about the importance of environment to people has, perhaps, most of all stimulated interest among decision makers, and, as Daily et al. (2009) have noted, perhaps we are at a point where it is 'time to deliver'. The task of developing a rigorous body of research that addresses both science and user concerns, alongside credible decision support tools that can be used beyond the academy, will not be an easy one. As Sagoff (2011) has argued, the conceptual distance between market- and science-based approaches to constructing and using knowledge is considerable. The challenges of this transdisciplinary exercise will not, however, be met by uncritical puzzle solving.

In this paper we have sought to argue that Physical Geographers, along with other natural scientists, can make a significant contribution to the research and policy questions posed by the notion of ecosystem services by helping characterize the structure and dynamics of social-ecological systems. As we have shown, the need to provide understandings of social and physical processes within the context of places and regions has never been more important. Thus social-ecological systems should be a key part of what physical geographers study. Although such systems are 'socially contracted', in the sense that they depend on how beneficiaries see the world as well as on understanding its biophysical characteristics, they also constitute meaningful and relevant process-response units. They provide new, inter- and transdisciplinary frameworks in which more traditional approaches can be set. Future research challenges include describing how the ecological structures and functions embedded in such systems link to service outputs, and how sensitive these outputs are to the various drivers of change. Such knowledge is needed before an economic valuation of ecosystem services can be made and to avoid the problems of double counting. More importantly, it is an essential ingredient of the ethical and political debates at the interface of people and the environment. We need to see the ecosystem service paradigm as part of broader discussions about environmental governance, and find ways of combining the generic insights that science can provide with more contextual or place-based knowledge to identify what is critical in relation to our natural capital base and the choices we face in sustaining it.

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Notes

1. See www.teebweb.org.
2. See http://www.ipbes.net.
3. See www.scopus.com.
4. Five articles in *Progress in Physical Geography* make reference to the term ecosystem services either in the title, abstract or body text according to Scopus, up to the end of 2010.
5. See for example the Royal Geographical Society: http://www.rgs.org/GeographyToday/What+is+geography.htm.
6. We understand 'interdisciplinarity' to be an integrated attempt at problem solving involving experts from a number of research domains; 'transdisciplinarity' also provides integrated perspectives but includes lay knowledge to frame questions and evaluate outcomes.
7. A subglobal assessment in the style of the Millennium Ecosystem Assessment (MA, 2005).
8. Some authors use the term 'socio-ecological system' rather than 'social-ecological system'; we use the latter for consistency but regard them as the same thing.
9. See The Conference Of The Parties to the Convention On Biological Diversity at its Fifth Meeting, Nairobi, 15–26 May 2000. Decision V/6, Annex 1. CBD COP-5 Decision 6 UNEP/CBD/COP/5/23.

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