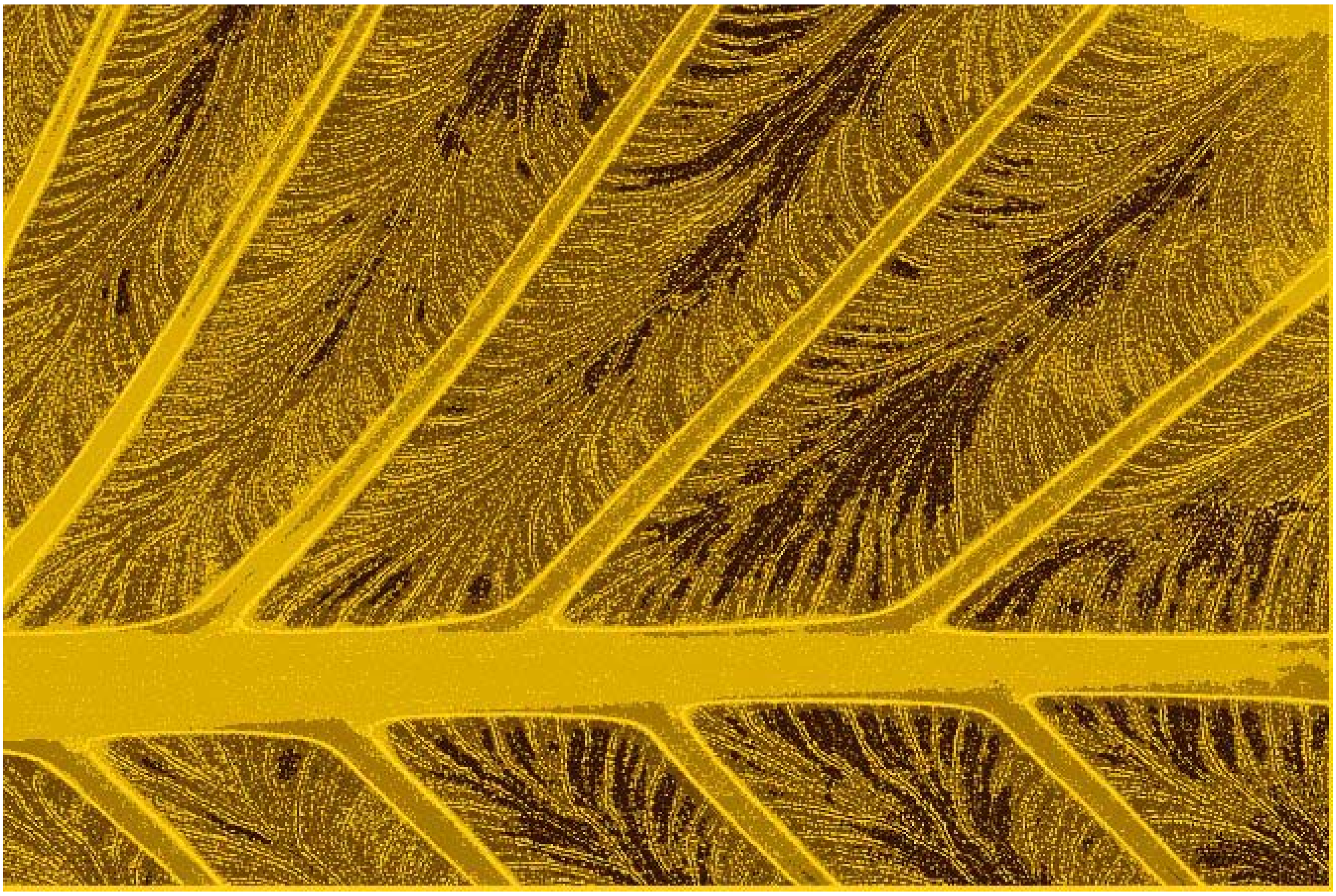
Methodologies for defining and assessing ecosystem services



The University of Nottingham

CEM Report | No 14

CEM Centre for Environmental Management

Methodologies for defining and assessing ecosystem services

A research study to

JOINT NATURE CONSERVATION COMMITTEE

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Executive Summary

Background

1. The idea that ecosystems can provide a range of benefits to people has become the focus of intense research and policy interest. Recent debates have partly been stimulated by the publication of the Millennium Ecosystem Assessment, but have also been given added impetus by an awareness that if we want to manage our natural capital in sustainable ways, a more integrated, cross-sectoral approach to decision making is required. The notion of ecosystem services is now widely recognised as a fundamental part of the Ecosystem Approach, and the challenge that now faces us is how to embed this more firmly in policy and management practices.

2. At a time of rapid conceptual change, however, when new ideas and information are being introduced and discussed, it is often difficult to be confident that decision making is based on the most robust evidence available. Thus the **aim of this study** is to take stock of what has been achieved, and clarify some of the important issues for an organisation like JNCC, which works at the interface of science and policy.

3. The purpose of this study is therefore to:
    a. Undertaken a critical review or methodologies used to describe ecosystem goods and services;
    b. Examine the ways links are made between services, functions, ecological structures and processes and human well-being;
    c. Consider what is known about the relationships between biodiversity and ecosystem services; and,
    d. Review current approaches for the valuation of ecosystem services and better understand the barriers to future progress.

4. Our review has been based on extensive bibliographic search and scrutiny of key national and international initiatives, such as *TEEB* (The Economics of Ecosystems and Biodiversity) and the UK National Ecosystem Assessment.

Describing ecosystem services and ecological functions

5. **Our review of approaches to the classification of ecosystem services suggests that no universally accepted typologies presently exist, although the MA framework is still widely applied.** In contradistinction to the MA definition of a service as the benefits ecosystems provide for people, this review suggests that ecosystem service are now broadly understood as the contributions that ecosystems make to human well-being. However, most commentators accept the equivalence of the terms ‘goods’ and ‘services’ as suggested by the MA.

6. **Recent debates have increasingly stressed the need to differentiate benefits, services, ecological functions, and ecological structures and processes, to emphasise the mechanisms that underpin the links between natural capital and human well-being**. Because the elements of human well-being may be aggregations of different kinds of benefit, it is useful to differentiate services from benefits to emphasis the particular role that ecosystems play.

7. Although the MA categories of provisioning, regulating and cultural services remain useful, the supporting services are best regarded as synonymous with concepts such as 'intermediate services' or 'ecological functions' to avoid the problem of 'double counting' in any assessments, and to emphasise the 'production chain' that underpins services.

8. Existing typologies are ambiguous about the extent to which ecosystem services are fundamentally dependent upon biodiversity or can also be generated by abiotic ecosystem elements. However, **it is important to retain the focus on biodiversity in any typology, to help make stronger the utilitarian arguments for conserving natural capital.**

9. **New, hierarchical approaches to classifying ecosystem services are probably required to help make the evidence more useful for decision makers.** Such approaches would describe more rigorously and systematically the relationships between the different conceptual elements that make up the ecosystem services approach.

Linking services and biodiversity

10. There is a considerable body of evidence to suggest that biodiversity and ecosystem functioning are closely linked:
    a. particular combinations of species may have a complementary or synergistic effect on their patterns of resource use which can increase average rates of productivity and nutrient retention;
    b. the vulnerability of communities to invasion by alien species is influenced by species composition and under similar environmental conditions, generally increases as species richness falls; and,
    c. ecosystems subject to disturbance can be stabilised if they contain species with traits that enable them to respond differently to changes in environmental conditions

11. Because of the complexity of causal chains it is much more difficult to trace the impact of changes in biodiversity through to changes in service output. **To examine**

the links between biodiversity and services further, it is recommended that more service focused research and assessment approaches are required.

12. Our review suggests that new assessment methods are being developed, and a greater range of sophisticated tools and approaches to support biophysical appraisals are now becoming available The concept of service providing units has emerged as a useful basis for developing functional mapping approaches, and new mapping tools are being actively developed. **However, there is an urgent need to ensure that these new biophysical assessment methods link to and support social and economic methods for assessment, so that robust, integrated appraisals can be undertaken in ways that support the needs of decision makers.**

Valuing ecosystem services

13. The importance of the valuation issue is demonstrated by the fact that this topic area forms the largest group of papers published in the context of the ecosystem services framework. The key messages that are emerging from this growing body of work are that:

    a. It is essential to distinguish benefits and values clearly, because different groups may hold different values or perspectives on benefits. While the capacity of ecosystems to deliver benefits to people may be constant the values we attach to them may also change over time;
    b. While economic valuation is the most widespread method used to compare people's perspectives on benefits, there is growing interest in non-monetary techniques; and,
    c. While the range of valuation methods available has grown in number and sophistication, there is still a need to improve the robustness of techniques, especially those relying on stated preference approaches and benefit transfer approaches.

14. **Our review suggests that it is essential to understanding the biophysical and social contexts of in which economic valuation is carried out if the analysis is to be relevant to the needs of decision makers and society more generally.** It is now widely recognised that economic valuation has to be viewed from a cross-disciplinary perspective if it is to be effective.

15. **In terms of future research there is an urgent need to ground valuation studies on an understanding of the biophysical mechanisms that underpin ecosystem services, to make a better analysis of the marginal changes in value that can occur in ecosystems subject to different pressures and interventions**.

16. **It is also essential to develop a better understanding of what minimum safe levels of natural capital are required to produce a sustainable flow of services.** Economic analysis becomes difficult and unreliable in situations where ecosystems exhibit sudden regime shifts or collapse. There is growing interest in valuing ecosystem resilience and the insurance it provides against risk, and of calculating the costs of ecosystem maintenance.

Conclusions and Recommendations

17. A key conclusion that can be drawn from recent developments is that disciplinary perspectives are being transformed. **If JNCC is to adopt and cope with these changes then the implication of the review is that the assessment methods it uses and promotes must be grounded on social, economic and biophysical criteria in a balanced and integrated way**.

18. **Since no universally accepted frameworks for classifying and assessing ecosystem services presently exit, it is recommended that JNCC actively engage in the design and application of new conceptual models that emphasise more clearly the links between ecological structures and processes and human well-being on the other.** The purpose of such involvement should be to help create decision making frameworks that are fit for the purposes that JNCC seeks to promote.

19. **In promoting future research we recommend that JNCC should focus not only on establishing the links between the different components of biodiversity and ecosystem functioning, but also the wider connections between biodiversity and ecosystem services.** This may involve taking a service-orientated perspective rather than the traditional one that focuses mainly on biodiversity issues, involving understanding how marginal change in economic values relate to changes in ecosystem output, and what levels of natural capital are required to sustain the benefits that ecosystems of concern to the UK provide.

Part 1 Introduction

Background and Aims

At a time of rapid paradigm change, concepts and terms are often used in different ways. As a result, new science and policy frameworks may initially be difficult to use and the opportunities they provide to resolve outstanding questions might be realised only slowly. This situation exists in relation to recent discussions surrounding 'ecosystem services', a set of ideas that received considerable stimulus by the publication of the Millennium Ecosystem Assessment (MA) in 2005.

The novel aspect of the ecosystem services paradigm is that it encourages people to examine the links between ecosystems and human well-being in novel ways. The so-called 'ecosystem services approach' also seems to offer the prospect of developing more integrated solutions to the problem of understanding the nature and scale of ecosystem degradation, and the kinds of strategy that might be needed in the face of future environmental change. However, despite the recent, rapid increase in the number of publications on the topic, several important issues need to be clarified (Fisher et al., 2008; Egoh et al., 2007).

The aim of this study is therefore to make a wide ranging review of the current scientific and policy literature surrounding the concept of ecosystem services, so that the similarities and differences between approaches for defining and using the ecosystem service concept can be identified. By taking stock of recent progress, it will be possible to identify those areas of work which seem to hold more promise in relation to supporting the work of JNCC.

The brief for this review has identified the following key areas of interest:

1. The methodologies used to describe ecosystem goods and services;
2. The ways links are made between services, functions, ecological structures and processes and human well-being;
3. The relationships that have been identified between biodiversity and ecosystem services; and,
4. Current approaches for the valuation of ecosystem services.

On the basis of the review, the brief asked for the similarities and differences in approaches and their applications to be identified. The main sections of this Report cover each of these topic areas in turn, and document the progress that has been made and barriers to application of the ecosystem service framework.

The ecosystem services approach

The key elements of the 'new' ecosystem services paradigm have been described by several recent commentators, essentially as a problem solving framework. Thus Tallis et al. (2008) see it as highly pragmatic in character, allowing us to 'assess the connections between ecosystem services and economic development on a project-by-project basis and suggest indicators and metrics that could increase the likelihood of win–win outcomes.' Turner and Daily (2008), by contrast, argue that the emerging Ecosystem Services Framework (ESF) has both practical and theoretical implications. They agree that it emphasises the 'role that healthy ecosystems play in the sustainable provision of human wellbeing, economic development and poverty alleviation…' (p.25), but also suggest that it provides a template for a more holistic analytical approach for decision making (Figure 1.1).

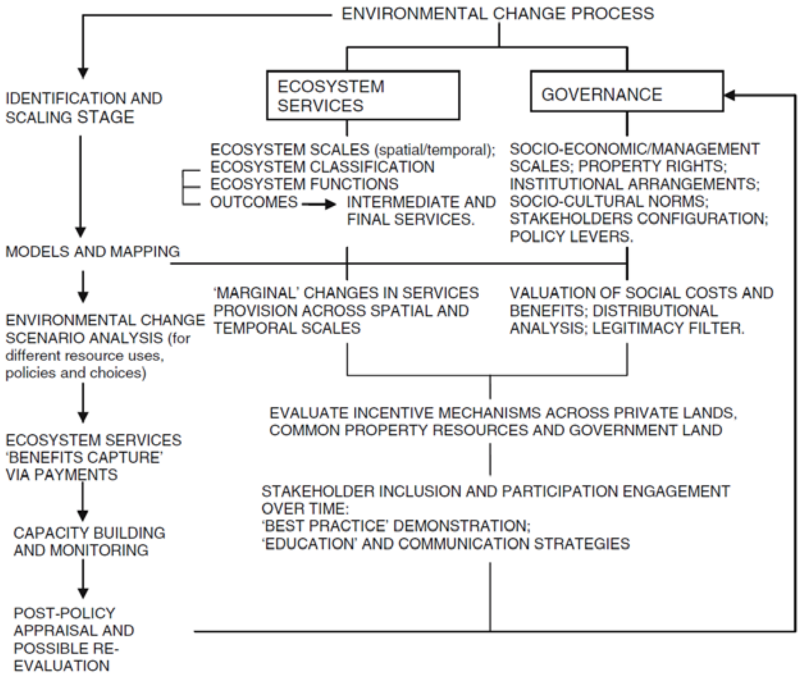

Figure 1.1: The ecosystem services framework (after Turner and Daily, 2008)

Turner and Daily (2008) argue that information at scales useful for decision makers on how people benefit from specific services is lacking, and that better integrated approaches are required for modelling, mapping and valuing ecosystem services. The remedy, they conclude is the development and implementation of the Ecosystem Services Framework, which includes a 'tighter classification' of ecosystem services and the distinction between intermediate and final products in order to achieve a reliable and realistic valuation of ecosystem services. The classification and valuation of services is seen as supporting the development of appropriate governance mechanisms and effective participatory decision making processes.

The ESF model shown in Figure 1.1 usefully contextualises the present study which also starts from the premise that a better classification of ecosystem services is needed before these ideas can be used operationally. It is also broadly consistent with other attempts to describe the ecosystem service framework recently proposed, for example, by Brown et al. (2007), Daily et al. (2009) and the US Environmental Protection Agency Science Advisory Board, EPA-SAB (2009). As indicated in the diagram the classification issue links closely to key methodological questions concerning the wider relationship between services, functions, ecological structures and processes and human well-being. Perhaps one of the most striking features of the approach, as outlined, is its inter-disciplinary nature, linking natural science elements with aspects of economic valuation and governance. In terms of the novelty of the ideas expressed in this diagram, it is a moot point as to whether the framework differs in any major key respects from the more widely discussed Ecosystem (or Ecosystems) Approach[1] (Defra, 2007a), which also seeks to emphasise the importance of a cross-sectoral approach that ensures that the full value of natural capital is reflected in decision making. Nevertheless, clearly one of the merits of this Figure is that the linkages between different concepts and areas of concern can be seen clearly. It seems to offer a kind of 'road map' for anyone interested in using the ecosystem service approach as part of their work.

In using the term 'ecosystem services approach' throughout this document, there is no implication that it is an alternative to or substitute for the Ecosystem Approach, but more a set of ideas that usefully articulates how the latter might be implemented or embedded in research or policy work. Given the brief for this study it is clear that we only focus on part of this framework. Part 2 deals with the classification of services and the way links between functions, ecological structures and processes are conceptualised. In Part 3, recent work on the relationship between biodiversity and service output is reviewed and further discussion of the links between services an underlying functions and processes are considered. Part 4, deals with the problem of valuation of services is considered. The report concludes by providing a set of recommendations on how, given the present state of knowledge, the ecosystem services approach might be applied. The study has identified a number of important science and policy issues that must be resolved if the concepts surrounding ecosystem services are to be used operationally to inform decision making, and the recommendations describe some potential ways forward.

Context

This study comes at a time when there are many important national and international initiatives focusing on different aspects of ecosystem services. One of the key findings of the Millennium Ecosystem Assessment (MA) was that at global scales, loss of ecosystem services probably means that the UN's Millennium Development Goals are unlikely to be met. As a result the links between ecosystem services and poverty alleviation has become a focus on recent international work[2].

It is clear, however, that the impact of human pressures on ecosystem services is not a problem that is exclusive to the developing world. The significant contribution that the MA has made globally was acknowledged by the House of Commons Environmental Audit Committee (House of Commons, 2007), who went on to review its relevance in the UK context. They noted the slow uptake of the implications of the MA for both domestic and foreign policy by the UK, and recommended that 'ultimately the Government should conduct a full MA-type assessment for the UK to enable the identification and development of effective policy responses to ecosystem service degradation' (para.

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1 It should be noted that the literature contains a number of variations in terminology designed to emphasise different aspects of the idea. Reference is often made to an 'ecosystem-based approach', a term used mainly to promote holistic thinking in the design of specific management strategies for natural resource systems. More commonly the term 'Ecosystem Approach' is employed. The latter originates from the Convention on Biological Diversity (CBD) and emphasises the higher-level or more strategic issues surrounding decision making. Defra, in a recent publications (e.g. Defra, 2007), refer to an 'Ecosystem***s*** Approach', using the plural to emphasise that no prescriptive methodology is implied. In this report we employ the terminology used by Defra – but see no substantive difference in the way the two ideas are conceptualised. In this report we also avoid abbreviating the term 'Ecosystems Approach' as 'EA' because it can be confused with the abbreviation for the Environment Agency; the IUCN CEM suggests using EsA as an alternative (written communication, 2007).

2 http://www.nerc.ac.uk/research/programmes/espa/

125). Such a national assessment is now underway[3], and builds on a range of studies commissioned by Defra, Natural England, Environment Agency and others on what the current evidence base can tell us about the state and trends of ecosystem services at national scales, and the range of benefits obtained from 'well-functioning' ecosystems at the national, regional and local scales.

Elsewhere, the European Environment Agency (EEA) has launched *EUREKA* 2012 initiative, which is a European Ecosystem Assessment that will contribute to the MA follow-up as a sub-global assessment. The Report will be published in 2012, and will include an assessment of the stocks, flows and value of selected ecosystem goods and services under different policy-relevant scenarios. Such work coupled with that currently being undertaken in other European countries, will potentially feed into the next global assessment planned for 2015[4]. *EUREKA* 2012 sits alongside other work relevant to ecosystem services being undertaken by the EEA linked to the streamlining of biodiversity indicators (SEBI2012) and the SEEA2003 revision of economic and environmental accounting methodologies.

Perhaps the most significant international initiative that is currently underway, however, is *TEEB*, The Economics of Ecosystems and Biodiversity[5]. This study stems from a proposal by the German Government that was accepted by the meeting of the environment ministers of the G8 countries and the five major newly industrialising countries that took place in Potsdam in March 2007. The aim was to better understand the global economic benefit of biological diversity, the costs of future losses resulting from the failure to take protective measures compared to the costs of conservation. As the Phase I, interim report (European Communities, 2008) demonstrated, although ecosystem services are a major focus of the work but that their analysis poses significant methodological challenges. Thus a major aim of the second phase of work is to both clarify these issues and make a comprehensive analysis. The results will be published between 2009 and 2010 as one background report and several reports targeted towards specific groups of potential users of evaluation tools for biodiversity and ecosystem services. The final results will be presented at CBD COP-10 in 2010.

Chan et al. (2006) have observed that despite the importance of ecosystem services, decision makers in both the private and public sectors have been slow to incorporate them into their work. Although they attribute this to many factors including some from outside science the core of the problem is, they suggest, a 'poor characterization of the flow of services in the necessary biophysical and economic terms at the local and regional scales' (p. 2138). The commissioning of this study is therefore timely, in that the output will potentially help JNCC to formulate their both their input and response to these wider initiatives that focus upon issues relating to ecosystem services. The challenge that confronts us is to integrate science and policy perspectives in ways that support decision makers, and help people to understand the benefits that natural capital can provide.

Review Methodology

This study has been based mainly on a systematic review of the recent research literature. A number of authors have commented on the rapid growth of journal articles dealing with aspects of ecosystem services. Fisher et al. (2008), for example, identified over 1100 papers using Web of

[3] http://www.defra.gov.uk/news/latest/2008/environ-0722.htm

[4] Reference to other European countries and ma follow-up 2015

[5] http://ec.europa.eu/environment/nature/biodiversity/economics/index_en.htm

Science and the keywords “ecosystem services”, or “ecological services”, or “environmental services”. When embarking on this study we used both Web of Knowledge (WoK) and Science Direct (SD), and it appears that the number of potentially relevant references in 2009 is substantially larger. It was found that by including “environmental services” in the search protocol, a number of papers from outside the field were identified, and so the additional constraint that the paper had to include reference to “ecosystem” or “ecological” were added to the search string; even so Web of Knowledge identified over 4000 papers.

Table 1.1: Criteria used in the meta-analysis to identify differences and similarities in the ecosystem services approach

	Analytical theme	Thematic issues	Key words “ES=ecosystem service*”
1	**The methodologies used to describe ecosystem goods and services**	• How are services defined? • What service typologies are widely used? • What difficulties with service typologies have been noted?	• ES classification • Classification of ES • ES typology • Typology of ES
2	**The ways links are made between services, functions, ecological structures and processes and human well-being**	• How is/are the service(s) characterised? o Are services estimated model-based or are they measured empirically? o Does the study deal with supply of the service and/or demand for it? • How is the link to human well-being made? To what extent is service demand considered? • What components of the underlying ecosystem are the services assumed or shown to be dependent on?	• ES AND measurement • ES AND model(l)ing • ES and mapping • ES AND production function • ES AND supply OR demand
3	**The relationships that have been identified between biodiversity and ecosystem services**	• How is the notion of biodiversity constructed or operaitonalised? • How is the link to a service made? • How is the notion of an ecosystem constructed? o Is the study habitat-focused, system focused or essentially place-based? • How is the sensitivity of service output to changes in biodiversity assessed?	• ES AND biodiversity • ES AND biodiversity AND relationship • Biodiversity AND ecosystem functioning
4	**How are ecosystem services valued?**	• How is/are the output of the ecosystem service(s) valued? o What component(s) of the TEV framework are covered? o What methods are used to estimate values? • Is the valuation original or based on benefit-transfer methods? • How does the study construct the notion of change in marginal value? • Does the study consider the multi-functional aspect of ecosystems? o Are notions of trade-off included in the study? • What limitations in the estimate of value are noted? • If the study considered non-economic aspects of value, what are they?	• ES AND valuation AND method* • ES AND valuation AND multifunctional • ES AND trade-off • ES AND threshold • ES AND limit

Clearly the volume of material potentially available is so large that more refined examination of the topic is required. To help clarify search strategies, a series of questions were developed covering the four main topic areas identified above. These questions and illustrative search criteria are summarised in Table 1.1. Using these protocols to identify more specific groups of publications the results were downloaded into an *EndNote* database, and grouped around the different thematic areas. Numbers of citations were used to identify key papers, and these were also used to extend and widen the review. Since many papers on the topic of ecosystem services are recent in origin, the volume of citations was only a partial guide to the importance of a paper, thus for the later publications a judgement about their significance had to be made. The references cited by the core papers identified were also used to widen the rage of material included in the review.

The search criteria used to explore each of the four thematic areas are discussed in detail in the each of the main sections of the Report. In each case, the publications identified were drawn from the larger group of 3000 or so publications that contained reference to the main key words. Once relevant sub-groups had been identified, they were downloaded into *EndNote* and duplicates eliminated. Only peer-reviewed journal or review publications in English were considered. In practice it was found that the searches undertaken by Web of Knowledge were more comprehensive and was more clearly able to identify papers that were known to be key contributions in the field. Thus, this search engine was used as the basis of the analysis that follows.

In addition to the literature review, the study was also informed by the outputs of a number of workshops and seminars that took place in the period which covered the work. For example, given the difficulties surrounding the classification of ecosystem services, the European Environment Agency, together with UNEP and the German Federal Ministry of the Environment organised an international expert meeting on the topic in December 2008[6], to arrive at a consensus on nomenclature that can be used in future work, such as the MA-follow-up, Eurika 2012, SEBI2012, and the SEEA2003 revision of economic and environmental accounting. The authors also took part in meetings held as part of the recently completed *Rubicode*[7] Project, and discussions relating to Phase II of TEEB, and the recently initiated UK National Ecosystem Assessment. These and other relevant sources of evidence are also identified clearly in the sections that follow.

6 International expert meeting on classification of ecosystem services 10 and 11 December 2008 at EEA/Copenhagen

7 http://www.rubicode.net/rubicode/index.html

Part 2 Defining Ecosystem Services

Introduction

We consider here the methodologies used to describe ecosystem goods and services, and the ways links are made between services, functions, ecological structures and processes and human well-being. These two thematic areas were found to be so closely connected that it proved best to consider them together.

From the two large sets of papers identified by the search engines, a more specific search was made to identify those which discussed issues related to the definition of ecosystem services and their classification. While many papers (65) referred to some classification schema, a smaller number (approx 28) explicitly used the phrase "ecosystem service(s) classification" OR "classification of ecosystem service(s)" in the title or abstract. From this core, about 8 sources emerged as providing the main pointers to the approaches used in the recent scientific literature, and using their reference to track back a final set of 13 key sources were identified[8] (Table 2.1). Although other listings of services probably exist in the literature, it would seem that these represent the set which have been most widely discussed.

Many papers referring to a classification scheme for ecosystem goods and services simply cited the framework of the Millennium Ecosystem Assessment or some variation of it. This work therefore forms the focal point for this review. The other core sources, which both pre- and post-dated the MA, were selected for this review because they significantly differed from the MA in the way the formulated the key concepts. Some of the principle differences identified from the core papers are summarised in Figure 2.1. The principle dichotomy was the equivalence of the terms 'services' and 'benefits', and they role of ecosystem processes and functions; these issues have been used to organise the Figure. Differences also emerged in terms of the equivalence of the 'goods' and 'services' and the inclusion of biotic and abotic elements in the classification systems. The eight classification typologies that are provided by these core papers can be found in Appendix 1. However, it has also been informed by recent work on the classification of services undertaken as part of the TEEB process and the initiatives being led by the EEA (See Part 1).

Defining Ecosystem Services

Although much recent work has adopted the classification of ecosystem goods and services proposed in the Millennium Ecosystem Assessment (MA), there has been considerable debate about the adequacy of the framework shown in Figure 2.2. Criticisms have focused on its inherent ambiguity, its internal logic and the practical basis it offers to decision makers concerned with management or policy issues. This situation prevails despite the many attempts to provide systematic typologies of ecosystem functions, goods and services (Binning et al., 2001; Daily, 1997; de Groot, 1992; de Groot et al., 2002; MA, 2005; Kremen, 2005). The review that follows mainly focuses on the discussion represented by the core papers identified in Figure 2.1

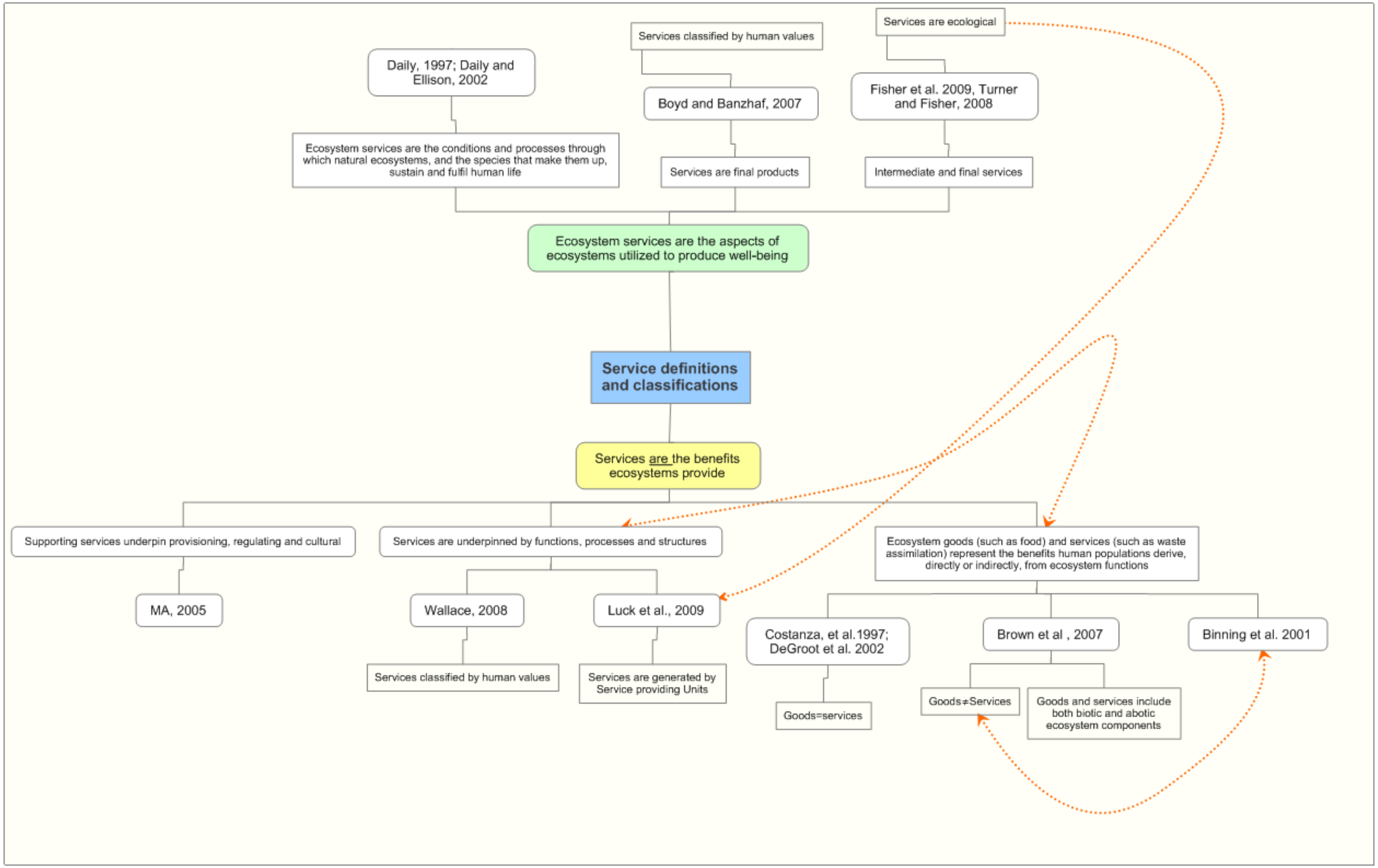
[8] An Endnote bibliography and an EXCEL spreadsheet are provided as part the output of this study, in which references are grouped as described in the main text.

Table 2.1: Core papers and sources identified in relation to debates abot ecosystem service definition and classification

Source	Exclusively biotic (1)	Provides classification (2)	Basis of classification (3)
Binning, C., et al. (2001): Natural Assets: An Inventory of Ecosystem Goods and Services in the Goulburn Broken Catchment. CSIRO Sustainable Ecosystems, Canberra.	N	Y	S
Boyd, J. and Banzhaf, S. (2007): What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63(2-3): 616-626.	N	Y	B
Brown, T. C. et al. (2007): Defining, valuing, and providing ecosystem goods and services. Natural Resources Journal **47**(2): 329-376.	N	Y	S
Costanza, R. (2008): Ecosystem services: multiple classification systems are needed. Biological Conservation, 141, 350-352.	Ns	Y	multiple
Costanza, R. et al. (1997): The Value of the World's Ecosystem Services and Natural Capital. Nature, 387, 253–260.	Ns	Y	S
Daily, G. C. (1997): Introduction: What are Ecosystem Services? In: Daily, G.C. (Ed.) Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D.C., 1-10.	Ns	Y	S
De Groot, R.S. et al. (2002): A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics, 41, 393–408.	N	Y	F
Fisher, B. and Turner, K. (2008): Ecosystem services: Classification for valuation. Biological Conservation, 141, 1167-1169.	Y		
Fisher, B. et al. (2009): Defining and classifying ecosystem services for decision making. Ecological Economics 68(3): 643-653.	Y		
Luck, G. W. et al. (2009): Quantifying the Contribution of Organisms to the Provision of Ecosystem Services. Bioscience **59**(3): 223-235.	Y	Y	S
MA [Millennium Ecosystem Assessment] (2005): Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.	Ns	Y	S
Wallace, K.J. (2007): Classification of ecosystem services: problems and solutions. Biological Conservation 139, 235-246.	Ns	Y	B
Wallace, K. (2008): Ecosystem services: Multiple classifications or confusion? Biological Conservation, 141, 353-354.	NS		

Key: (1) Services exclusively dependent on biodiversity (Y/N and Not specified); (2) Source provides classification (Y/N); (3) Basis of classification: Classified by services (S), Classified by benefits (B), multiple means several approaches suggested.

Figure 2.1: Conceptual map showing different approaches to the characterisation of ecosystem goods and services.



According to the MA, ecosystem services are seen as ‘the benefits ecosystems provide’ (MA, 2005, p.1). By way of describing these ‘benefits’ four broad categories of service are identified (Figure 2.2), namely: those that cover the material or provisioning services; those that cover the way ecosystems regulate other environmental media or processes; those related to the cultural or spiritual needs of people; and finally the supporting services that underpin these other three types. Although this categorisation has been widely accepted, as is evident from the recent debate many have found it difficult to apply this definition and the classification, particularly in the context of valuation.

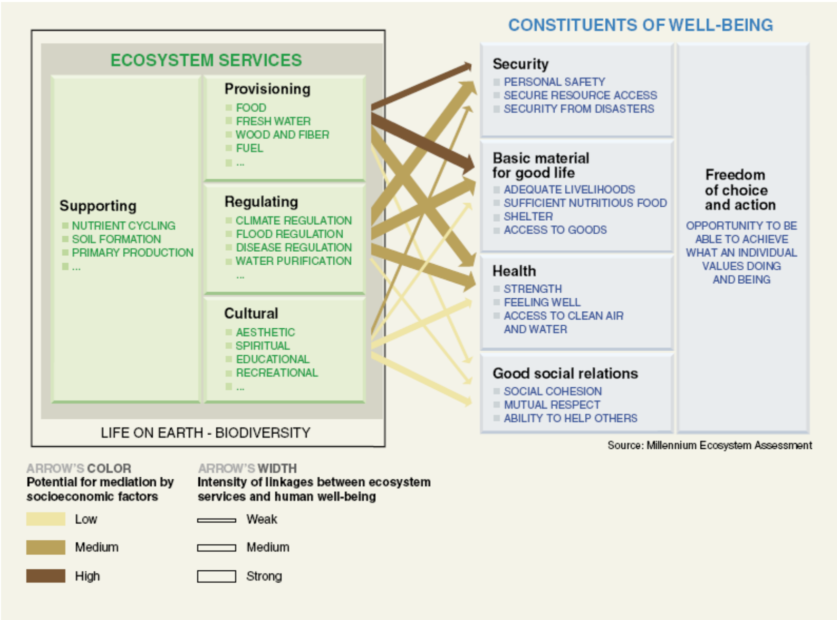


Figure 2.2: The Links between Ecosystem Services and Human Well-being (after MA, 2005)

The ambiguity of many aspects of the MA typology was, for example highlighted by Boyd and Banzhaf (2007) who argued that like other classification schemas (e.g. Daily 1997), it mixes up notions of ‘ecological function’ with that of ‘service’ and ‘benefit’. They argue that fundamentally, services are components of nature that are ***directly*** consumed, used or enjoyed by people, and that we should distinguish these from the intermediate ecosystem processes and functions that deliver them. Services, they claim, do not exist in isolation from people’s needs. Thus we have to be able to identify a specific benefit or beneficiary to be able to say clearly what is, or is not, a service. It is this property which Boyd and Banzhaf (2007) suggest make the construction of service typologies in general are difficult.

BENEFIT	Final Services	Intermediate Components
Recreational angling	The water body The bass population The riparian forest	The water body’s quality
Drinking water	The water body’s quality	Wetlands, natural riparian land cover

Figure 2.3: Services and benefits related to water quality in wetlands (after Boyd and Banzhaf, 2007)

The 'contingent' nature of any service is illustrated by an example provided by Boyd and Banzhaf (2007) involving water quality in wetlands (Figure 2.3; see also Appendix 1, Table A1). In terms of the benefits arising from recreational angling and drinking water, the quality of the water body plays an important role. However, only in the case of drinking is the water ***directly*** consumed, and so only here Boyd and Banzhaf (2007) argue, is 'the water body's quality' to be regarded as a service. Wetlands and natural riparian land cover are important assets that help deliver that service, but they are not, according to these authors services in themselves. By contrast, for recreational angling the water body's quality is no longer the service. Here the things being used directly are the fish population (bass) and elements of the environment such as the presence of the surrounding vegetation which may influence the quality of the angling experience. The value of the water body's quality is taken account of in the service represented by the fish stock. Thus in this situation the quality of the water is more of a ***function*** or capability of the ecosystem; it is needed to produce the service but cannot be regarded as a service as such.

Notice also in Figure 2.3 that, according to Boyd and Banzhaf (2007), services and benefits are quite distinct; for them 'services' ***are not*** 'benefits'. As Fisher and Turner (2008) also argue, a benefit is more usefully regarded something that directly impacts on the welfare of people, like more or better drinking water or a more satisfying fishing trip. For them, in contradistinction to the definition given by the MA, service is not a benefit – but rather something that changes the level of well-being (welfare).

The distinction between services and benefits has also been discussed recently by Wallace (2007) who suggested an alternative service classification that attempted to make a clearer distinction between functions, service and benefits that could serve as a more suitable 'framework for decisions in natural resource management'. He suggested that if we are to use the idea of ecosystem services to help us make decisions, then it is essential that we are able to classify them in ways that allow us to make comparisons and so evaluate the consequences of different management or policy strategies. The main problem with the MA typology, according to Wallace (2007, 2008), is that it 'confuses ends with means', that is the benefit that people actually 'enjoy' and the mechanisms that give rise to that service. For him, as with Boyd and Banzhaf (2007), a service is something that is consumed or experienced by people. All the rest, he argues, are simply part of the ecological structures and processes that give rise to that benefit.

Wallace (2007) argues that an effective typology of ecosystem services must be underpinned by a set of clearly defined terms and a clear understanding of the point at which processes deliver a service. He therefore both suggests some key definitions, and proposes an alternative service typology that takes account of the structure and composition of particular ecosystem elements or 'assets' and groups services according to the 'specific human values they support' (Table 2.2). The schema makes no distinction between 'ecological processes' and 'functions', and in contradistinction to the proposal of Boyd and Banzhaf (2007), follows the MA definition of a service, as a benefit people obtain from ecosystems. The main modification that Wallace (2007) appears to be suggesting is the regrouping of services around these 'preferred end-states of existence'.

Table 2.2: Classification of ecosystem services and links to human values, ecosystem processes, and natural assets (after Wallace, 2007)

<table>
<tr><th>Category of human values</th><th>Ecosystem services – experienced at the individual human level</th><th>Examples of processes and assets that need to be managed to deliver ecosystem services</th></tr>
<tr><td>Adequate resources</td><td>• Food (for organism energy, structure, key chemical reactions)
• Oxygen
• Water (potable)
• Energy (e.g., for cooking – warming component under physical and chemical environment)
• Dispersal aids (transport)</td><td rowspan="4">Ecosystem processes
• Biological regulation
• Climate regulation
• Disturbance regimes, including wildfires, cyclones, flooding
• Gas regulation
• Management of ‘‘beauty’’ at landscape and local scales.
• Management of land for recreation
• Nutrient regulation
• Pollination
• Production of raw materials for clothing, food, construction, etc.
• Production of raw materials for energy, such as firewood
• Production of medicines
• Socio-cultural interactions
• Soil formation
• Soil retention
• Waste regulation and supply
• Economic processes

Biotic and abiotic elements
Processes are managed to provide a particular composition and structure of ecosystem elements. Elements may be described as natural resource assets, e.g.:
• Biodiversity assets
• Land (soil/geomorphology) assets
• Water assets
• Air assets
• Energy assets</td></tr>
<tr><td>Protection from predators/disease/parasites</td><td>• Protection from predation
• Protection from disease and parasites</td></tr>
<tr><td>Benign physical and chemical environment</td><td>Benign environmental regimes of:
• Temperature (energy, includes use of fire for warming)
• Moisture
• Light (e.g., to establish circadian rhythms)
• Chemical</td></tr>
<tr><td>Socio-cultural fulfilment</td><td>Access to resources for:
• Spiritual/philosophical contentment
• A benign social group, including access to mates and being loved
• Recreation/leisure
• Meaningful occupation
• Aesthetics
• Opportunity values, capacity for cultural and biological evolution
o Knowledge/education resources
o Genetic resources</td></tr>
</table>

Wallace’s proposals have at the present time drawn little support. Indeed, the only two published responses have largely been critical of the approach he suggests, and overall it is difficult to see how the classification by value category does much to overcome the ambiguities surrounding questions of what a service is, and more importantly how we might measure them operationally. Probably the main contribution of Wallace’s paper has been to widen the terms of the debate.

In his response to Wallace (2007), Costanza (2008) has argued that attempts to devise a single, all-encompassing typology and strict definitions are bound to result in a gross oversimplification of the world, although he too follows the MA definition of services ***as*** benefits. He proposes that we contemplate multiple classification systems, designed to fulfil different purposes. For example, Costanza (2008) suggests that ecosystem services can also be classified according to their spatial characteristics (Table 2.3) (see also Fisher et al., 2008). Some, like carbon sequestration, are global in nature; since the atmosphere is so ‘well-mixed’ all localities where carbon is fixed is potentially useful. By contrast, others, like waste treatment and pollination depend on proximity. ‘Local proximal’ services are, according to Costanza (2008), dependent on the co-location of the ecosystem providing the service and the people receiving the benefit. He also distinguishes services that ‘flow’ from the point of production to the point of use (like flood regulation) and those that are enjoyed at

Table 2.3: Ecosystem services classified by their spatial characteristics (after Costanza, 2008)

Global non-proximal (does not depend on proximity) • *Climate regulation* • *Carbon sequestration (NEP)* • *Carbon storage* • *Cultural/existence value*
Local proximal (depends on proximity) • *Disturbance regulation/ storm protection* • *Waste treatment* • *Pollination* • *Biological control* • *Habitat/refugia*
Directional flow related: flow from point of production to point of use • *Water regulation/flood protection* • *Water supply* • *Sediment regulation/erosion control* • *Nutrient regulation*
In situ (point of use) • *Soil formation* • *Food production/non-timber forest products* • *Raw materials*
User movement related: flow of people to unique natural features • *Genetic resources* • *Recreation potential* • *Cultural/aesthetic*

the point of where they originate ('in situ' services). Finally he identifies services like cultural and aesthetic ones, which sometimes depend on the movement of users to specific places.

To emphasise his point about the need for multiple classification schemes, Costanza (2008) also highlights classifications of services that try to describe the degree to which users can be excluded from accessing them, or the extent to which users may interfere with each other when they enjoy the service (Table 2.4). Those goods and services that are privately owned sold on a market are classified as 'excludable'. The owner or provider can regulate access to the service, normally via price. Moreover, with such services, consumers are often 'rivals' in that if one consumes or enjoys the good the other cannot because the service or good is finite. Most provisioning services fall into this category. A variation on this type of service is something like 'observing wildlife', which is in principle excludable but non-rival; what one person observes does not prevent others from experiencing the same thing. The problem with many ecosystem services, and this is the significance of this type of classification for ecosystem managers, is that some services are open access or 'common pool' resources, from which it is very difficult to exclude potential users. While users may or may not interfere with each other in using them, on the whole it is very difficult to quantify their value to society or have these values included in decision making. As Hardin (1968) pointed out many years ago, the fate of such common pool resources is often one of progressive degradation or loss. Marine fisheries are examples of rival, non-excludable services. Many of the regulating services, like flood protection are open access but non-rival.

Table 2.4: Ecosystem services classified according to their excludability and rivalness (After Costanza, 2008)

	Excludable	Non-excludable
Rival	Rival Market goods and services (most provisioning services)	Open access resources (some provisioning services)
Non-rival	Non-rival Club goods (some recreation services)	Public goods and services (most regulatory and cultural services)

Given the complexity of coupled socio-ecological systems and the problems we face in managing them, Costanza (2008) is probably right in suggesting that it is useful to think of classifying ecosystem services in different ways. **However, some consistency or precision in the way terms are used is probably worthwhile, especially when different disciplines come together to open up a new research area.** Thus the problems highlighted by Boyd and Banzhaf (2007) and Wallace (2007) cannot be side-stepped so easily.

In their response to Wallace (2007) and subsequent work, Fisher et al. (2008) and Fisher and Turner (2009) return to the problem of defining a service, and develop the approach introduced by Boyd and Banzhaf (2007). They agree with the latter that ecosystem services are the aspects of ecosystems utilized (actively or passively) to produce human well-being, and suggest that the important points that emerges from this discussion are that services are fundamentally ecological in character and that they do not have to be used directly. Defined this way, they suggest, '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' (Fisher and Turner, 2009, p.645). For them, ecosystem functions become services only if people can benefit from them and therefore should be regarded simply as 'intermediate services' (Figure 2.4).

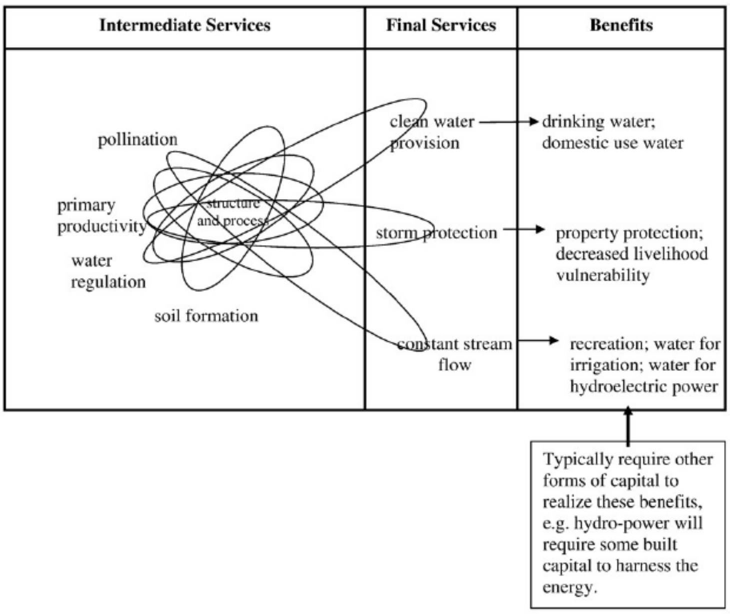


Figure 2.4: Conceptual relationship between intermediate and final services (after Fisher and Turner, 2009)

These debates about what is implied by the term 'ecosystem service' may seem academic, but are in fact very important in an operational context, when we need to measure or value some ecosystem output that contributes to human well-being. The distinction between intermediate and final products is highly significant for Boyd and Banzhaf (2007) and Fisher et al. (2009), for example, because it helps avoid the problem of **'double counting'** when undertaking valuation. Valuation should ***only*** be applied to the thing directly consumed or used by a beneficiary, because the value of the ecological structures and processes that contribute to it are already wrapped up in this estimate. In terms of the example shown in Figure 2.3, the water body's quality contributes to both of the benefits arising from the wetland, recreational angling and drinking water. However, only in the case of water supply, is any value directly attached to it. By way of further explanation of the issue, Boyd and Banzhaf (2007) suggest that the situation is the same as with a conventional market good like a car. The calculation of GDP only takes account of the value of the car and not the value of the steel and other materials that went into its production.

It is clearly impossible to legislate about the way terms and concepts should be applied, particularly at a time when new approaches are being developed and new analytical frameworks promoted. The best that can be done is to be clear about the differences that exist and how they might be applied in particular contexts. Setting aside definitional issues of whether services are benefits or not, the key point illustrated by the recent debate is that both conceptually and operationally it is important to make a distinction between the ecological processes and structures that give rise to some benefit and the particular aspect of human well-being that is being considered. The main challenge, it seems, is how we identify and describe these linkages in ways that both aid communication and lead to the creation of a robust evidence-base to support decision making.

Service cascades

The idea of a 'service cascade' (Figure 2.5) can be used to summarise much of the logic that underlies the contemporary ecosystem service paradigm and key elements of the debate that has developed around it (Haines-Young and Potschin, 2010). The model attempts to capture the prevailing view that there is something of a 'production chain' linking ecological structures and processes on the one hand and elements of human well-being on the other, and that there are potentially a series of intermediate stages between them.

Thus in terms of the example used in Figure 2.5, we might focus on the benefit people gain from ecosystems in relation to reduced risk of flooding. The presence of ecological structures like woodlands or other habitats such as wetlands in a catchment may have the capacity (function) of slowing the passage of surface water. This 'function' of the ecosystem has the potential of modifying the intensity of flooding. It is something humans find useful – and not always a fundamental property of the ecosystem itself – that is why it is sometimes helpful to separate this capability out and call it a function. However, whether this function is regarded as a service or not depends upon whether 'flood control' is considered as a benefit. People or society will value this function differently in different places at different times. Therefore in defining what the 'significant' functions of an ecosystem are and what constitutes an 'ecosystem service', an understanding of spatial context (geographical location), societal choices and values (both monetary and non-monetary) is as important, as knowledge about the structure and dynamics of ecological systems themselves.

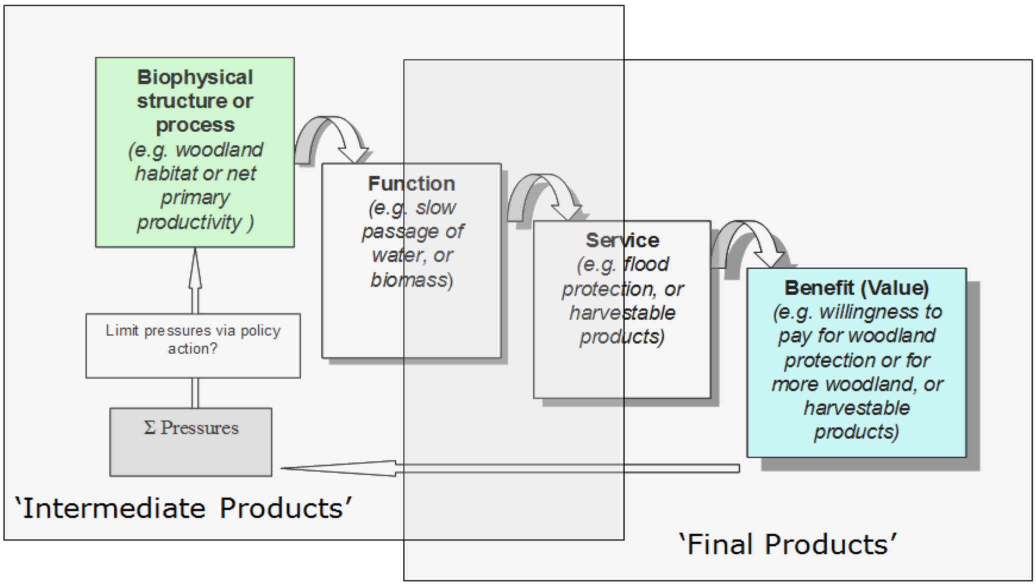


Figure 2.5: The relationship between biodiversity, ecosystem function and human well being (Haines-Young and Potschin 2009).

In following the 'cascade' idea through it is important to note the particular way that 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. Costanza et al., 1997; Daily, 1997; Brown et al., (2007) use it in their account of services. In his *Functions of Nature,* de Groot (1992) actually proposed a *classification of functions* that attempted to capture the relationships between ecosystem processes and components and goods and services, which he has subsequently revised on several occasions (Appendix 1, table A.5). However, as Jax (2005) notes the term function can mean a number of other things in ecology. It can mean something like 'capability' but it is often used more generally also to refer to 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-had side of the diagram that ultimately give rise to some service and benefit, as 'intermediate services'. The key messages that seem emerge from these debates is that, in relation to this cascade idea, whether or not there 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.

Thus a pragmatic way forward could be:

- That it is possibly wise to treat the things called 'services' simply as thematic labels and seek to understand or articulate the production chain (cascade) that underlies them;
- That labels like benefits, services, functions, structures/processes are helpful in understanding the transformations that link humans to nature, even though the precise boundaries between them might be difficult to define, unless referenced to specific situations;

- 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.
- That the main issue is to ensure the rigour of the outputs from our analysis and not become preoccupied with definitions, hence efforts should be directed to: achieving consistent valuation and no double counting; making the predictions about the spatial/temporal patters of service testable in some way.

Although the cascade model shown is a useful conceptual device for understanding the links between ecosystems and people, it is clearly a gross simplification of the 'real world'. Most services depend, for example, on a number of functional properties and probably many more structural components and processes. Nevertheless, it does provide something of an analytical template that can be used to identify the different elements that have to be taken into account when making some kind of assessment or analysis of ecosystem services. The boxes can be used to identify the different categories or types of things that are useful in for the researcher or decision maker to consider. It may be that in a particular valuation exercise measurement of the output of some 'final product' is the key issue so that judgements can be made about the implications of future change. However, in other contexts, where for example, management of policy interventions are being considered in relation to strategies for sustaining or restoring the output of some service, an detailed understanding of the components of the supply chain are more necessary. Here one would be interested in the sensitivity or marginal change in service output to resulting from modifications to particular structural elements or processes and their associated functional properties.

The cascade model shown in Figure 2.5 is also simplistic in that it does not really bring out the fact that most ecosystems are capable of generating a number of services simultaneously. Thus while the combination of many structures, processes and functions be needed to produce a particular service, some or all of those intermediate components may also lead to the generation other kinds of service output. Thus, Calder et al. (2008) report that current evidence suggests that native woodland creation on intensively managed land will benefit water quality but may pose issues for water resources. Improvements in water quality may arise from reduced soil disturbance, reduced nitrates, phosphate, pesticide and sediment inputs to runoff, but at the same time there may be lower volumes or water delivered. Surface run-off and groundwater recharge generally decreases under woodlands because they use more water than crop areas or grasslands. The need to understand the potential trade-offs between services is one of the key themes of the Ecosystem Approach and what has been described here as the ESF. Given the importance of such issues, this is perhaps one of the most important reasons why it is important to separate out the notions of ecosystem functions or capabilities from ideas about structures and processes. In this particular example, we can see that the same set of woodland structures and processes has different consequences (functional properties) in relation to service outputs relating to water quality and quantity; clearly management can intervene to modify service output according to needs.

Both the limitations of the cascade model described above are, however, more to do with the problems of applying the Ecosystem Services Framework and coping with the complexity of the real world. As a conceptual device, however, it has the merit of helping to represent the different theoretical positions that have been explored in the recent literature and some of the assumptions that underpin the work. We now use these insights to turn to the particular problem of devising typologies of ecosystem services

Ecosystem Service Typologies

Notwithstanding the difficulties of defining what exactly an ecosystem service is, many authors have attempted to provide a typologies or check-lists, to help describe the broad area of interest. These typologies both pre- and post-date the MA and vary considerably in their approach and level of sophistication. As noted above, our review identified 8 such typologies (Appendix 1). Some of their characteristics are summarised in Figure 2.1 and Table 2.1. A number of points emerge from a review of these materials; these concern various issues relating to the categorisation of services and the extent to which they are fundamentally underpinned by living processes.

Goods vs Services

The first difference that can be identified between the different typologies is the extent to which ecosystem 'goods' and 'services' are regarded as something as distinct. Following the recommendation of the MA, many recent commentators have treated them as synonymous (Figure 2.1 and Table 2.1). However, Brown et al. (2007) maintains that it is useful to make the distinction (Appendix 1, Table A.2); Binning et al. (2002) makes a similar distinction. According to Brown et al. (2007) goods are fundamentally tangible, material products that result from ecosystem processes, while ecosystem services are in most cases 'improvements in the condition or location of things of value [goods]' (Brown et al., 2007, p.331). They note, however, that this categorisation is sometime difficult to apply, in that things like recreation opportunities do seem to fit into either category, because they are neither tangible nor lead to improvements in conditions of goods, like water purification, flood mitigation, and pollination. However, none of the other the typologies shown in Appendix 1 make the distinction between goods and services, and in terms of current usage it is probably best to take the position that they are essentially equivalent concepts. Goods and services are outputs from ecosystems that, in some way, contribute to human well-being.

Services vs Benefits

A second feature that is evident from a comparison of the different typologies is that the way services are grouped also varies. Thus while the four-fold categorisation of the MA is widely used, Boyd and Banzhaf (2007) and Wallace (2007) prefer to group service themes around different kinds of benefit (see Figure 2.1). Their approach appears to be one of identifying benefits and seeking to understand how outputs of ecosystems contribute to them. By contrast, all the others start with the identification of services, and choose either to lump or group them in various ways. Thus Brown et al. (2007) (Appendix 1, Table A.1) and Costanza (1997) (Appendix 1, Table A.3) simply list relevant services, Daily (2002) (Appendix 1, Table A.4) identifies four broad groups, namely: 'the production of goods', 'regeneration processes', 'life-fulfilling functions' and 'preservation of options'. Although these are broadly equivalent to the provisioning, regulating, cultural and supporting categories used by the MA, other typologies suggest more fundamentally different combinations.

In his classification of ecosystem functions de Groot et al. (2002) (Appendix 1, Table A.5) recognises 'habitat' and 'information' functions alongside those for production and regulation. Habitat functions relate to the refugium and nursery roles that ecosystems often fulfil, while information functions cover elements such those relating to the aesthetic, spiritual, scientific and cultural properties of ecosystems[9].

The category of 'habitat services' has been carried over into the typology proposed in the Phase II work for TEEB (de Groot, pers com., Table 2.5). In this new typology, supporting services have been dropped, on the basis of the arguments about their equivalence with ecological functions outlined above, but the other three broad categories of the MA have been retained[10]. The rationale for the approach is, however, unclear because the way the habitat services are described seems to imply that they mainly have a supporting role, underpinning the provisioning of food or genetic resources (items 1 and 4, Table 2.5). Thus the topology may still confuse final and intermediate products.

Table 2.5: Typology of ecosystem services in proposed in TEEB (de Groot, pers com., August 2009)

	Main service-types
	PROVISIONING SERVICES
1	**Food** (e.g. fish, game, fruit)
2	**Water** (e.g. for drinking, irrigation, cooling)
3	**Raw Materials** (e.g. fibre, timber, fuel wood, fodder, fertilizer)
4	**Genetic resources** (e.g. for crop-improvement and medicinal purposes)
5	**Medicinal resources** (e.g. biochemical products, models & test-organisms)
6	**Ornamental resources** (e.g. artisan work, décorative plants, pet animals, fashion)
	REGULATING SERVICES
7	**Air quality regulation** (e.g. capturing (fine)dust, chemicals, etc)
8	**Climate regulation** (incl. C-sequestration, influence of veg. on rainfall, etc.)
9	**Moderation of extreme events** (e.g. storm protection and flood prevention)
10	**Regulation of water flows** (e.g. natural drainage, irrigation and drought prevention)
11	**Waste treatment** (esp. water purification)
12	**Erosion prevention**
13	**Maintenance of soil fertility** (incl. soil formation)
14	**Pollination**
15	**Biological control** (e.g. seed dispersal, pest and disease control)
	HABITAT SERVICES
16	**Maintenance of life cycles of migratory species** (incl. nursery service)
17	**Maintenance of genetic diversity** (esp. gene pool protection)
	CULTURAL SERVICES
18	**Aesthetic information**
19	**Opportunities for recreation & tourism**
20	**Inspiration for culture, art and design**
21	**Spiritual experience**
22	**Information for cognitive development**

Biotic vs abotic services

The third issue to emerge from a review of the typologies collected together in Appendix 1 is the extent to which the ecosystem services identified by the different commentators are fundamentally dependent on ***living*** processes.

[9] Note – genetic (information) resources is generally regarded as a provisioning service.
[10] Note – the typology is still subject to peer review, although it is a product of wide consultation within the TEEB process.

The issue has also been noted by Fisher and Turner (2008) and Fisher et al. (2009) in their discussion of the problems of classifying ecosystem services. For them ecosystem services are fundamentally ***ecological*** in character. Thus, aesthetic, cultural and recreation outputs, for example, are not ecosystem services, but rather best regarded as benefits to which ecosystems may make a contribution. They claim that these phenomena are not exclusively a property of ecosystems but depend on other factors such as 'human capital', 'built capital' and so on. If the idea of an ecosystem service is to help us understand the benefits that people gain from nature, then for them the idea of a service has to lead to some thing that can be valued, like 'water used for irrigation, bushmeat, timber products and carbon stored' (Fisher and Turner, 2008, p.1168).

In their discussion of the *ecological* character of ecosystem services Fisher and Turner (2008) are mainly concerned with the problem of identifying services as final products that can be valued. They recognise that the eventual benefits to people may involve more than the output of ecosystems, hence the point they make about the combinations of different sorts of capital. The examples used to illustrate their argument all, however, involve services in which *living organisms*, that is biodiversity in its broadest sense, play an important role. This raises the question of the extent to which the notion of ecosystem services can applied to things that mainly or wholly depend on the ***abiotic*** elements of ecosystems without living organisms playing any active role in the generation processes. For example, can snow be regarded as an ecosystem service? As the existence of the winter sports industry testifies, snow in mountain ecosystems can *directly* deliver a range of recreational benefits. Similarly, are renewable energy sources like wind or waves to be considered as ecosystems services? Although the MA conceptualisation (Figure 2.2) suggests that services are fundamentally dependent upon biodiversity, other commentators have drawn the definition more broadly.

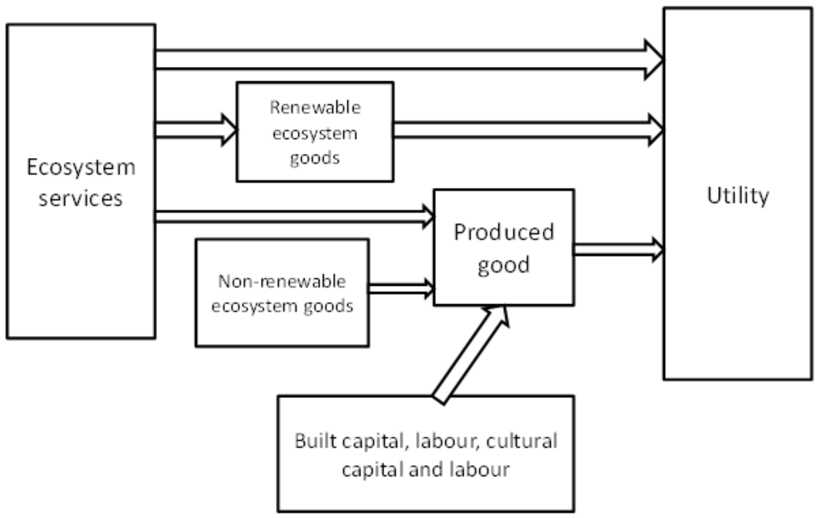


Figure 2.6: Pathways from Ecosystem Goods & Services to Utility (modified after Brown et al., 2007)

Thus, in their typology of ecosystem services Brown et al. (2007) not only make the distinction between goods and services, but also include in their category of 'goods' non-renewable natural resources such as rocks and minerals, and fossil fuels. For them, ecosystem goods and services are generated through ecosystem processes that 'act on natural capital' (Brown et al., 2007, p.337) and which require no input of labour or built capital. Services and renewable ecosystem goods, like food and fibre, can both directly and indirectly (via some produced good) be used by people (Figure 2.6), while non-renewable goods tend to be inputs to some other production process involving human or built capital. By contrast, other commentators, such as Cowling et al. (2008, p. 9483) regard ecosystem services as the 'end products of nature that benefit humans [that are] provided by natural and semi-natural habitats (wild nature)'. Such an extreme position perhaps puts in question whether the many of services delivered by the types of cultural landscapes we find in Britain as *ecosystem* services in this strict sense – particularly those in the cultural category.

We will return to the issue of how elements of nature combine with other forms of capital to produce a benefit later in this report (Part 4). The conclusion that can be drawn at this stage in relation to the extent to which the different typologies identified in Appendix 1 refer to services which are mainly related to the abiotic elements of ecosystems or physical processes is that they generally do not specify where the boundaries lie. Thus only in the typology suggested by Brown et al. (2007) (Appendix 1, Table A.2) do we find rocks and minerals mentioned as ecosystem goods. 'Energy' where referred to at all, for example in the typologies of Boyd and Banzhaf (2007) (Table A.1), Daily (2002) (Table A.4), de Groot et al. (2002) (Table A.5) and Wallace (2007) (Table A.8) is mainly mentioned in the context of sources dependent on biomass rather than other natural process such as wind or insolation. Only in the case of the typology provided from the *Rubicode* Project (Luck et al., 2009; Appendix 1, Table A.6) is the list of services exclusively and explicitly confined to ones upon biodiversity.

In their defence perhaps all of the authors of the typologies considered here would not claim that the lists they provide are comprehensive. Moreover, they might also argue that they were attempting to provide a description at the global scale, and must therefore inevitably gloss-over the richness of detail that might be necessary for particular places or circumstances. Nevertheless, in helping to communicate what is important about ecosystems it is clear that these typologies should attempt at least to describe the main conceptual elements in the field of debate. **It would seem, therefore, that further work is needed to refine these typologies and make clear the assumptions on which they are based.**

While we may accept that there are no fundamental categories, because systems are complex, it is important to be clear about how terms are used even if codifications are arbitrary. This is particularly so in relation to describing the role of biodiversity in the generation of ecosystem services. Part of the attraction of the idea of ecosystem services has been that it expands the utilitarian arguments in favour of conserving biodiversity in ways that might help convince society that it is in its best interest to sustain all living things. To expand the concept to include all biotic and abiotic ecosystem elements may tend to dilute this perspective and return the discussion to a more traditional one about renewable and non-renewable natural resources.

Clearly various alternative conceptual devises are possible in drawing up service typologies, if we want to emphasise the important role that biodiversity can play. For example, in the context of the work that the EEA has done on ecosystem accounting for Mediterranean Wetlands as part of its contribution to the TEEB process (see EEA, 2009), the services associated with these ecosystems have been categorised in terms of the strength of their link to biodiversity. This tactic was used because it was important to capture significant natural products from these ecosystems, like salt production, which are not obviously dependent on living processes. Another strategy might be to use the terms 'ecosystem service' and 'environmental service' in different ways, with the implication that the latter takes in both the biotic and aboitic elements, while the former is more focussed on the ways biodiversity supports human well-being. This is the terminology employed by the Land Use Policy Research Group in the UK, for example, in describing the role that land management can play in enhancing environmental quality. Agri-environmental schemes can, for example, deliver a range of benefits for soil, air and water quality that are largely independent of any processes dependent on biodiversity (Rollett et al., 2008).

Evolving Service Typologies

The aim of Part 2 was to examine how ecosystem services are presently defined and classified, and how links are made between services, functions, ecological structures and processes, on the one hand, and aspects of human well-being on the other. **The key message to emerge from this review is that while the idea of ecosystems producing services is an attractive and increasingly popular one, consistent definitions and universally accepted typologies do not currently exist**.

Despite the fact that there continues be some diversity in current approaches and deficiencies in terms of data and information, it could fairly be claimed that some progress has been made. As with all things the researcher and policy advisor has to be careful to specify clearly what he or she is looking at. This is particularly so in a new inter-disciplinary field like ecosystem services, where concepts are still evolving and ideas from different knowledge cultures need to be combined. Thus some guidelines for JNCC can be suggested.

For those wishing to work within the ecosystem services framework what does seem certain from recent debates is that when attempting to operationalise the notion of an ecosystem service, an understanding of the actual or potential link to human activities or needs is essential. We many never devise any simple, generic checklist of services that ecosystems or regions might support, as many commentators have tried to do. However, if ecosystem services are viewed as the *contributions* that ecosystems make to *well-being*, then the nature of that contribution and the character of the benefit both have to be specified; they are fundamental parts of the definition of a service. The main short coming with all current typologies seems to be that they lack such definitional rigour.

From a review of the current 'state of the art', the most useful recommendation that emerges is that the main analytical task is one of treating typologies such as the MA list of services more as a menu of potential **'service-benefit themes'**, and of using something like the cascade model to examine how particular systems operate in particular places. In other words we should treat concepts like 'processes', 'functions', 'services' and 'benefits' more as prompts to help sort out the complexities of a given problem, rather than as a set of water-tight definitions into which the world has to be squeezed.

Of all the typologies identified in Appendix 1, perhaps the one that comes closest to what is required in terms of building a rigorous understanding of the nature of services and their relationships to well-being is the one suggested by Luck et al. (2009) (Table A.6). Before considering this 'framework' in detail it must be acknowledged that it was not intended to be a comprehensive listing of all ecosystem services. Indeed it was constructed more as a table of examples from the literature rather than a typology as such. Nevertheless, its structure does illustrate what a good typology might include. Thus against the service themes on the left hand-side, the Table sets out the type of ecosystem concerned and the ecological unit providing the service (Service Providing Unit, SPU) and its characteristics. It also provide details of the particular attribute of the service providing unit that gives rise to the service (i.e. some insight into the underlying ecological functions) and a response measure that can be used to describe the relationship between the particular components of biodiversity identified and the level service provision.

The material in Table A.6 may not represent a fully articulated ecosystems service typology, but it does stand out amongst those identified as providing the basis for a more rigorous classification of services than others. Indeed, while lists of service themes might be useful as an *aide memoire*, a framework such as this probably provides a more useful analytical template for collecting and reviewing evidence. It suggests more of an hierarchical or nested approach to the categorisation of services functions and processes than has presently been attempted. Such an approach could also be extended to include the identification of benefits. Several examples of the kind of approach to that might be used to build a comprehensive typology have been identified, both involving wetland ecosystems. Thus McInnis et al. (2008) used a nested approach based on the cascade idea to describe graphically the relationships between services, functions and processes for selected services in the particular case of Otmoor, Oxfordshire (Figure 2.7), while Maltby (2009, p.15-16) provides a more extended, tabular approach that also links to benefits, for wetlands more generally.

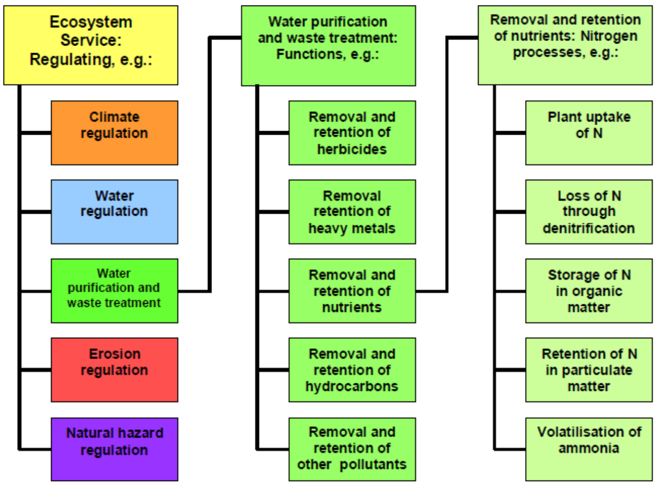


Figure 2.7: Relationships among ecosystem services, functions and processes: example for removal and retention of nitrogen as a component of the regulating ecosystem service (after McInnis et al. 2008)

In the final part of this Report we will consider the possibly of extending these approaches to all ecosystems, and what merits there might be in an organisation such as JNCC investing in such an initiative. Before undertaking such a discussion we must turn to the problem of better understanding the role of biodiversity in the ecosystem service debate and how, ultimately insights about the value of services can be developed. Both issues may ultimately shape the way we define and classify services and treat 'biodiversity'.

Part 2: Defining Ecosystem Services - Key messages

- *No universally accepted typologies of ecosystem services presently exist, although the MA framework is still widely applied.*
- *In contradistinction to the MA definition of a service as the benefits ecosystems provide for people, this review suggests that ecosystem service are now broadly understood as the contributions that ecosystems make to human well-being. However, most commentators accept the equivalence of the terms 'goods' and 'services' as suggested by the MA.*
- *Recent debates have increasingly stressed the need to differentiate benefits, services, ecological functions, and ecological structures and processes, to emphasise the mechanisms that underpin the links between natural capital and human well-being. Because the elements of human well-being may be aggregations of different kinds of benefit, it is useful to differentiate services from benefits to emphasis the particular role that ecosystems play.*
- *Although the MA categories of provisioning, regulating and cultural services remain useful, the supporting services are best regarded as synonymous with concepts such as 'intermediate services' or 'ecological functions' to avoid the problem of 'double counting' in any assessments, and to emphasise the 'production chain' that underpins services.*
- *Existing typologies are ambiguous about the extent to which ecosystem services are fundamentally dependent upon biodiversity or can also be generated by abiotic ecosystem elements. However, it seems clear that it is important to retain the focus on biodiversity in any typology, to help make stronger the utilitarian arguments for conserving natural capital.*
- *New, hierarchical approaches to classifying ecosystem services are probably required to help make the evidence more useful for decision makers. Such approaches would describe more rigorously and systematically the relationships between the different conceptual elements that make up the ecosystem services approach.*

Part 3 Biodiversity, ecosystem function and service output

Introduction

In the previous section we focused on the problem of defining and classifying ecosystem services. In so doing, a good deal of the discussion concerned the relationship between services and benefits on the one hand, and underlying ecological functions, processes and structures on the other. However, this discussion was mostly framed at the conceptual level. We now turn to consider more of the recent empirical work. Following the brief for this study we focus particularly on the role of biodiversity in the context of ecosystem services; using the search strategy outlined in Part 1 (Table 1.1) we have looked at how the relationships between biodiversity and ecosystem function has been characterised and measured, how the notion of an 'ecosystem' has been constructed and used as a framework for making assessments of services. The discussion therefore covers a range of modelling and mapping issues that are currently being debated in the various research literatures.

Service Production Functions

Modelling service output

Ecological production functions describe the relationships between the structure and function of ecosystems and the provision of services. Importantly they describe how service output varies as the underlying structure and function of ecosystems change. Luck et al. (2009) have recently illustrated the nature of such functions and how they may be used to consider the level of service output in relation to the needs of particular beneficiaries (Figure 3.1).

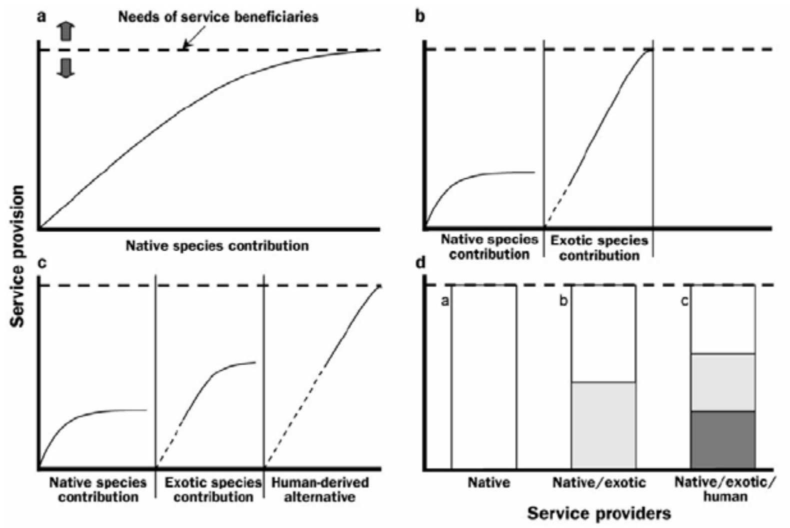


Figure 3.1: The relationship between different service providers and service output in relation to the needs of beneficiaries (after Luck et al., 2009)

Notes: (a) The service is provided entirely by native organisms; (b) the contribution by native species asymptotes before beneficiary needs are met with the remaining contribution provided by exotic species; (c) the contribution of both native and exotic species asymptotes and a human-derived alternative is required to meet needs; (d) summarizes the relationships in a, b, and c.

As Daily et al. (2009) note, while they have long been used in agriculture and manufacturing to relate the amount of a commodity produced to the volume of inputs, the construction of such functions for ecosystem services is much less well developed – but is now an essential task. Solan et al. (2006) make a similar case for the importance of understanding such relationships in the marine environment. The particular challenge therefore is to understand just how sensitive ecosystem service output is to changes in biodiversity; the identification of such relationships would go some way to making operational the cascade model descried in Part 2. Carpenter et al. (2009) suggest that it is rare to find a linear causal path from changes in drivers, through biodiversity, ecosystem processes, to ecosystem services, human well-being and human responses, because of the complexity of the issues being considered. However, the assumption that there is a strong and direct relationship is implicit in many of the arguments people make about conserving and restoring ecological systems, thus it is important to scrutinise the evidence supporting this assertion.

Table 3.1: Key references dealing with ecological production functions or relationships between biodiversity and ecological function identified by Web of Science, using number of citations and relevance as selection criteria.

Papers	Citations
Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, J. P. Grime, A. Hector, D. U. Hooper, M. A. Huston, D. Raffaelli, B. Schmid, D. Tilman and D. A. Wardle (2001): Ecology - Biodiversity and ecosystem functioning: Current knowledge and future challenges. Science 294(5543): 804-808.	722
Hooper, D. U., F. S. Chapin, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setala, A. J. Symstad, J. Vandermeer and D. A. Wardle (2005): Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecological Monographs 75(1): 3-35.	570
Tilman, D., P. B. Reich, J. Knops, D. Wedin, T. Mielke and C. Lehman (2001): Diversity and productivity in a long-term grassland experiment. Science 294(5543): 843-845.	358
Tilman, D., C. L. Lehman and K. T. Thomson (1997): Plant diversity and ecosystem productivity: Theoretical considerations. Proceedings of the National Academy of Sciences of the United States of America 94(5): 1857-1861.	321
McGradySteed, J., P. M. Harris and P. J. Morin (1997): Biodiversity regulates ecosystem predictability. Nature 390(6656): 162-165.	314
Yachi, S. and M. Loreau (1999): Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. Proceedings of the National Academy of Sciences of the United States of America 96(4): 1463-1468	282
Loreau, M. (2000): Biodiversity and ecosystem functioning: recent theoretical advances. Oikos 91(1): 3-17.	233
Wardle, D. A., K. I. Bonner and K. S. Nicholson (1997): Biodiversity and plant litter: Experimental evidence which does not support the view that enhanced species richness improves ecosystem function. Oikos 79(2): 247-258.	226
Schwartz, M. W., C. A. Brigham, J. D. Hoeksema, K. G. Lyons, M. H. Mills and P. J. van Mantgem (2000): Linking biodiversity to ecosystem function: implications for conservation ecology. Oecologia 122(3): 297-305.	181
Loreau, M. (1998): Biodiversity and ecosystem functioning: A mechanistic model. Proceedings of the National Academy of Sciences of the United States of America 95(10): 5632-5636.	156
	Relevance Rank
Balvanera, P., A. B. Pfisterer, N. Buchmann, J. S. He, T. Nakashizuka, D. Raffaelli and B. Schmid (2006): Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology Letters 9(10): 1146-1156.	2/262
Ostfeld, R. S. and K. LoGiudice (2003): Community disassembly, biodiversity loss, and the erosion of an ecosystem service. Ecology 84(6): 1421-1427.	1/262
Raffaelli, D. G. (2006): Biodiversity and ecosystem functioning: issues of scale and trophic complexity. Marine Ecology-Progress Series 311: 285-294.	5/262

Using the core set of papers described in Part 1 that dealt with some aspect of ecosystem services, a more refined search of those making reference to production functions or some aspect of the relationship between biodiversity and ecosystem function was made. Search terms based on the phrase ‘production function’ tended to identify papers from the fields of environmental economics or accounting, while those in the ecological literature were identified better using variations of the search phrase ‘biodiversity and ecosystem function’. Using variations of these two search protocols, a sub-set of 262 journal and review papers were identified using Web of Knowledge (WoK); the ‘number of citations’ and ‘relevance’ raking methods available in WoK were used to identify the most significant contributions. A group of key 13 publications was identified for more detailed consideration (Table 3.1); these together with some of the papers that cite them are used as the basis of the discussion that follows.

Biodiversity and ecosystem functioning

Over the last decade or so a number of relevant review papers have appeared, namely those of Balvanera et al. (2006), Hooper et al. (2005), Loreau (2000), Loreau et al. (2001), McGradySteed et al. (1997), Raffaelli (2006), Schwartz et al. (2000), Tilman et al. (1997) and Yachi et al. (1999). Amongst the earlier contributions, that of Schwartz et al. (2000) is particularly relevant in the context of the role of biodiversity and ecosystem functioning, in that they set out come of the key issues that have to be resolved.

Schwartz et al. (2000) suggest that if the link between biodiversity and ecosystem function is to be used to support the conservation case, then we would need to show that the maintenance of ecosystem function and the output of ecosystem services are dependent on a *wide range of native species.* Moreover, while a number of different types of relationships between biodiversity and ecosystem function are possible, we would also need to show a *direct and positive association* between the two. These ideas are summarised in Figure 3.2, which attempts to illustrate the range of different types of relationship that potentially exist between biodiversity and ecosystem function. Curves A and B are those suggested by Schwartz et al. (2000); a third relationship (C) has been added to extend the discussion, based on the discussion of Kremen (2005).

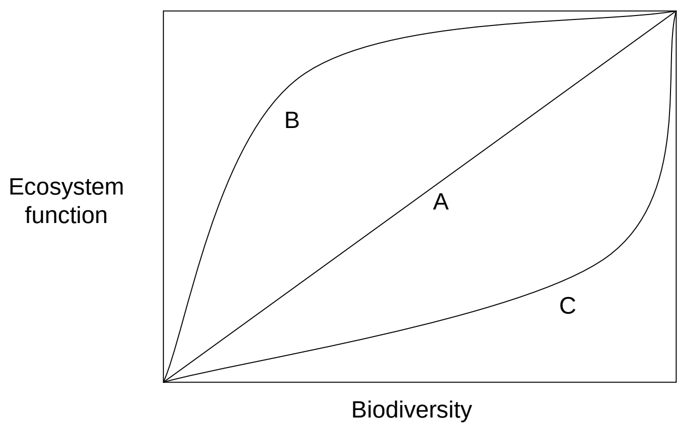


Figure 3.2: Potential relationships between biodiversity and ecosystem functioning (after Schwartz et al., 2000: and Kremen, 2005)

The difference between curves A and B is that in the case of the former, ecosystem function is highly sensitive to variations in biodiversity, whereas in B there is a 'saturation' effect, that is ecosystem function is only dependent upon biodiversity at low levels of, say, species richness. Schwartz et al. (2000) argue that if such saturation effects are observed widely, then this poses a difficulty for those arguing the conservation case. It suggests that systems can lose much of their diversity without affecting their functioning (operation) and potentially the benefits they provide for people. In these situations it would seem that human well-being might be buffered from the effects of biodiversity loss – but it opens the door to arguments that some biodiversity loss is acceptable.

The review that Schwartz et al. (2000) made of a range of empirical and modelling studies found that few studies supported the hypothesis that there was a simple, direct linear relationship between species richness and some measure of ecosystem functioning like productivity, biomass, nutrient cycling, carbon flux or nitrogen use. Instead the available evidence suggested that these ecosystem functions did not increase proportionally above a threshold, which was often represented by a fairly low proportion of the available species pool. In their review, Wardle et al. (1997) also questioned whether such direct linear relationships existed, at least in the context of the influence of species diversity of plant litter soil decomposition processes. Aarssen (1997), Grime (1997), and Huston (1997) have argued against the existence of any simple, direct relationship. Some commentators have even suggested that any observed positive association is an artefact or sample effect, brought about by the fact that if a greater number of species is considered, we are more likely to include highly productive ones which will tend to increase levels of productivity (e.g. Huston & McBride, 2002; Thompson et al., 2005).

The 13 reviews identified by this study illustrate the fact that, notwithstanding the early conclusion of commentators such as Schwartz et al. (2000) there is still considerable disagreement about what the evidence shows in relation to the links between biodiversity and ecosystem functioning. Loreau et al. (2001) suggested for example, that the question is difficult to resolve because there is considerable uncertainty about how results 'scale up' to whole landscapes and regions, and how far one can generalise across ecosystems and processes. Many of the studies on which both the earlier and later reviews are based are small-scale, empirical studies. The same point is made by Swift et al. (2004) in relation to agricultural systems. The complexity of the issue is exacerbated by the fact that 'biodiversity' itself is not a simple concept, but can be measured is different ways.

Biodiversity as represented by measures of species richness may be important for ecosystem functioning, but other aspects of ecosystem structure might be equally significant. Díaz et al. (2007) notes that biodiversity in its 'broadest sense' covers not only the number of species, but also the number, abundance and composition of genotypes, populations, functional groups, and even the richness of spatial patterns exhibited by habitats mosaics and landscapes. Thus before one accepts or rejects the existence of a relationship between 'biodiversity' and ecosystem functioning one has to look at what is being measured. In contradistinction to the conclusions of commentators like Schwartz et al. (2000), others have argued that the evidence suggests there is a clear and direct relationship between key aspects of ecosystem function and various measures of biodiversity, besides richness (e.g. Tilman et al., 1997; Hooper et al., 2005; and, Balvanera et al., 2006).

The review by Hooper et al. (2005) provides a rich discussion of the different components of biodiversity and their link to ecosystem functioning. They frame the discussion of biodiversity effects around the influence of variations in functional traits, functional types (or groups) and functional diversity. Broadly, a functional trait is a characteristic of an organism that has demonstrable links to what an organism does or how it behaves in a community or ecosystem. In other words it describes how it is connected to other organisms or the wider environment, in terms of matter and energy flow, or how it behaviour is influenced or influences other organisms or aboitic components of an ecosystem. Depending on the direction of influence, Díaz et al. (2004) have argued that we may distinguish response and effects traits. A functional group is simply a collection of organisms with a common set of traits, and the notion of function diversity refers to the number of functional traits or groups that might be present in a particular situation.

From a review of the evidence available to them, Hooper et al. (2005) conclude that a species functional characteristics can strongly influence ecosystem properties and by implication the output of ecosystem services. The strength of influence is not, it seems, entirely dependent on the relative abundance of an organism; there are a number of instances where it has been found that even rare species can have a marked influence over the patterns of matter and energy flow within an ecosystem, as is evidenced by looking at the consequences of the ecological transformations brought about by species invasions or extinctions due to human action. Kremen (2005) also notes that although we generally understand ecosystem services to be properties of whole ecosystems or communities, the functions that support them often depend upon particular populations, species, species guilds or habitat types; it is on this basis that she suggests relationship C Figure 3.2, representing the sudden collapse of a system when a keystone species or functional group is lost.

Hooper et al. (2005) conclude that while that it is extremely difficult to generalise about how particular ecosystems will respond to changes in the abundance of species or groups with particular traits or characteristics, some conclusions can be drawn with confidence. Namely, that:

- there is evidence that particular combinations of species may have a complementary or synergistic effect on their patterns of resource use which can increase average rates of productivity and nutrient retention;
- the vulnerability of communities to invasion by alien species is influenced by species composition and under similar environmental conditions, generally increases as species richness falls; and,
- that ecosystem subject to disturbance can be stabilised if they contain species with traits that enable them to respond differently to changes in environmental conditions.

The most recent review of the relationships between biodiversity and ecosystem function is provided by Balvanera et al. (2006) who undertook an extensive meta-analysis of experimental studies involving the manipulation of different components of biodiversity and the assessment of the consequences for ecosystem processes. They showed that in general, evidence supports the contention that for various measures of biodiversity there is a positive association with a number of different measures of ecosystem functioning, including primary and secondary productivity and nutrient cycling (Figure 3.3). The small number of negative relationships reported in the literature, tended to be associated with studies which measured properties at the population (individual species density, cover or biomass), rather than the community level characteristics (e.g. density,

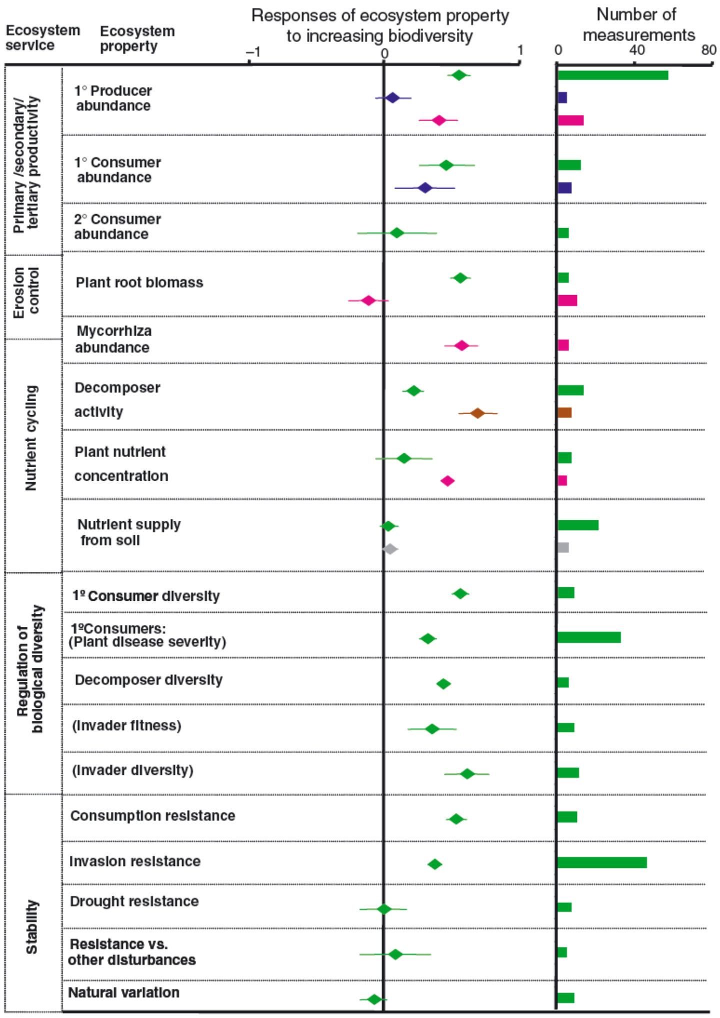


Figure 3.3: Magnitude and direction of biodiversity effects on ecosystem functioning (after Balvanera et al., 2006).

Notes: The size and direction of biodiversity effects (shown are mean values and SE of normalized effect sizes Zr, weighted by the reciprocal of the variance of the individual Zr-values) and number of measurements available for ecosystem properties organized into ecosystem services. Coloured bars show differential effects of trophic level manipulated: green, primary producers; blue, primary consumers; pink, mycorrhiza; brown, decomposer; grey, multi-trophic (multiple levels simultaneously manipulated). Ecosystem properties shown in parentheses were considered of negative value for human well being, and thus opposite of effect sizes are shown.

biomass, consumption). The strength of the relationship between biodiversity and the measure of ecosystem function tended to be strongest at the community rather than the whole ecosystem level.

Kremen (2005) has pointed out that if we are to manage ecosystem services successfully, then we must understand how changes in community structure collectively affect the level and stability (resilience) of the ecosystem services over space and time. The analysis of (Balvanera et al., 2006), like that of the earlier review of Hooper et al. (2005) also suggests that more diverse systems have greater temporal stability, as well as greater resistance to external forces such as nutrient perturbations and invading species. This finding supports the earlier widely cited work of Yachi and Loreau (1999), and McGradySteed et al. (1999), noted in Table 3.1. Balvanera et al. (2006) observe that in their review most of the studies that considered stability aspects, dealt with resistance

Table 3.2: Examples of work demonstrating direct relationships between components of biodiversity and different aspects of ecosystem functioning

Ecosystem function	Source	Conclusion
Primary productivity	Gaston (2000)	Output of food, timber and fibre tends to be higher in areas with high net primary production, and that at global scales, patterns of biodiversity and the services associated with it generally increases with net primary production.
	Costanza et al. (2007)	Investigated the inter-dependence of net primary productivity and biodiversity at very broad spatial scales, namely for ecoregions in North America. They found that over half the spatial variation in net productivity could be explained by patterns of biodiversity, if the effects of temperature and precipitation were taken into account. Using the relationships they develop, these authors predict that across the temperature ranges in which most of the world's biodiversity is found occur, a 1% change in biodiversity results in a 0.5% change in the value of ecosystem services.
	Fagan et al. (2008)	Concluded that increased levels of plant species diversity enhances grassland productivity in restored grasslands on a range of soil types across southern England.
	Cardinale et al. (2007)	Observed the productive advantage of mixtures or over monocultures appears to increase over time.
	Lavelle et al. (2006)	Provide experimental evidence from soil ecosystems to show that there can be significant enhancements of plant production in the presence of Protoctista, Nematodes and Enchytraeidae, Collembola and combinations of these organisms, as well as termites, ants and earthworms. Effects possibly related to factors such as increased release of nutrients in the plant rhizosphere; the enhancement of mutualistic micro-organisms, mycorrhizae and N-fixing micro organisms; greater protection against pests and diseases, both above and below ground; greater protection against pests and diseases; the positive effect of micro-organisms on soil physical structure; and the production of plant-growth promoters.
	Worm et al. (2006)	Identified a fairly strong positive association between biodiversity and productivity in marine systems, based on their meta-analysis of published experimental data. They found that the evidence suggested that increased biodiversity of both primary producers and consumers appeared to enhance the ecosystem processes examined. By way of explanation they identified a number of factors, including complementary resource use, positive interactions between species and increased selection of highly performing species at high diversity. Moreover, they noted that the restoration of biodiversity in marine systems was also found to substantially increase productivity.
Nutrient cycling	Hooper and Vitousek (1997, 1998); Niklaus et al. (2001)	Functionally diverse systems appear to be more effective in retaining nutrients than simpler ones; retention of soil nutrients appears to be due to direct uptake of minerals by vegetation and by the effects of plants on the dynamics of soil microbial populations.
	Engelhardt and Ritchie (2001)	Showed that in wetland systems, not only does increased flowering plant diversity enhance productivity, but it also aids the retention of phosphorus in the system, thereby aiding the water purification service.
	Barrios (2007)	Reviewed the importance of the soil biota for ecosystem services and land productivity, and notes the evidence pointing to the positive impacts of micro-symbionts on crop yield, as a result of increases in plant available nutrients.
	Brussaard et al. (2007),	Report that there is evidence to suggest that increased mycorrhizal diversity positively contributes to nutrient and, possibly, water use efficiency, especially in this functional groups that contribute to fertility through biological nitrogen fixation, such as *Rhizobium*, and phosphorus through arbuscular mycorrhizal fungi.

Table 3.2, cont.

Ecosystem function	Source	Conclusion
Nutrient cycling, cont.	Marrs et al. (2007)	Found that bracken has a much greater capacity to store C, N, P, K, Ca and Mg than the other vegetation components associated with semi-natural habitats. As a consequence when bracken control measures are applied, there is a higher risk of the nutrients being released to into the environment through run-off, thus the trade-offs between the different types of benefit associated with different management strategies or policy options needs to be considered.
Soil Stability	Zhang et al. (2007)	Earthworms and macro- and micro-invertebrates can increase soil structure via burrows or casts and enhance soil fertility through partial digestion and communition of soil organic matter.
	de Ruiter et al. (2005)	Showed that stability of the soil ecosystem is closely linked to the relative abundance of the different functional groups of organisms.
Pollination	Richards (2001)	Describe a number of cases where low fruit or the setting of seeds by crops and the reduction in crop yields has been attributed to a fall in pollinator diversity.
	Klironomos (2002)	Showed that the soil microflora may also be important in controlling invisibility of communities.
Impact of alien species on water budgets	Calder (2002)	Reports that in South Africa reforestation with exotic species such as Pinus spp. and Eucalyptus spp. significantly increased the probability of drought by reducing water flows in the dry season.
	Robinson et al. (2003)	Report significant changes in flows at the local scale, especially in *Eucalyptus globulus* plantations in Southern Portugal.
	Oyarzun and Huber (1999)	Show that *Pinus radiata* and *Eucalyptus* decreased water supply during the summer period in Chile.

of the ecosystem to invasion of invasive species. The effects of increasing biodiversity on 'consumption stability' appeared to be the strongest of the criteria considered; consumption stability is the effect of variations in biodiversity at one tropic level on the next. The positive effect of changing species diversity on drought resistance and susceptibility to other kinds of disturbance was, however, less marked. Intriguingly, those studies which looked at 'natural variations' in ecosystem properties, as opposed to those arising from experimental manipulations, showed a negative relationship to species diversity.

The case in favour of the hypothesis that generally positive relationship exist between components of biodiversity and ecosystem function is now, perhaps, stronger than it was at the time of the earlier reviews. A recent extensive review is provided by EASAC (2009), and Table 3.2 provides further examples of the kinds of evidence that is available. However, despite such progress, it is also clear that while recent commentators stress the possible implications for human well-being, it is also apparent from this work that the extent to which changes in ecosystem functions impact on service output remains an area of much greater uncertainty. Productivity is perhaps an important ecosystem function to consider because while it may not always be a 'final' service, except in the case of provisioning, it may control other kinds of ecosystem output. Thus while Richmond et al. (2007) suggests that terrestrial net primary productivity can be used as a proxy or indicator for a number of other ecosystem services, a more work is probably needed to substantiate this claim.

Raffaelli (2006) has also argued that there is now a need to move the study of biodiversity ecosystem function relationships on to a more 'service-orientated' footing. He suggests that although changes in ecosystem processes brought about by variations in biodiversity are 'relatively straightforward' to measure there may, however, be considerable problems extending the linkages to ecosystem goods and services. He flags up a number of factors may make the task a difficult one. These include the fact that particular services may depend on a number of different functions so that the analysis is more complex. Difficulties also arise because there is a wider the gap between particular processes and final services, and so relationships may be less sensitive. These issues are in compounded by the that losses of biodiversity are likely to affect processes and services in quite different ways, depending on what component of biodiversity is lost.

The unpredictable consequences of biodiversity loss in ecosystems has been emphasised by Ostfeld and LoGiudice (2003), who used an empirically based simulation model to assess how different sequences of species loss from vertebrate communities might influence risk of human exposure to Lyme disease. In this study the regulation of disease risk was considered to be the relevant ecosystem service. The study showed that there were marked differences in disease risk depending on the order with which species were lost from the community; change in risks levels were, in fact, lower when species were removed randomly compared to the effects of loss sequences that were more similar to those experienced in real world as a result of habitat fragmentation and habitat destruction.

Service orientated approaches

To cope with the types of complexities highlighted by Ostfeld and LoGiudice (2003), Raffaelli (2006) recommends that as part of the more service-orientated approach it may be more analytically efficient to start from particular services of interest and then track back to the functions that underpin them and ultimately the biodiversity components on which they depend. He illustrates the strategy by reference to the examples shown in Table 3.3. This approach he feels has the merit that changes in 'relevant biodiversity can be assessed much less ambiguously, and, hence, more persuasively to policy makers, than is presently the case' (Raffaelli, 2006, p.291).

Table 3.3: A service-orientated approach for identifying the relevant underpinning processes and biodiversity elements in marine coastal systems (after Raffaelli, 2006).

Service	Ecosystem process	Relevant biodiversity
Fibre/timber/fuel	Primary production	Mangrove trees
Fertility/nutrient cycling	Nutrients from sediment	Benthic infauna
Waste processing	Nutrient stripping	Salt marsh plants
Flood protection	Primary production	Marine vegetation
Pharmaceutical		Corals, sponges
Cultural/amenity		Shorebirds
Food	Secondary production	Estuarine bivalves

Note: Raffaelli (2006) observes that some ecological goods, such as marine pharmaceuticals and culture, aesthetics and recreation, have no obvious 'process' underpinning them. It is suggested that this arises because these particular biodiversity components can be regarded as final products or services, and pharmaceuticals and cultural elements regarded as benefits. The relevant ecosystem processes in these examples are the processes on which corals, sponges and sea birds depend.

However, whatever analytical perspective is adopted, it does not seem to avoid the problem that relationships across complex networks of interactions may be quite insensitive. As Balvanera et al. (2006) found in their review, studies suggest that as the number of trophic levels increased between the point where the experimental intervention was made and the measurement of effects were recorded, the change important functional properties like productivity was less marked. This is an interesting finding, because it suggests that ecosystems may sometimes have the capacity to buffer the effects of disturbance at one level and prevent or minimise impacts elsewhere. Such buffering has in fact been widely recognised in the ecological literature, and has been considered in much wider debates concerning the issue of ecosystem resilience. The problem is that generalisations are difficult to make for as Balvanera et al. (2006) also found, the buffering effects of biodiversity may be quite specific. The evidence suggests that while the buffering of biodiversity on nutrient retention and the susceptibility to invasive species was positive, it was not so clear for disturbances related to warming, drought or high environmental variability. In the absence of further work, they conclude that a precautionary approach to the management of biodiversity is required.

Assessment Frameworks

The nature of assessments

An understanding of the ecological mechanisms underpinning service output is clearly a vital part of the ecosystem services framework described in Part 1. If such insights are to support decision making, however, it is also clear that we have to apply these concepts to shape ecosystem assessments. We now consider the kinds of assessment framework that are being discussed in the recent literature, and what they can tell us about the importance of different components of biodiversity in the context of ecosystem services.

When beginning our review it became clear that compared to a notion like 'production function', the idea of an 'assessment framework' is one that appears to have been widely discussed in the recent literature. However, while the term might not have been widely used, it is apparent that the question of what kind of spatial or conceptual unit provides the basis for making an assessment is a live one. We found the body of literature on this topic is much more diffuse than that on the relationship between biodiversity and ecosystem function, and as a result the search strategies used as the basis of this review were probably not able to identify all the relevant material. For example, of the 4000 or so core papers that dealt with some aspect of ecosystem services, using Web of Knowledge, only 14 contained some variation of the phrase 'assessment framework', but none of these dealt with the issue in a substantive way or offered recommendations about what kinds of framework might be most suitable. By contrast, over 700 dealt with some issue related to assessment in its broadest sense. As an initial way into the literature, we therefore attempted to identify the most relevant papers from this larger group, and refine the review by looking at papers which dealt with modelling or mapping issues from an assessment perspective. Those dealing with the mapping of ecosystem services provide the most useful. The search exercise resulted in the identification of 14 core texts (Table 3.4), which combined with papers identified earlier, provided a basis for a review of assessment frameworks. Both 'relevance' and 'citation count' were used as the basis to extract papers using the sets identified by Web of Knowledge.

Table 3.4: Core papers identified in the context of assessment and mapping issues

Assessment issues	
Carpenter, S. R., H. A. Mooney, J. Agard, D. Capistrano, R. S. DeFries, S. Diaz, T. Dietz, A. K. Duraiappah, A. Oteng-Yeboah, H. M. Pereira, C. Perrings, W. V. Reid, J. Sarukhan, R. J. Scholes and A. Whyte (2009): Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences of the United States of America 106(5): 1305-1312.	RR: 17/740
Cowling, R. M., B. Egoh, A. T. Knight, P. J. O'Farrell, B. Reyers, M. Rouget'll, D. J. Roux, A. Welz and A. Wilhelm-Rechman (2008): An operational model for mainstreaming ecosystem services for implementation. Proceedings of the National Academy of Sciences of the United States of America **105**(28): 9483-9488.	RR: 5/740
Fisher, B., K. Turner, M. Zylstra, R. Brouwer, R. de Groot, S. Farber, P. Ferraro, R. Green, D. Hadley, J. Harlow, P. Jefferiss, C. Kirkby, P. Morling, S. Mowatt, R. Naidoo, J. Paavola, B. Strassburg, D. Yu and A. Balmford (2008): Ecosystem service and economic Theory: Integration for policy–relevant research. Ecological Applications 18(8): 2050-2067.	RR: 4/740
Luck, G. W., R. Harrington, P. A. Harrison, C. Kremen, P. M. Berry, R. Bugter, T. P. Dawson, F. de Bello, S. Diaz, C. K. Feld, J. R. Haslett, D. Hering, A. Kontogianni, S. Lavorel, M. Rounsevell, M. J. Samways, L. Sandin, J. Settele, M. T. Sykes, S. van den Hove, M. Vandewalle and M. Zobel (2009): Quantifying the Contribution of Organisms to the Provision of Ecosystem Services. Bioscience 59(3): 223-235.	RR: 10/740
Schröter, D., W. Cramer, R. Leemans, I. C. Prentice, M. B. Araujo, N. W. Arnell, A. Bondeau, H. Bugmann, T. R. Carter, C. A. Gracia, A. C. de la Vega-Leinert, M. Erhard, F. Ewert, M. Glendining, J. I. House, S. Kankaanpaa, R. J. T. Klein, S. Lavorel, M. Lindner, M. J. Metzger, J. Meyer, T. D. Mitchell, I. Reginster, M. Rounsevell, S. Sabate, S. Sitch, B. Smith, J. Smith, P. Smith, M. T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, S. Zaehle and B. Zierl (2005): Ecosystem service supply and vulnerability to global change in Europe. Science 310(5752): 1333-1337.	RC:8/740
Mapping Issues	
Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le Maitre and A. S. van Jaarsveld (2008): Mapping ecosystem services for planning and management. Agriculture Ecosystems & Environment 127(1-2): 135-140.	RR: 4/237
Imhoff, M. L., L. Bounoua, T. Ricketts, C. Loucks, R. Harriss and W. T. Lawrence (2004): Global patterns in human consumption of net primary production. Nature 429(6994): 870-873.	RC: 3/237
Kremen, C. (2005): Managing ecosystem services: what do we need to know about their ecology? Ecology Letters 8(5): 468-479.	RR 3/237; RC: 2/237
McMahon, G., S. M. Gregonis, S. W. Waltman, J. M. Omernik, T. D. Thorson, J. A. Freeouf, A. H. Rorick and J. E. Keys (2001): Developing a spatial framework of common ecological regions for the conterminous United States. Environmental Management 28(3): 293-316.	RC: 13/237
Mumby, P. J., K. Broad, D. R. Brumbaugh, C. P. Dahlgren, A. R. Harborne, A. Hastings, K. E. Holmes, C. V. Kappel, F. Micheli and J. N. Sanchirico (2008): Coral reef habitats as surrogates of species, ecological functions, and ecosystem services. Conservation Biology 22(4): 941-951.	RR: 5/237
Raymond, C. M., B. A. Bryan, D. H. MacDonald, A. Cast, S. Strathearn, A. Grandgirard and T. Kalivas (2009): Mapping community values for natural capital and ecosystem services. Ecological Economics 68(5): 1301-1315.	RR: 1/237
Schimel, D. S., W. Emanuel, B. Rizzo, T. Smith, F. I. Woodward, H. Fisher, T. G. F. Kittel, R. McKeown, T. Painter, N. Rosenbloom, D. S. Ojima, W. J. Parton, D. W. Kicklighter, A. D. McGuire, J. M. Melillo, Y. Pan, A. Haxeltine, C. Prentice, S. Sitch, K. Hibbard, R. Nemani, L. Pierce, S. Running, J. Borchers, J. Chaney, R. Neilson and B. H. Braswell (1997): Continental scale variability in ecosystem processes: Models, data, and the role of disturbance. Ecological Monographs 67(2): 251-271.	RC: 1/237
Schmitz, O. J., E. Post, C. E. Burns and K. M. Johnston (2003): Ecosystem responses to global climate change: Moving beyond color mapping. Bioscience 53(12): 1199-1205.	RR: 14/237 RC: 11/237
Note: RR= ranking by relevance; RC= ranking by number of citations	

Carpenter et al. (2009) have emphasised that despite the achievements of the MA we still need to develop more rigorous approaches to assessment. They call for the development of better assessment methods designed to describe the effects of biodiversity in social-ecological context, and improve quantitative modelling across a range of social-ecological topics, in ways that help us

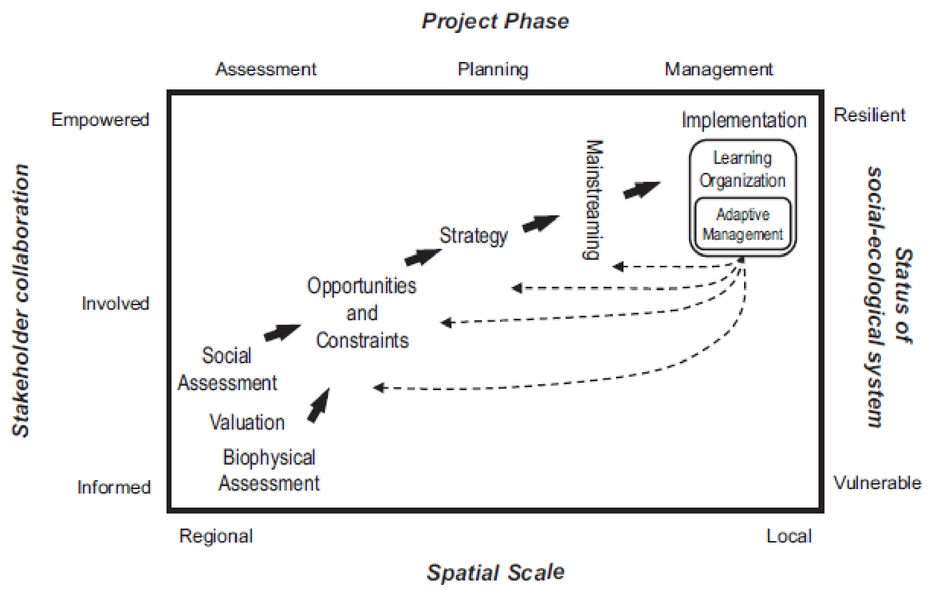


Figure 3.4: Assessment contexts (after Cowling et al., 2008)

understand the abrupt changes (regime shifts) that ecosystems may exhibit when disturbed, and which will our capacity to communicate uncertainty. Cowling et al. (2008) have specifically considered the nature of assessment and suggests that it is fundamentally a systematic process that aims to provide support for decision making. Assessments, they suggest, seek 'to answer questions inspired by the beneficiaries and managers of ecosystem services' (Cowling et al. 2008, p. 9484); they distinguish three complementary types of assessment according to whether they focus on social, biophysical or valuation issues (Figure 3.4).

Cowling et al. (2008) 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, which aim more to generate information about the character and geography of the ecological systems that generate the services and benefits over space and time, and the impacts of direct and indirect drives of change. Valuation assessments are dependent on inputs from the social and biophysical and generally, but not exclusively, seek to place a monetary value on the services being considered and provide insights into the marginal change in value under different conditions or assumptions. Cowling et al. (2008) argue that collectively these three types of assessment allow decision makers and stakeholders to consider the opportunities and constraints available to them and the tools needed to design effective management strategies (Figure 3.4).

Given the present focus on biodiversity and ecosystem functioning, in this chapter we will concentrate mainly on biophysical assessments, leaving discussion of the social and valuation approaches to the next.

Mapping services

As Cowling et al. (2008) note, and our review confirms, most of the published assessments approach the problem by attempting to map services, their flows and the external pressures upon them. Important recent mapping studies include those of Chan et al. (2006), Nadoo et al. (2008), Imhoff et al. (2004) and Schröter et al. (2005). The development of methods is also the focus of on-going international effort through initiatives like the Natural Capital Project in the US (see also Daily et al. 2008).

The starting point for the work of Chan et al. (2006) was the observation that because ecosystem services are generally poorly characterised, their protection has often not been given a high priority. Thus they attempted to map ecosystem services in the Central Coast eco-region of California, to examine whether there was a spatial coincidence between those areas which were being targeted for conservation and those important those for sustaining ecosystem services. Six services were considered, namely carbon storage, flood control, forage production, outdoor recreation, crop pollination, and water provision. Each was mapped using a model-based approach, involving the use of surrogates or proxy measures. The study showed that while strategies for biodiversity conservation could also protect flows of ecosystem services, a strategy that focused on both services and biodiversity was not as efficient in conservation terms, as one that targeted biodiversity alone. Although they found some important trade-offs between conservation for biodiversity and ecosystem services they concluded that the mapping approaches provided a good basis for developing a systematic planning framework that offered the scope for identifying synergies between the different objectives. Nadoo et al. (2008) also examined the same kind of issue, but this time at global scales. They compared ecosystem service maps with those areas conventionally targeted for biodiversity conservation, and found that for the four services were examined (Carbon sequestration, carbon storage, grassland livestock production and water provision) there was generally little concordance between the two themes. Once again, mapping was based on the use of modelled estimates or proxies.

Cowling et al. (2008) criticise the approach used in many mapping studies in so far as they are mainly concerned with the identification and mapping of natural features, and rarely consider markets or beneficiaries. In other words they tend to deal with the supply side of ecosystem services rather than the demand for them. The studies are deficient in that they are 'not user-inspired and lack social assessments for identifying the suite of services that fulfil social needs, both presently and potentially' (Cowling et al., 2008, p. 9485). Clearly there can be not understanding of services without information about beneficiaries. However, in their defence it should be noted that both Chan et al (2006) and Nadoo et al. (2008) do recognise the preliminary nature of their mapping and modelling, and in a sense some aspects of demand are built into the work implicitly, by comparing service profiles with socially agreed targets for conservation. Other mapping studies, like that of Schröter et al. (2005) which considered the vulnerability of ecosystem services in Europe to global change might also claim that some aspects of demand are considered though the use of scenarios. Nevertheless it is clear that we probably do need more sophisticated biophysical assessment tools than these types of approach illustrate.

Our review suggests that there is therefore increasing interest in the development of spatially explicit modelling frameworks for ecosystem services and that these are providing an important arena for a range of interdisciplinary work. Some of the most advanced modelling approaches are those associated with the Natural Capital Project (Daily et al. 2009). This initiative is being led by the Woods Institute for the Environment at Stanford University, and is sponsored by the US Nature Conservancy and WWF. Other examples include MIMES, which is a collaborative mapping project being led by the Grund Institute for Ecological Economics at the University of Vermont.

The Natural Capital Project aims to provide maps of ecosystem services, assessments of their values in economic and other terms. A key analytical resource provided by the project is the inVEST toolbox (Figure 3.5), which has been designed to support stakeholder involvement in defining management or policy issues and the construction of change scenarios. Indeed, the structure proposed coincides with that suggested for integrated social, biophysical and valuation assessments suggested by Cowling et al (2008). Within INnVEST, a suite of biophysical models are used to explore the consequences of different options or choices with stakeholders and outputs are generated in the form of maps, trade-off curves and 'balance sheets'.

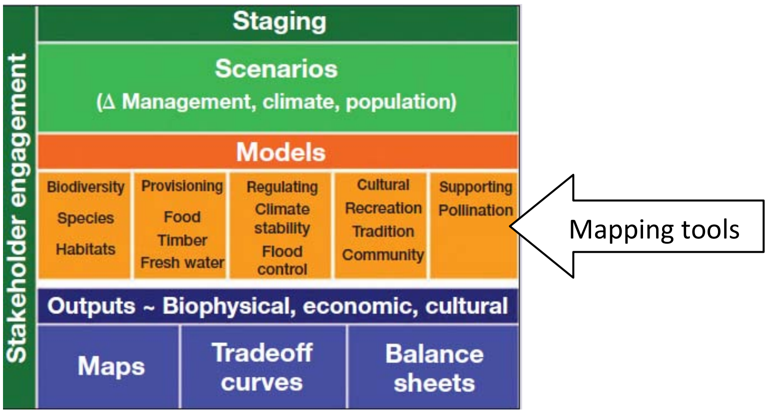


Figure 3.5: Structure of Natural Capital Initiative InVEST Toolbox (after Daily et al., 2009)

InVEST is publically available, and so is likely to be widely used. It runs as a set of script tools in the ArcGIS ArcTool Box environment, and currently includes models for carbon sequestration, pollination of crops, managed timber production, water pollution regulation and sediment retention for reservoir maintenance. The modelling framework is customisable, and generally requires land cover information as a basic input to the analysis. There is also a biodiversity model that permits the analysis of tradeoffs between biodiversity and ecosystem services. It is planned that the range of biophysical models offered will be extended to cover flood mitigation, agriculture production, irrigation, open-access harvest and hydropower production. The modelling tools currently only concern ecosystem services associated with the terrestrial and freshwater systems, but it is planned that the set will be extended to include marine areas, especially reefs and other coastal systems.

Apart from the problems of understanding how services arise and how to measure them in biophysical terms, a key issue that all of these mapping studies have to address is the nature of the physical or conceptual unit that forms the basis of the assessment – in other words what actually constitutes 'an ecosystem'. Our review suggests that there is growing interest in how these units can be defined, and how they can be used operationally.

An important recent theoretical advance is provided by the work of Luck et al. (2003, 2009) who have proposed the idea of a Service Providing Unit (SPU). These workers suggest that instead of defining a population or organisms along geographic, demographic or genetic lines, it can also be specified in terms of the services or benefits it generates at a particular scale. For example, an SPU might comprise all those organisms contributing to the wildlife interest of a site or region, or all those organisms or habitats that have a role in water purification in a catchment. It is a kind of ecological 'foot-print' of the biophysical mechanisms and processes that give rise to the service. Luck et al. (2009) suggest that by defining a population according to the contribution it makes to ecosystem services will help us to better describe how changes in species distribution and abundance might ultimately impact on human well-being. Kremen (2005) has extended the SPU concept and proposed that we can define key Ecosystem Service Providers (ESPs) in terms of their functional traits or the functional importance of populations, communities, guilds, and interacting networks of organisms that deliver services. Luck et al. (2009) also show how these ideas can be linked to the notion of Ecosystem Service Beneficiaries (ESBs).

Although the distinction between SPUs and ESPs is yet to be fully resolved, the more general idea of Service Providers (SPs) provides a powerful conceptual device for exploring the structures and processes that underpin different services. By way of illustration Luck et al. (2009) provides a number of examples to show how the concept works, and as noted in Part 2, the framework they used offers an interesting template on which information about ecosystem services might be represented (see also Appendix 1, Table A.6). While SPUs are essentially functional rather than spatial units, they seem to provide a means for developing a more rigorous approach to mapping than is presently often the case.

Assessment approaches

An significant limitation of many current biophysical assessment frameworks, including the MA, is the assumption that ecosystems are equivalent to biomes or habitats, and that services simply 'map' on to them. The recent discussion surrounding the concept of a Service Providing Unit suggests, however, this is view should not be used without some scrutiny. Even so, the concept is widely held. Nadoo et al. (2008), for example, used the terrestrial eco-regions of the world as a framework for their analysis, and other studies such as those of Mumby et al. (2008), Schimel et al. (1997), and McMahon et al. (2001) used habitat units as the basis for assessment. The approaches currently being developed in TEEB and the UK National Ecosystem Assessment are also based on the same supposition.

In the case of the UK NEA, it is proposed that the BAP Broad Habitats will be grouped into more general units, like 'semi-natural grasslands', 'mountain heath and moor', and 'urban'[11]. However, as pointed out elsewhere (Haines-Young and Potschin, 2008), while the 'habitat approach' to service assessment has a number of advantages, it may not be able to provide a picture of what is happening overall to an individual services. Although there may, for example, be strong habitat-service associations the contributions that individual habitats make to some aggregated assessment of service output is often unclear; weighting habitats by their area may, for example, not reflect the contributions that they make.

[11] The grouping also reflects that used for in recent countryside surveys

From their review Egoh et al. (2007) identify three main ways in which ecosystem services are currently accounted for in conservation assessments, namely methods based on the analysis of biodiversity patterns, methods based on ecological processes and mapping approaches. Although the terminology is somewhat confusing, analyses based on biodiversity patterns are those that we have described above, as 'habitat based'. The approach essentially involves weighting such units by some criteria of value to make some overall assessment. By contrast, processes based approaches, focus on a particular service and seek to uncover the mechanisms by which it is generated. Finally, what they call the mapping approach considers how biophysical units can be constructed and used to examine changes in service output over space and time.

The mapping approach identified by Egoh et al. (2007) is of interest here because it represents a growing body of literature that implicitly shows how the concepts such as those of Service Providing Units and Ecosystem Service Providers can be made operational. Thus, for example, in the study cited by Egho et al. (2007) by Gou and Gan (2002) water retention, a function important for water regulation and supply in a watershed, was modelled in China by defining a set of customised biophysical units based on combinations of vegetation, soil and slope. The study of Chan et al (2006) also attempts to model predict the functional characteristics of different types of 'planning unit' in their study. Egoh et al. (2007) suggest that an advantage of this function-based mapping approach is that it can potentially describe both service supply and demand.

Table 3.5: Comparison of habitat, systems and place-based assessment approaches.

Approach	Characteristic	Advantages	Disadvantages
Habitat (Biodiversity Pattern) based	Mapping of services made on the basis of spatial patterns in underlying components of biodiversity, e.g. habitat types, biomes	• Clear links with exiting conservation frameworks and approaches; • multi-functional character of 'ecosystems' evident • Can often make use of existing biodiversity or habitat monitoring data	• Unclear how different habitats should be weighted to make some overall assessment of services. • Unclear how habitat combinations influence service output
Systems (Process) based	Mapping services based on the spatial characteristics of biophysical elements on which the service is functionally dependent, e.g. catchment	• Allows overall assessment of service state and trend to be made • Generalisation easier	• Unclear how issues of multi-functionality can be addressed • Systems modelling is complex and present understandings may be limited – especially in the context of predicting spatial pattern
Place-based	Mapping services as bundles across units that have strong social relevance or resonance	• Allows better understanding of local contexts, and therefore priorities and values • Allows issues of trade-offs to be identified and potentially resolved • Allows implications of alternative management of policy options to be tested easily through participatory methods	• Difficult to generalise results • Difficult to model services at local scales because of uncertainties and lack of base-line data

The description of different assessment approaches by Egoh et al. (2007) is, perhaps unhelpful because in principle all can result in some kind of spatial mapping. Thus as an alternative the framework suggested in an earlier study by Haines-Young and Potschin (2008) might be reconsidered considered; this involved distinguishing assessment approaches involving on habitat, systems and place-based approaches. The characteristics of these different approaches and their relationship to the groups suggested by Egoh et al. (2007) are described in Table 3.5. The argument here is not that one approach is superior to others, but that all have merits that may be exploited in particular analytical situations. The 'habitat approach' used in TEEB and the NEA is not intrinsically mistaken, the point is, that assessment units whatever their character, should not be accepted uncritically.

Although the focus of this section has been on the biophysical assessment, increasingly it appears from a review of the literature that the methods applied cannot be looked at in isolation from the other elements of the appraisal process. While it is clear that increasingly sophisticated biophysical methods for mapping and modelling services are developing, it is also clear that if they are to be relevant they also have to link with and support the social- and value-based components of the appraisal process if progress is to be made. Raymond et al. (2009), for example, argue that while biophysical and economic assessments of ecosystem services are now common, there remains a great need to develop methods that can take account of community values. Carpenter et al. (2009) assert even more strongly the need for broadening perspectives. 'Discipline-bound approaches', they suggest, 'that hold one component constant while varying the other lead to incomplete and incorrect answers' (Carpenter et al., 2009, p.1309). For the future they suggest we should focus on a networked, place-based type of long-term social-ecological research if we are to develop a more rigorous approach to assessment.

Biodiversity and Ecosystem Service Output

In Part 3 we have considered the relationships between biodiversity, ecosystem functioning and the output of ecosystem services. Our review suggests that considerable progress in exploring these issues has been made, and that there is now a substantial body of evidence to support the view of that in many situations there is a direct relationship between a range of biodiversity components and elements of ecosystem functioning. Important insights into the nature of these relationships have been provided by the study of functional traits at both the species and group level. However, it is also clear that while the factors controlling ecosystem functioning are better understood, the evidence to demonstrate that changes in biodiversity that impact on ecosystem function carry over to service output. It has been suggested that more service-focused approaches to the study of biodiversity is required.

Part 3 concluded by a wider consideration of assessment approaches, and the issues surrounding the biophysical methods used in such work. A number of authors have called for the development of better assessment methods, echoing the conclusion drawn from the discussion of biodiversity ecosystem function relationships. The development of new spatial mapping and assessment concepts and tools was discussed, and the important contribution of the idea of Service Providing Units was identified.

Although biophysical methods for assessing the state and trends of ecosystem services will remain an important part of the ecosystems service framework, our review suggests that increasingly they will be seen as part of a broader approach to the problem of appraisal that also takes in social and economic valuation. In the final part of this report we therefore turn to look at these dimensions of assessment in greater detail.

Part 3: Biodiversity, ecosystem function and service output- Key messages

- Our review confirms that there is a considerable body of evidence to suggest that biodiversity and ecosystem functioning are closely linked:
    - particular combinations of species may have a complementary or synergistic effect on their patterns of resource use which can increase average rates of productivity and nutrient retention;
    - the vulnerability of communities to invasion by alien species is influenced by species composition and under similar environmental conditions, generally increases as species richness falls; and,
    - ecosystems subject to disturbance can be stabilised if they contain species with traits that enable them to respond differently to changes in environmental conditions.
- However, because of the complexity of causal chains it is much more difficult to trace the impact of changes in biodiversity through to changes in service output.
- To examine the links between biodiversity and services further, it has been argued that more service focused research and assessment approaches are required.
- The review suggests that new assessment methods are being developed, and a greater range of sophisticated tools and approaches to support biophysical appraisals are now becoming available:
    - The concept of Service Providing Units has emerged as a useful basis for developing functional mapping approaches.
    - New spatial mapping tools such as those in the InVEST tool box are being actively developed.
    - Assessment approaches built on habitat, system and place-based perspectives are now becoming available.
- There is an urgent need to ensure that these new biophysical assessment methods link to and support social and economic methods for assessment, so that robust, integrated appraisals can be undertaken in ways that support the needs of decision makers.

Part 4 The Valuation of Ecosystem Services

Introduction

Although the MA did not explicitly value the output of ecosystem services, many feel that this is the next step in taking these ideas forward in a policy or decision making context. And while it could be fairly claimed that the publication of the MA has given the stimulus to much recent work in this area, a review of the content of the recent literature suggests that it is the valuation issue which is now driving the field forwards. Of the 4000 or so papers that used the concepts of 'ecosystem', 'ecological' or 'environmental services', by far the greatest number were appeared in the journal Environmental Economics (Figure 4.1). The paper with the largest number of citations in the field was that of Costanza et al. (1997) which attempted to make an estimate of the value of the world's ecosystem services and natural capital. In fact, inspection of the data shown in Figure 4.1 suggests that the whole character of the field is currently dominated discussion of more by social science and management issues than it is by debates in mainstream ecology or the natural sciences more generally.

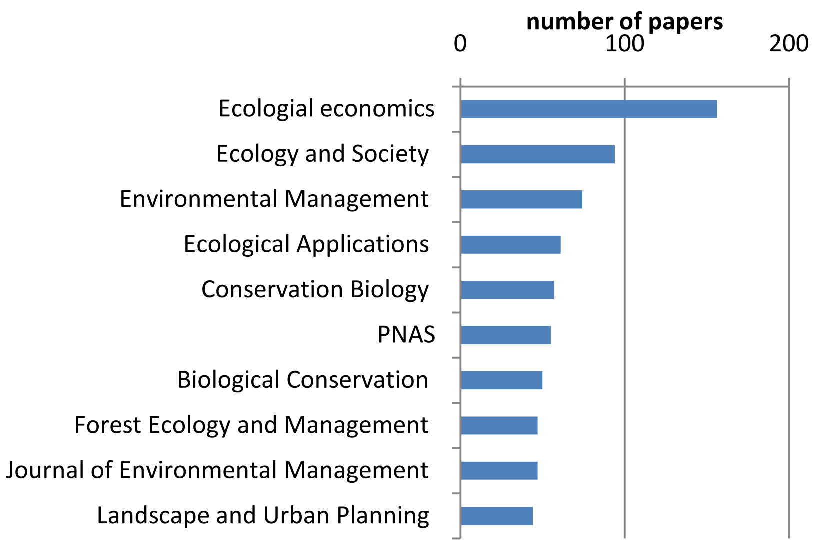


Figure 4.1: Key journals for papers dealing with ecosystem services identified using Web of Knowledge (August, 2009)

From the 4000 publications identified that make some reference to ecosystem, ecological or environmental services, the numbers of publications appearing in the top 10 journals are noted.

Table 4.1: Key publications dealing with valuation or valuing ecosystem services identified using Web of Knowledge

Barkmann, J., K. Glenk, A. Keil, C. Leemhuis, N. Dietrich, G. Gerold and R. Marggraf (2008): Confronting unfamiliarity with ecosystem functions: The case for an ecosystem service approach to environmental valuation with stated preference methods. Ecological Economics 65(1): 48-62.	RR: 1/299
Bockstael, N. E., A. M. Freeman, R. J. Kopp, P. R. Portney and V. K. Smith (2000): On measuring economic values for nature. Environmental Science & Technology 34(8): 1384-1389.	RC: 9/299 (54)
Chan, K. M. A., M. R. Shaw, D. R. Cameron, E. C. Underwood and G. C. Daily (2006): Conservation planning for ecosystem services. Plos Biology 4: 2138-2152.	RR: 12/299
Chee, Y. E. (2004): An ecological perspective on the valuation of ecosystem services. Biological Conservation 120(4): 549-565.	RR: 8/299
Costanza, R. and H. E. Daly (1992): Natural capital and sustainable development. Conservation Biology 6(1): 37-46.	RC: 2/299 (148)
Costanza, R., R. dArge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. Oneill, J. Paruelo, R. G. Raskin, P. Sutton and M. vandenBelt (1997): The value of the world's ecosystem services and natural capital. Nature 387(6630): 253-260.	RC: 1/299 (1479) RR: 1/299
Cowling, R. M., B. Egoh, A. T. Knight, P. J. O'Farrell, B. Reyers, M. Rouget'll, D. J. Roux, A. Welz and A. Wilhelm-Rechman (2008): An operational model for mainstreaming ecosystem services for implementation. Proceedings of the National Academy of Sciences of the United States of America 105(28): 9483-9488.	RC: 6/299
Daily, G. C., T. Soderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P. R. Ehrlich, C. Folke, A. Jansson, B. O. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K. G. Mäler, D. Simpson, D. Starrett, D. Tilman and B. Walker (2000): Ecology - The value of nature and the nature of value. Science 289(5478): 395-396.	RC: 3/299 (114)
Farber, S., R. Costanza, D. L. Childers, J. Erickson, K. Gross, M. Grove, C. S. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren and M. Wilson (2006): Linking ecology and economics for ecosystem management. Bioscience 56(2): 121-133.	RR: 17/299
Hein, L., K. van Koppen, R. S. de Groot and E. C. van Ierland (2006): Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57(2): 209-228.	RR: 2/299
Kumar, M. and P. Kumar (2008): Valuation of the ecosystem services: A psycho-cultural perspective. Ecological Economics 64(4): 808-819.	RR: 13/299
Moberg, F. and C. Folke (1999): Ecological goods and services of coral reef ecosystems. Ecological Economics 29(2): 215-233.	RC: 6/299 (75)
Raymond, C. M., B. A. Bryan, D. H. MacDonald, A. Cast, S. Strathearn, A. Grandgirard and T. Kalivas (2009): Mapping community values for natural capital and ecosystem services. Ecological Economics 68(5): 1301-1315.	RR: 15/299
Turner, R. K., J. Paavola, P. Cooper, S. Farber, V. Jessamy and S. Georgiou (2003): Valuing nature: lessons learned and future research directions. Ecological Economics 46(3): 493-510.	RC: 5/299 (77)
Turner, R. K., J. van den Bergh, T. Soderqvist, A. Barendregt, J. van der Straaten, E. Maltby and E. C. van Ierland (2000): Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35(1): 7-23.	RC: 4/299 (81)
Villa, F., M. Ceroni and S. Krivov (2007): Intelligent databases assist transparent and sound economic valuation of ecosystem services. Environmental Management 39(6): 887-899.	RR: 9/299
Zhang, W., T. H. Ricketts, C. Kremen, K. Carney and S. M. Swinton (2007): Ecosystem services and dis-services to agriculture. Ecological Economics 64(2): 253-260.	RC: 4/299
Note: RR= ranking by relevance; RC= ranking by number of citations (number of citations in brackets)	

From the larger set of papers identified using Web of Knowledge, 299 journal or review articles in English used the concepts of 'valuation' or 'valuing'; from these a smaller key publications have been identified using the, using the 'criteria of number of citations' and 'relevance' (Table 4.1). These, together with publications identified in the earlier sections of this Report (esp. Brown et al., 2007; Carpenter et al., 2009; Cowling et al., 2008; Daily et al., 2009 and Fisher et al., 2008), and more general sources, such as Defra (2007b), the Interim *TEEB* Report and supplementary materials (European Communities, 2008), were then used as the basis of the review. Part 4 aims to provide an overview of recent development in relation to the task of valuing ecosystem services, and in particular explore how better understandings of the links between biodiversity and ecosystem function enable monetary estimates of the value of biodiversity to be made; the problem of valuation in the context of multi-functional ecosystems is also discussed.

The Valuation Debate

Understanding benefits and values

If decisions are to be made about preserving or modifying natural capital, then society must be as well informed as it can be about the consequences and impactions of its actions. In a very broad sense, valuation techniques provide a set of tools to help people compare the benefits and costs associated with different options. The techniques also usually provide ways of expressing benefits and costs in a common framework, so that comparisons can more easily be made. Although many different types of valuation approach are possible, the one which expresses costs and values in monetary terms (i.e. economic valuation) is, perhaps the most widely used, although as Raymond et al. (2009) suggest community values can also be captured using simple scoring techniques.

A feature of the recent literature has been the attempt to clarify exactly what economic valuation can and cannot do, and to develop and apply valuation methods in ways that address the complexities associated with ecological systems.

In the discussions surrounding Phase II of TEEB, for example, there has been some effort to distinguish more clearly the notion of benefits from values (de Groot, pers com; see also Bockstael et al., 2000 and Chee et al., 2004 for a more detailed discussion of these topics). In the TEEB discussions it has been argued that people have needs which, when fulfilled, are translated into some measurable benefits. The close link between services and benefits is one of the things stressed by the MA framework (Figure 2.2) and as we have seen, there have been some attempts to draw up typologies of services starting from some listing of potential benefits that they can deliver (e.g. Boyd and Banzhaf, 2007, Appendix 1, Table A.1; Wallace, 2007. Appendix 1, Table A.8). Thus agricultural systems can deliver health benefits in terms of nutrition, as well as providing such things as cultural identity and recreational opportunity. How different people prioritise or value these benefits may, however, be quite divergent. Some people will attach greater value to food production, say, while others might emphasise the cultural importance of particular types of farming system, even though they may not be the most efficient at producing food. Thus different values can be attached to the same benefit; and these values also vary over time, even within the same interest group. As Kontogianni et al. (2008) have recently noted, these values can change as a result of a number of demand- and supply-side factors. Their review of recent work suggested, in fact, that there was little conclusive evidence to suggest that WTP values were stable over short to medium period of time, and that they are highly likely to change in the longer term.

Thus in the TEEB discussions there has been some suggestion that the cascade modle should be refined to make the distinction between benefits and values clearer (Figure 4.2); the task of economic valuation therefore requires an understanding of what kinds of benefit people receive through ecosystem services, and how they prioritise them in monetary terms compared to other things. In conventional economics it is largely 'the market' that determines what these values are. The problem with ecosystem services is that many of them lie outside conventional markets, and so their values are difficult to capture or estimate.

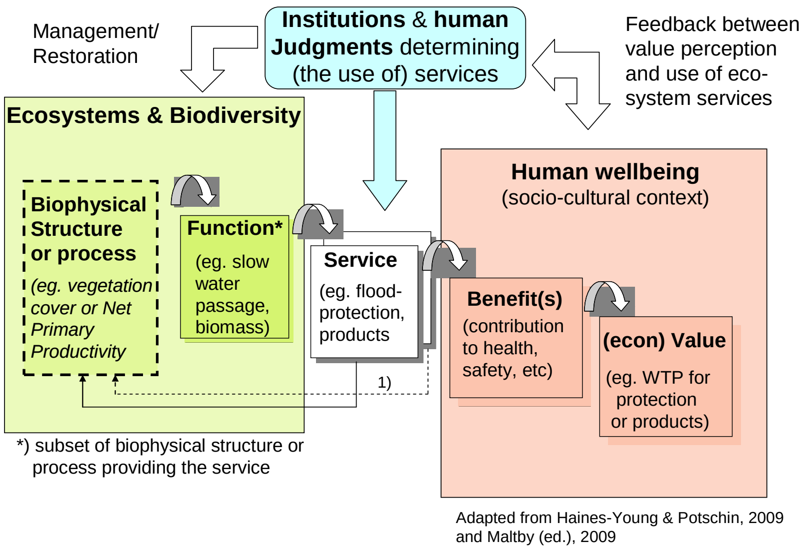


Figure 4.2: Adaptation of cascade mode suggested in Phase II of TEEB (Original Haines-Young and Potschin, 2010, modified in de Groot et al., in prep.)

The Total Economic Value (TEV) framework has been widely employed to estimate both the use and non-use values that individuals and society gain or lose from marginal changes in ecosystem services. A feature of recent work as been the attempt to describe more clearly how different methods can be used to estimate the various components of TEV, and how such data can be used to provide the most robust monetary estimates of how these values might change under different conditions. Important contribution is provided by Hein et al. (2006) and Pagiola et al. (2004), both of whom emphasise the need for an interdisciplinary approach. Valuation issues cannot be resolved by economists working alone.

Hein et al. (2006) provides a useful discussion of the steps involved in valuing ecosystem services and their relationship to the TEV framework, which emphasises how important it is to ground the analysis on a sound understanding of biophysical relationships (Figure 4.3). Four steps are envisaged in the process, namely:

1. Specification of the boundaries of the ecosystem to be valued;
2. Assessment of the ecosystem services supplied by the system;
3. Valuation of the ecosystem services; and,
4. Aggregation or comparison of the values of the services.

As Figure 4.3 suggests, it is the envisaged that although the main service groups (provisioning, regulating and cultural) have different profiles in terms of the various TEV categories but that overall the aim is to achieve an aggregated value for the ecosystem that can be used to compare the

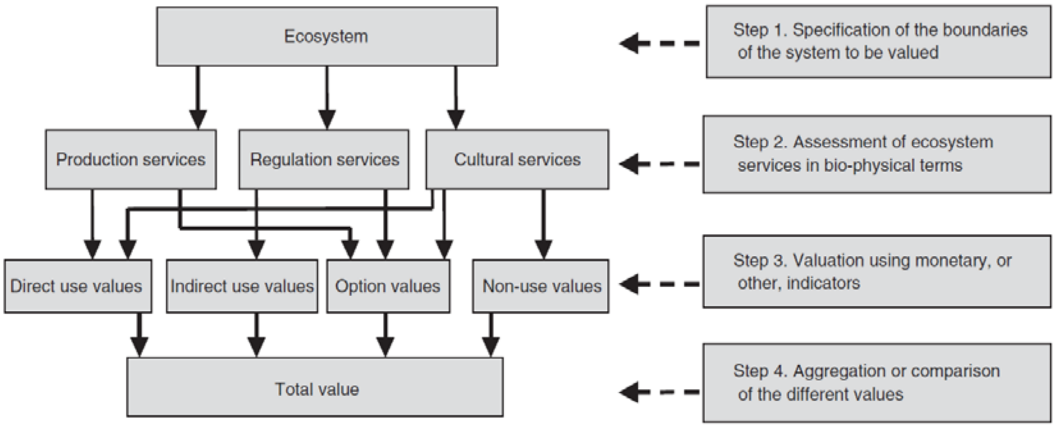


Figure 4.3: The ecosystem valuation framework (after Hein et al., 2006)

different sets of circumstances; say, as the result of different types of policy or different types of impact or intervention.

Specification of the boundaries of the ecosystem is a particularly important step in the process, and the issues they flag up here have strong resonances with our discussion of assessment frameworks in Part 3. The task of specifying boundaries amounts to making clear exactly what the 'Service Providing Unit' actually is. As Hein et al. (2006) note these 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, in fact that stakeholders can have quite different interests in the associated ecosystem services, depending on the scale of analysis. Thus a multi-scale perspective may even be necessary for in analyses. Nevertheless, what this study demonstrates is that the initial stages of any valuation study have to be grounded on some kind of social assessment (cf. Cowling et al., 2008, and see also Figure 3.4, p. 36). Such preliminary work may, as the work of Barkman et al. (2008) illustrates be essential, if the problem of stakeholder unfamiliarity with issues is to be overcome when using stated preference valuation methods. Chee et al. (2004) also argues for the importance of active stakeholder involvement at the early stages of an assessment.

In terms of making an assessment of the Total Economic Value (TEV), Hein et al. (2006) suggest that the different components of direct and indirect use, option and non-use values can be summed if they are expressed in monetary terms. However, they also note that other types of physical indicator or stakeholder rankings can also be used; in this case the values are simply compared through some kind of deliberative process. They also provide a set of guidelines on how the issue of 'double counting' can be avoided such exercises, based on the spatial configuration of services and associated benefits.

Table 4.2: An overview of valuation methods, contexts and issues (after Pagiola et al., 2004).

Valuation method	Approach	Applications	Examples	Limitations
Market prices	Observe prices directly in markets	Environmental goods and services that are traded in markets	Timber and fuel wood from forests; clean water from wetlands	Market prices can be distorted e.g. by subsidies. Environmental services often not traded in markets
Replacement cost	Estimate cost of replacing environmental service with man-made service	Ecosystem services that have a man-made equivalent that could be used and provides similar benefits to the environmental service.	Coastal protection by mangroves; water storage and filtration by wetlands	Over-estimates value if society is not prepared to pay for man-made replacement. Under-estimates value if man-made replacement does not provide all of the benefits of the environmental service.
Damage cost avoided	Estimate damage avoided due to ecosystem service	Ecosystems that provide protection to houses or other assets	Coastal protection by mangroves/ reefs; river flow control by wetlands	Difficult to relate damage levels to ecosystem quality.
Net factor income	Revenue from sales of environment-related good minus cost of other inputs	Ecosystems that provide an input in the production of a marketed good	Filtration of water by wetlands; commercial fisheries supported by coral reef	Over-estimates ecosystem values
Production function	Estimate value of ecosystem service as input in production of marketed good	Ecosystems that provide an input in the production of a marketed good	Filtration of water by wetlands; commercial fisheries supported by coral reef	Technically difficult. High data requirements
Hedonic pricing	Estimate influence of env. characteristics on price of marketed goods	Environmental characteristics that vary across goods (usually houses)	National parks, air pollution, proximity to waste dumps	Technically difficult. High data requirements
Travel cost	Travels costs to access a resource indicate its value	Recreation sites	National parks, marine protected areas	Technically difficult. High data requirements
Contingent valuation	Ask survey respondents directly for WTP for environmental service	Any environmental good or service	Species loss, natural areas, air pollution	Expensive to implement
Choice modelling	Ask survey respondents to trade-off environmental and other goods to elicit WTP	Any environmental good or service	Species loss, natural areas, air pollution	Expensive to implement. Technically difficult
Value transfer	Use values estimated at other locations	Any environmental good or service	Species loss, natural areas, air pollution	Possible transfer errors. Can be as technically difficult as primary valuation

Table 4.3: Methods for valuing ecosystem services (after Farber et al. , 2006).

Ecosystem service	Amenability to economic valuation	Most appropriate method for valuation	Transferability across sites
Gas regulation	Medium	CV, AC, RC	High
Climate regulation	Low	CV	High
Disturbance regulation	High	AC	Medium
Biological regulation	Medium	AC, P	High
Water regulation	High	M, AC, RC, H, P, CV	Medium
Soil retention	Medium	AC, RC, H	Medium
Waste regulation	High	RC, AC, CV	Medium to high
Nutrient regulation	Medium	AC, CV	Medium
Water supply	High	AC, RC, M, TC	Medium
Food	High	M, P	High
Raw materials	High	M, P	High
Genetic resources	Low	M, AC	Low
Medicinal resources	High	AC, RC, P	High
Ornamental resources	High	AC, RC, H	Medium
Recreation	High	TC, CV, ranking	Low
Aesthetics	High	H, CV, TC, ranking	Low
Science and education	Low	Ranking	High
Spiritual and historic	Low	CV, ranking	Low

AC, avoided cost; CV, contingent valuation; H, hedonic pricing; M, market pricing; P, production approach; RC, replacement cost; TC, travel cost.

Valuation methods and contexts

Many commentators (e.g. Brown et al., 2007; Chee et al., 2004; Farber et al., 2006) have attempted to provide systematic overviews of valuation methods, the contexts in which they are applied and the problems associated with them. Useful contributions include those of Pagiola et al. (2004) who provide an overview of valuation methods and the limitations (Table 4.2), and Faber et al. (2006) who provide an analysis of the most appropriate methods for valuing different kinds of ecosystem service and the difficulties of applying and generalising from them (Table 4.3).

Table 4.4: Economic valuation keyword search by broad natural science topic areas (after Graves et al., 2009)

	Air related keywords	Land related keywords	Water related keywords	Living systems keywords	Energy keywords	Total
Contingent valuation	89	701	316	304	26	**1220**
Choice model	5	31	13	16		**61**
Market price	6	68	24	23	4	**98**
Production function	2	41	9	10	3	**46**
Random utility	3	16	12	10		**36**
Hedonic	11	100	35	28	2	**151**
Travel cost	12	104	55	45	4	**205**
Benefit transfer	12	49	34	17	2	**83**
Production function	2	41	9	10	3	**46**
Market price	6	68	24	23	4	**98**
Total	**226**	**2007**	**717**	**836**	**112**	**3898**

Graves et al. (2009) recently attempted to take stock of the rapidly growing number of applications of valuation techniques and to examine what limitations lack of knowledge in the natural sciences had for future progress. Using bibliographic search combined with survey information from researchers, they were able to determine both the frequency of use of the different valuation methods, the broad topics area in which they were being applied and some of the difficulties researchers identified in the various applications. Although the study focuses on natural resources in general the topic areas constructed provide insights into some of the main ecosystem serve themes; a summary of key results is provide in Table 4.4.

It would seem that of the more than 4000 papers analysed, by far the most commonly use method was contingent valuation (roughly 31%). In terms of the different topic areas, more than half of the papers identified were concerned with land-based issues, with a further fifth being focused on living systems. In this analysis it should be noted that some papers (~20%) were placed in more than one group, because sometimes several methods were used in a particular case study or a number of topic themes considered. CAB abstracts were used as the basis of the search and not time limit was placed on publication date.

The views of forty researchers in the UK and elsewhere were elicited through the survey element of the study. In general it was found that they thought more work was needed to improve the reliability of stated preference[12] methods (contingent valuation), and there were also concerns about the reliability of benefit transfer methods. A number of respondents argued that a wider range of methods could be applied and that, in particular, more use could be made of revealed preference methods by drawing upon information about the actual behaviour of people, and by exploiting spatial mapping techniques in the analysis. Graves et al. (2009) concluded that there was scope for better guidance on the selection, design and application of the different methods, and a need to include tests for the rigour and the robustness of the analysis and results.

Contingent valuation methods thus remain a highly contentious issue, despite their widespread use. As the recent discussion of Kumar and Kumar (2008) show, a stronger psycho-cultural perspective may be needed before better revealed preference methods can be developed. Similarly, despite the wider availability of valuation databases such as EVRI and ENVALUE, the current consensus is that benefit transfer methods need to be used carefully with both a good understanding of scientific context and an awareness of the purposes to which valuation data are put (Spash and Vatn, 2006).

Pagiola et al. (2004) suggest that in the context of valuing ecosystem services, there are four broad areas of application. The first concerns attempts to determine the total value of the current flow of benefits from an ecosystem, to better understand the contribution that ecosystems make to society. The analytical strategy adopted here is to identify all the mutually compatible services provided, to measure the quantity of each service and multiply these outputs by the value. They argue, however, 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?' At global scales they suggest, this kind of question makes less and less sense, which is one reason why the 'notorious' paper by Costanza et al. (1997) is felt to be so deeply flawed.

The second area of the application identified by Pagiola et al. (2004) is in valuing the costs and benefits of interventions that modify ecosystems. The aim here is generally to determine whether the intervention is economically worthwhile, and the approach suggested is to measure how the quantity of each service changes as a result of the intervention compared to doing nothing. The change in quantity of service is multiplied by the marginal value; that is the value a user would be prepared to pay for one more unit of a service or to replace a unit lost. These kinds of exercise form the basis of cost-benefit analysis for projects, and can clearly be a useful aid to decision making. The recently published pilot study which considered the changes in value of different ecosystem services affected by the Alkborough coastal set back scheme on the Humber is an example of this kind of exercise (see Environment Agency, 2009). On a larger stage, the TEEB initiative also illustrates this kind of application, in seeking to determine the costs of 'policy inaction' in relation to the prevention of biodiversity loss.

[12] See glossary of terms for explanation of valuation methods discussed here.

The penultimate area of application described by Pagiola et al. (2004) concerns examining how the costs and benefits of an ecosystem (or an intervention) are distributed across society and over time. The aim here is to explore social equity issues for ethical and practical reasons. The approach to valuation involves identifying all the relevant stakeholder groups, the services they use, need and value, and how they would be affected by any intervention. This kind of distributional analysis is now being widely applied to ensure that management interventions do not harm vulnerable groups and to try to ensure that interventions reduce poverty; a number of projects of this kind have, for example, recently been funded through the Ecosystem Service and Poverty Alleviation Programme jointly funded in the UK by the Natural Environment Research Council, the Economic and Social Research Council and Department for International Development.

A case study that illustrates how this kind of analysis might be used to explore different development paths is provided by the recent work of Steffan-Dewenter et al. (2007) who looked at the trade-offs between income, biodiversity and ecosystem functioning during tropical rainforest conversion and agroforestry intensification in Indonesia. Their study considered the way that incomes changed along a gradient of increasing land use intensity associated with the gradual removal of forest canopies and the reduction of shade. It appeared that while there was a doubling of farmers income associated with the reduction of shade from more than 80% to around 30-50% this was associated with only limited losses of biodiversity and ecosystem function, compared to the initial conversion of forest or the complete conversion of agroforestry systems to intensive agriculture. While farmer’s incomes increased further with conversion to unshaded agricultural systems, Steffan-Dewenter et al. (2007, p.4973) conclude that low-shade agroforestry represents the ‘best compromise between economic forces and ecological needs’. However, it is clear that all forms of agriculture must depend in fundamental ways on outputs from the natural environment.

The final area of application considered by Pagiola et al. (2004) concerns the area of identifying potential financing sources for conservation. The aim here is to help make ecosystem conservation self-sustaining in a financial sense, and the approach suggested involves identifying the groups in society who receive benefit from the flows of ecosystem services and understanding the level of payments they can make to the people who provide the service. It is in this last application therefore area where we are seeing growing interest in the development of schemes involving making Payments for Ecosystem Services (PES) (see Smith et al., 2006 and Wunder, 2005 for reviews).

PES schemes have emerged as one policy response that might be generally employed to help realign the private and social benefits resulting from decisions related to the management of the environment. They are based the of paying individuals or communities to undertake actions that increase the levels of the desired services; in their purest form such schemes enable those who directly benefit from a service to make a contractual or conditional payments to local landholders and or providers who in return for adopting practices that secure the integrity of ecosystems or work to restore it. Such schemes are often difficult to negotiate or set up, because they often challenge traditional property rights, nevertheless, it is clear that when such difficulties are overcome they can be extremely effective. The use of PES mechanisms to secure improvements in water quality in New York State is a widely discussed exemplar (Turner and Daily, 2006). In the UK, the SCaMP initiative, led by United Utilities and others, provides an additional model study, involving the promotion of improved water quality through more sustainable forms of land management in the uplands[13].

Pagiola et al. (2004) emphasise that the four approached described are not mutually exclusive, but build on and support on each other. Fundamentally, the approaches simply represent alternative ways of looking at similar data about ecosystems. The point is, however, that these same data are used in quite different ways, depending on the situation and the type of decisions that have to be made. To be effective and credible, it seems, valuation has to be built on a solid understanding of social and biophysical contexts (cf. Cowling et al., 2008).

The cost of ecosystem maintenance

The interim report on *The Economics of Ecosystems and Biodiversity* (TEEB) (European Communities, 2008) notes that if we are sustain benefits that ecosystems provide then we may have to rethink the way market systems operate, and try to ensure that the contribution nature makes to human well-being is fully recognised. While market-based approaches involving payments for ecosystem services are likely to shape the management of land and the transactions that surround it, new types of regulatory or legal measures are also likely to be needed to secure the public benefits which arise from land and its associated biodiversity resources. To make such arguments will involve understanding how much natural capital we need and how much 'reinvestment' is required to sustain it. Fisher et al. (2008) have recently provided a valuable insights into the theoretical framework in which such issues are set.

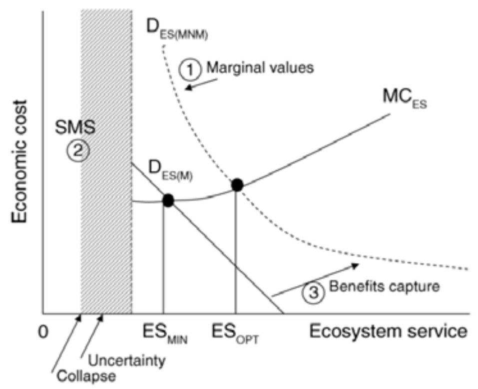


Figure 4.4: An economic framework for ecosystem service provision (after Fisher et al. 2008)

For explanation of terms see text

Fisher et al. (2008) use Figure 4.4 as the basis for key aspects of their discussion, which describes how ecosystem services and human welfare are linked through a demand-supply relationship. In the graph, the level of ecosystem service provision along the horizontal axis represents, and marginal human welfare, measured in monetary terms if measured on the vertical. The curve, $D_{ES(M)}$ represent ***marketed*** ecosystem service benefits (aggregated across all services) and shows how they change as the supply of the service alters: it slopes downwards because it is assumed that the value of the service falls as supply increases. In the Figure, $D_{ES(MNM)}$ is the demand curve for ***all*** ecosystem service benefits, and includes those that cannot be traded in markets. Fisher et al. (2008) suggest that because most ecosystem services are public goods, we can assume that this curve is to the right of the one for marketed benefits.

The supply curve for ecosystem services is represented by MC_{ES}, which shows how the marginal cost of adding an extra unit of service changes at different levels of supply. It slopes up at an increasing rate because it is assumed that it is increasingly costly to secure each additional unit of service. ES_{MIN}

[13] http://www.unitedutilities.com/AboutSCaMP.htm

and ES_{OPT} are the points on the service axis where the demand and supply curves intersect for the marketed services and all services respectively.

Fisher et al. (2008) use this diagram to make two important points. First that there is serious under provision of services if only marketed values are considered (i.e. $ES_{MIN} < ES_{OPT}$), and that we need ways of 'capturing' or taking care of the additional benefits arising from the non-marketed services if this situation is to be resolved. Second, this valuation regime only applies if the ecosystem is operating above some 'Safe Minimum Standard' (SMS), which represent the level of ecosystem structure and process needed to maintain its functional integrity. The difficulty that Fisher et al. (2008) recognise is that we generally do not know exactly where this safe point is for most ecosystems, and therefore at what level of degradation the system will collapse.

It is now widely recognised that ecosystems can exhibit complex dynamics, involving nonlinearities, thresholds and discontinuities, as well as more gradual changes to external pressures (Holling, 2001). As a result, management or policy interventions in such systems may be difficult, and can involve making decisions against a backdrop of considerable uncertainty. Collapse, or sudden regime shifts are often hard to predict or anticipate (Scheffer et al., 2001; Scheffer et al., 2003; Scheffer and Carpenter, 2005; Walker and Meyers, 2004). In the context of the model presented by Fisher et al. (2008) the existence of such behaviour is significant because it then becomes difficult to estimate how the value of a resource might change in response to different levels of demand. As Limberg et al. (2002) have also pointed out, if the valuation process is fundamentally about 'the 'difference' something makes', then analysis of marginal value is *only* possible when an ecosystem is far from an unstable threshold or tipping point.

The analysis presented by Fisher et al. (2008) leads them to make a number of recommendations which usefully identifies current knowledge gaps and future research agendas. In the context of the Figure 4.4, they argue that it is now increasingly important that work seeks to include the concept of marginality and/or ecosystem transition states, so that analytical results are more clearly relevant to policy. Future empirical work should also focus on the question of system integrity, and identify amount of structure and function needed to produce a sustainable flow of services across a landscape. 'With this type of study we can begin to see where on the ecosystem service provision continuum…. we currently stand, so that we can inform policy on which trade-offs society can and cannot make' (Fisher et al., 2008, p.2065).

The conclusions of Fisher et al. (2009) are significant because they illustrate what is likely to be a growing interest in understanding the conditions under which economic valuation is appropriate and relevant. The issue of what these minimum levels of natural capital might be and how we might describe, maintain and restore them, has also been the focus of recent work on environmental accounting promoted by the European Environment Agency, as part of their contribution to the *TEEB* Initiative (EEA, 2009).

The EEA argue that while much of the current literature dealing with the problem of valuing the benefits from natural capital has focused on these final products or services, the importance of the intermediate or supporting services, should not be underestimated. The scale and/or value of the intermediate services consumed in the production of final goods should be identified, and, in the same way that society has to reinvest in human-made capital to take account of depreciation, we must also consider the level of reinvestment in our natural capital needed to sustain the output of ecosystem services (see also Bartelmus, 2009; Mäler et al., 2009).

The 'reinvestment' in natural capital may take many forms including: maintenance or management, protection and restoration costs. However, it could also include less tangible things like 'use forgone'; which 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. In the literature identified, resilience, interpreted as a kind of insurance against the risk of ecosystem disruption and the interruption of the supply of services to people has been a recurring theme in much of the literature identified by this study (e.g. Vergano and Nunes, 2007; Deutsch et al., 2003). Resilience, like other benefits provided by ecosystems, is not priced by current markets, but this does not mean that it is of no value to people. The challenge for those interested in assessing its importance lies in making the concept 'operational' or measurable, so that changes in resilience can be monitored and ultimately valued (Walker and Pearson, 2007).

The Valuation of Ecosystem Services

This review of recent developments in the valuation literature suggests that there is a growing consensus that the process of valuing ecosystem services requires a thoroughly inter-disciplinary perspective, which not only integrates ecology and economics, but also a range of other natural and social science disciplines. **Biophysical assessments are needed to provide an understanding of how services are generated, and socially grounded economic analysis is required to estimate the relative worth of services through market and non-market valuation techniques. By understanding how the quantity and quality of services changes in physical terms, it is increasingly clear that the natural scientist can provide a robust framework in which valuation studies can be made**.

It is also increasingly recognised that valuation of ecosystem services is highly context specific, and has to be guided by the perspectives and requirements of beneficiaries. There is, however, also a need for greater clarity about the different situations in which economic valuation can be applied, and what kinds of answers it can give. Our review suggests that participatory methods are increasingly likely to be used to improve the reliability of methods, and to ensure the relevance of outcomes to decision makers. However, such work will inevitably take place against a backdrop of considerable uncertainty, because questions of irreversibility and resilience are still far from being resolved.

Part 4: Valuing Ecosystem Services - Key messages

- *The importance of the valuation issue is demonstrated by the fact that this topic area forms the largest group of papers published in the context of the ecosystem services framework.*
- *Within this evolving body of literature there is increasing recognition that:*
  - *It is essential to distinguish benefits and values clearly, because different groups may hold different values or perspectives on benefits. While the capacity of ecosystems to deliver benefits to people may be constant the values we attach to them may also change over time.*
  - *That while economic valuation is the most widespread method used to compare people's perspectives on benefits, there is growing interest in non-monetary techniques.*
  - *That while the range of valuation methods has grown in number and sophistication, there is still a need to improve the robustness of techniques, especially those relying on stated preference approaches and benefit transfer approaches.*
  - *It is essential to understanding the biophysical and social contexts of in which economic valuation is carried out if the analysis is to be relevant to the needs of decision makers and society more generally. These contexts include:*
    - *the tasks of valuing the total flow of services;*
    - *assessing the costs and benefits of alternative interventions;*
    - *understanding and resolving social equity issues;*
    - *constructing payment systems for ecosystem service; and,*
    - *valuing resilience.*
  - *That economic valuation has to be viewed from a cross-disciplinary perspective if it is to be effective.*
- *There is an urgent need to ground valuation studies on an understanding of the biophysical mechanisms that underpin ecosystem services, to make a better analysis of the marginal changes value that can occur in ecosystems subject to different pressures and interventions.*
- *It is also essential to develop a better understanding of what minimum safe levels of natural capital are required to produce a sustainable flow of services. Economic analysis becomes difficult and unreliable in situations where ecosystems exhibit sudden regime shifts or collapse. There is growing interest in valuing ecosystem resilience and of calculating the costs of ecosystem maintenance.*

Part 5 Conclusions & Recommendations

The idea that ecosystems can provide a range of benefits to people has become the focus of intense research and policy interest. Recent debates have been stimulated by the publication of the Millennium Ecosystem Assessment, but have also been given added impetus by an awareness that a more integrated, cross-sectoral approach to decision making is required if we want successfully manage our natural capital in sustainable ways.

At a time of rapid conceptual change, however, when new ideas and information are being introduced and discussed, it is often difficult to be confident that decision making is based on the most robust evidence available. Thus the aim of this study has therefore to take stock of what has been achieved, and to clarify some of the important issues for an organisation like JNCC. Our review has been based on extensive bibliographic search and scrutiny of key national and international initiatives, such as *TEEB* (The Economics of Ecosystems and Biodiversity) and the UK National Ecosystem Assessment. A number of conclusions and recommendations follow from our review.

A key conclusion that can be drawn from recent developments is that disciplinary perspectives are being transformed.

The Ecosystem Approach, for example, emphasises that decisions about biodiversity and ecosystem services have to be looked at in a wider, social and economic context. Thus natural scientists are increasing interested in connecting their insights about the way ecosystems work to broader understandings of how people benefit from nature's services, and what can be done to help sustain and improve their well-being. As a result many of our most basic concepts may need to be rethought. The notion of an ecosystem is, perhaps, one of these.

As Jax (2007) has shown, the ecosystem concept has been used in a number of different ways, and he argues that there is probably no single 'right' definition of the term. People, he observes, have changed the content of the idea for their different purposes. It is interesting to note that the same thing is happening in the context of the debate about ecosystem services. Among other things, the cascade model for ecosystem services that we have presented seeks to emphasise that as scientists we are in fact dealing with a 'coupled social-ecological system' and that if we are to understand its properties and dynamics traditional disciplinary boundaries might need to be redrawn or dissolved.

The notion of a social-ecological system, or SES, is one that has increasingly been used in the research literature to emphasise the 'humans-in-the-environment' perspective that both the Ecosystem Approach and the notion of ecosystem services promotes. The term SES is also used to emphasise the fact that ecological and social systems are generally both highly connected and co-evolve at a range of spatial and temporal scales (see for example Folke, 2006, 2007). More particularly, Anderies et al. (2004) has suggested that their structure is best understood in terms of the relationships between resources, resource users and governance systems. If we follow this logic, then in defining the nature of the units of assessment (ecosystems) then we must combine our scientific understandings of the relationships between biodiversity and ecosystem functioning with insights into wider social and economic structures and processes. We can, in fact, see this kind of development in the recent work surrounding the concept of a 'service providing unit'. It is also apparent in the attempt of recent work to 'unpack' the production chain that links ecological structures and processes and the elements of human well-being through conceptual devices such as the cascade model.

The implications of the transformations in disciplinary perspectives that are now in train, for an organisation like JNCC, are considerable. ***The idea of working with socio-ecological systems rather than the traditional biophysical representation of an ecosystem will mean that no longer will natural scientists be the only source of evidence to support decision making**.*

As we look to the future, organisations like JNCC will increasingly have to work alongside economists, geographers and a range of other social scientists to understand the value that biodiversity and ecosystem services have, to assess the costs and benefits of different conservation and management strategies, and to help design the new governance systems needed for sustainable development.

Biodiversity has intrinsic value and should be conserved in its own right. However, the utilitarian arguments which can be made around the concept of ecosystem services and human well-being are likely to become an increasingly central focus of future debates about the need to preserve 'natural capital'. Amongst the many meanings of the term sustainable development we now find the proposition that it also has to take in ideas about the maintenance of ecosystem services and the elements of human well-being that depend upon them.

If an organising like JNCC is to adopt and cope with these changing perspective then the implication of the review we have undertaken here are that the assessment methods it uses should be grounded on social, economic and biophysical criteria in a balanced and integrated way. We have found that just as economic valuation cannot be conducted without a good understanding of social and ecological contexts, so the work of the natural scientist cannot be undertaken in isolation from these other concerns. We therefore recommend:

- *That since no universally accepted frameworks for classifying and assessing ecosystem services presently exit, JNCC actively engage in the design and application of new conceptual models that emphasise more clearly the links between ecological structures and processes, on the one hand, and human well-being on the other. The purpose of such involvement should be to help create decision making frameworks that are fit for the purposes that JNCC seeks to promote.*
- *That since terminology in the field of ecosystem services is currently fluid, in its communication JNCC should strive to be clear about how it is using terms and concepts, so that others can more easily understand its perspectives and concerns in this important area. Appendix 2 provides a glossary of terms, based on the work we have undertaken here, that may offer some guidance.*
- *That in promoting future research, JNCC should focus not only at establishing the links between the different components of biodiversity and ecosystem functioning, but also the wider connections to ecosystem services. This may involve taking a service-orientated perspective rather than the traditional one that focuses mainly on biodiversity issues. In framing its future work, our review suggests that important priorities are:*

- *to ground valuation studies on an understanding of the biophysical mechanisms that underpin ecosystem services, to make a better analysis of the marginal changes value that can occur in ecosystems subject to different pressures and interventions.*
- *to develop a better understanding of the minimum safe levels of natural capital needed to sustain the flow of ecosystem services.*

It has been recognised that economic analysis is difficult and unreliable in situations where ecosystems exhibit sudden regime shifts or collapse. The same holds true for those developing management and conservation strategies or designing policies for the future. To support the growing interest in valuing ecosystem resilience and of calculating the costs of ecosystem maintenance, it is essential that we also achieve much better understandings of the ecological processes that underpin our well-being. In promoting future research we recommend that JNCC should focus not only on establishing the links between the different components of biodiversity and ecosystem functioning, but also the wider connections between biodiversity and ecosystem services. This may involve taking a service-orientated perspective rather than the more traditional one that focuses mainly on biodiversity issues. It will involve understanding how marginal change in economic values relate to changes in ecosystem output, and what levels of natural capital are required to sustain the benefits that ecosystems of concern to the UK provide.

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Appendix 1:
Classification systems for ecosystem services

Table A.1: Inventory of services associated with particular benefits (after Boyd and Banzhaf, 2007)

Illustrative benefit	Illustrative ecosystem services
Harvests	
Managed commercial [a]	Pollinator populations, soil quality, shade and shelter, water availability
Subsistence	Target fish, crop populations
Unmanaged marine	Target marine populations
Pharmaceutical	Biodiversity
Amenities and fulfillment	
Aesthetic	Natural land cover in viewsheds [b]
Bequest, spiritual, emotional	Wilderness, biodiversity, varied natural land cover
Existence benefits	Relevant species populations
Damage avoidance	
Health	Air quality, drinking water quality, land uses or predator populations hostile to disease transmission [c]
Property	Wetlands, forests, natural land cover
Waste assimilation	
Avoided disposal cost	Surface and groundwater, open land
Drinking water provision	
Avoided treatment cost	Aquifer, surface water quality
Avoided pumping, transport cost	Aquifer availability
Recreation	
Birding	Relevant species population
Hiking	Natural land cover, vistas, surface waters
Angling	Surface water, target population, natural land cover
Swimming	Surface waters, beaches

[a] Managed commercial crops include the range of row crops, marine, and terrestrial species, for food, fiber, and energy.
[b] Viewsheds are a topographic concept, delineating the area from which a particular site can be seen.
[c] Biodiversity is thought by some ecologists to promote pest resistance.

Table A.2: Classification of Ecosystem Goods and services (after Brown et al., 2007)

Ecosystem goods

Nonrenewable

- Rocks and minerals
- Fossil fuels

Renewable

- Wildlife and fish (food, furs, viewing)
- Plants (food, fiber, fuel, medicinal herbs)
- Water
- Air
- Soils
- Recreation, aesthetic (e.g., landscape beauty), and educational opportunities

Ecosystem services

Purification of air and water (detofication and decomposition of wastes)
Translocation of nutrients
Maintenance and renewal of soil and soil fertility
Pollirtation of crops and natural vegetation
Dispersal of seeds
Maintenance of regional precipitation patterns
Erosion control
Maintenance of habitats for plants and animals
Control of pests affecting plants or animals (including humans)
Protection from the sun's harmful W rays r
Partial stabilization of climate
Moderation of temperature extremes and the force of winds and waves
Mitigation of floods and droughts

Table A.3: Classification of selected ecosystem services (after Costanza et al., 1997)

Number	Ecosystem service*	Ecosystem functions	Examples
1	Gas regulation	Regulation of atmospheric chemical composition.	CO_2/O_2 balance, O_3 for UVB protection, and SO_x levels.
2	Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels.	Greenhouse gas regulation, DMS production affecting cloud formation.
3	Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations.	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure.
4	Water regulation	Regulation of hydrological flows.	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation.
5	Water supply	Storage and retention of water.	Provisioning of water by watersheds, reservoirs and aquifers.
6	Erosion control and sediment retention	Retention of soil within an ecosystem.	Prevention of loss of soil by wind, runoff, or other removal processes, storage of stilt in lakes and wetlands.
7	Soil formation	Soil formation processes.	Weathering of rock and the accumulation of organic material.
8	Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients.	Nitrogen fixation, N, P and other elemental or nutrient cycles.
9	Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.	Waste treatment, pollution control, detoxification.
10	Pollination	Movement of floral gametes.	Provisioning of pollinators for the reproduction of plant populations.
11	Biological control	Trophic-dynamic regulations of populations.	Keystone predator control of prey species, reduction of herbivory by top predators.
12	Refugia	Habitat for resident and transient populations.	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds.
13	Food production	That portion of gross primary production extractable as food.	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing.
14	Raw materials	That portion of gross primary production extractable as raw materials.	The production of lumber, fuel or fodder.
15	Genetic resources	Sources of unique biological materials and products.	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants).
16	Recreation	Providing opportunities for recreational activities.	Eco-tourism, sport fishing, and other outdoor recreational activities.
17	Cultural	Providing opportunities for non-commercial uses.	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems.

* We include ecosystem 'goods' along with ecosystem services.

Table A.4: A classification of ecosystem services with illustrative examples (after Daily, 1997)

Ecosystem service

Production of goods

Food
Terrestrial animal and plant products
Forage
Seafood
Spice
Pharmaceuticals
Medicinal products
Precursors to synthetic pharmaceuticals
Durable materials
Natural fiber
Timber
Energy
Biomass fuels
Low-sediment water for hydropower
Industrial products
Waxes, oils, fragrances, dyes, latex, rubber, etc.
Precursors to many synthetic products
Genetic resources
Intermediate goods that enhance the production of other goods

Regeneration Processes

Cycling and filtration processes
Detoxification and decomposition of wastes
Generation and renewal of soil fertility
Purification of air
Purification of water
Translocation processes
Dispersal of seeds necessary for revegetation
Pollination of crops and natural vegetation
Stabilizing processes
Coastal and river channel stability
Compensation of one species for another under varying conditions
Control of the majority of potential pest species
Moderation of weather extremes (such as of temperature and wind)
Partial stabilization of climate regulation of hydrological cycle (mitigation of floods and droughts)

Life-fulfilling functions

Aesthetic beauty
Cultural, intellectual, and spiritual inspiration
Existence value
Scientific discovery
Serenity

Preservation of options

Maintenance of the ecological components and systems needed for future supply of these goods and services and others awaiting discovery

Table A.5: Functions, goods and services of natural and semi-natural ecosystems (after de Groot et al., 2002)

	Functions	Ecosystem processes and components	Goods and services (examples)
	Regulation Functions	*Maintenance of essential ecological processes and life support systems*	
1	Gas regulation	Role of ecosystems in bio-geochemical cycles (e.g. CO_2/O_2 balance, ozone layer, etc.)	1.1 UVb-protection by O_3 (preventing disease). 1.2 Maintenance of (good) air quality. 1.3 Influence on climate (see also function 2.)
2	Climate regulation	Influence of land cover and biol. mediated processes (e.g. DMS-production) on climate	precipitation, etc) for, for example, human habitation, health, cultivation
3	Disturbance prevention	Influence of ecosystem structure on dampening env. disturbances	3.1 Storm protection (e.g. by coral reefs). 3.2 Flood prevention (e.g. by wetlands and forests)
4	Water regulation	Role of land cover in regulating runoff & river discharge	4.1 Drainage and natural irrigation. 4.2 Medium for transport
5	Water supply	Filtering, retention and storage of fresh water (e.g. in aquifers)	Provision of water for consumptive use (e.g.drinking, irrigation and industrial use)
6	Soil retention	Role of vegetation root matrix and soil biota in soil retention	6.1 Maintenance of arable land. 6.2 Prevention of damage from erosion/siltation
7	Soil formation	Weathering of rock, accumulation of organic matter	7.1 Maintenance of productivity on arable land. 7.2 Maintenance of natural productive soils
8	Nutrient regulation	Role of biota in storage and re-cycling of nutrients (eg. N,P&S)	Maintenance of healthy soils and productive ecosystems
9	Waste treatment	Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds	9.1 Pollution control/detoxification. 9.2 Filtering of dust particles. 9.3 Abatement of noise pollution
10	Pollination	Role of biota in movement of floral gametes	10.1 Pollination of wild plant species. 10.2 Pollination of crops
11	Biological control	Population control through trophic-dynamic relations	11.1 Control of pests and diseases. 11.2 Reduction of herbivory (crop damage)
	Habitat Functions	*Pro viding habitat (suitable living space) for wild plant and animal species*	Maintenance of biological & genetic diversity (and thus the basis for most other functions)
12	Refugium function	Suitable living space for wild plants and animals	Maintenance of commercially harvested species
13	Nursery function	Suitable reproduction habitat	13.1 Hunting, gathering of fish, game, fruits, etc. 13.2 Small-scale subsistence farming & aquaculture
	Production Functions	Pro vision of natural resources	
14	Food	Conversion of solar energy into edible plants and animals	14.1 Building & Manufacturing (e.g. lumber, skins). 14.2 Fuel and energy (e.g. fuel wood, organic matter). 14.3 Fodder and fertilizer (e.g. krill, leaves, litter).
15	Raw materials	Conversion of solar energy into biomass for human construction and other uses	15.1 Improve crop resistance to pathogens & pests. 15.2 Other applications (e.g. health care)

Table A.5/cont:

Functions		Ecosystem processes and components	Goods and services (examples)
16	Genetic resources	Genetic material and evolution in wild plants and animals	16.1 Drugs and pharmaceuticals. 16.2 Chemical models & tools. 16.3 Test-and essay organisms
17	Medicinal resources	Variety in (bio)chemical substances in, and other medicinal uses of, natural biota	worship, decoration & souvenirs (e.g. furs, feathers, ivory, orchids, butterflies, aquarium fish, shells, etc.)
18	Ornamental resources	Variety of biota in natural ecosystems with (potential) ornamental use	
	Information Functions	*Pro viding opportunities for cognitive development*	
19	Aesthetic information	Attractive landscape features	Enjoyment of scenery (scenic roads, housing, etc.)
20	Recreation	Variety in landscapes with (potential) recreational uses	Travel to natural ecosystems for eco-tourism, outdoor sports, etc.
21	Cultural and artistic information	Variety in natural features with cultural and artistic value	Use of nature as motive in books, film, painting, folklore, national symbols, architect., advertising, etc.
22	Spiritual and historic	Variety in natural features with spiritual and historic value	Use of nature for religious or historic purposes
23	Science and education	Variety in nature with scientific and educational value	Use of natural systems for school excursions, etc. Use of nature for sceintfici research

Table A.6: Key examples from the literature of explicit or implicit links with ecosystem services (after Luck et al., 2009)

Service	Ecosystem [level of organization]	Service provider [level of organization]	Service-provider characteristics	Supporting element	Response measure	Relationship
Biological control	Agroecosystem [apple orchards]	Great tit [population]	Density of breeding pairs[a]	Density of nest boxes[b]	Caterpillar damage to apples	Control vs. treatment
Biological control	Agroecosystem [coffee plantation]	Azteca ant	Green scale [population]	Activity level[c]	Shade trees[d] Number of scale[e]	Time to removal[f] Linear[g]
Biological control	Agroecosystem [rice fields]	Egg parasitoids [functional group]	Abundance of predators and parasitoids[h]	Presence of parasitoid and absence of predator	Leaf and plant-hopper abundance	Control under negative impact of predators on parasitoids[i]
Pollination	Agroecosystem [watermelon crops]	Native bees[j] [functional group]	Functional group, species-specific visitation rates and efficiencies[k]	Upland habitat[l]	Pollen deposition[m]	Saturating, exponential increasing[n]
Pollination	Agroecosystem [coffee plantation]	Native and exotic bees [functional group]	Functional group dynamics[o]	Tropical forest[p]	Seed mass, fruit set, peaberry frequency, pollen deposition (number of visits per flower), bee species richness	Comparative[q]
Pollination	Agroecosystem [atemoya crops]	Nitidulid beetles[r] [functional group]	Functional group dynamics[s]	Rainforest	Beetle species richness[t]	Exponential decay[u]
Pollination	Agroecosystem [canola fields]	Wild bees [functional group]	Functional group dynamics[v]	Uncultivated land[w]	Bee abundance, seed set	Linear[x] Saturating[y]
Waste decomposition	Agroecosystem [rice fields]	Mallard [population]	Population density[z]		Residual surface straw[aa], structure of surface straw[ab], chemical composition[ac]	Control vs. treatment Control vs. treatment Control vs. treatment
Water regulation	Forest/terrestrial	Terrestrial vegetation [community]	Soil-slope-vegetation complex	Water regulation, hydroelectricity generation		Comparative[ad]
Water filtration	Freshwater	Forest [community]	Forest cover[ae]		Water and sediment nutrients	Various
Seed dispersal	Oak forest	Eurasian jay [population]	Population abundance[af]	Oak and coniferous forest[ag]	Oak saplings	n/a
Seed dispersal	Tropical forest	Insular flying fox [population]	Flying fox abundance index[ah] = 0.77 to 0.81		Chewed diaspores[ai]	Threshold

Table A.7: Classification of ecosystem services (after MA, 2005)

Provisioning Services	**Regulating Services**	**Cultural Services**
Products obtained from ecosystems	*Benefits obtained from regulation of ecosystem processes*	*Nonmaterial benefits obtained from ecosystems*
• Food • Fresh Water • Fuelwood • Fiber • Biochemicals • Genetic resources	• Climate regulation • Disease regulation • Water regulation • Water purification • Pollination	• Spiritual and religious • Recreation and ecotourism • Aesthetic • Inspirational • Educational • Sense of place • Cultural heritage
Supporting Services *Service necessary for the production of all other ecosystem services* ● Soil Formation ● Nutrient cycling ● Primary Production		

Note this is not a comprehensive list of services; those listed are indicative only

Table A.8: Classification of ecosystem services and links to human values, ecosystem processes, and natural assets (after Wallace, 2007)

<table>
<tr><th>Category of human values</th><th>Ecosystem services – experienced at the individual human level</th><th>Examples of processes and assets that need to be managed to deliver ecosystem services</th></tr>
<tr><td>Adequate resources</td><td>• Food (for organism energy, structure, key chemical reactions)
• Oxygen
• Water (potable)
• Energy (e.g., for cooking – warming component under physical and chemical environment)
• Dispersal aids (transport)</td><td rowspan="4">Ecosystem processes
• Biological regulation
• Climate regulation
• Disturbance regimes, including wildfires, cyclones, flooding
• Gas regulation
• Management of ‘‘beauty’’ at landscape and local scales.
• Management of land for recreation
• Nutrient regulation
• Pollination
• Production of raw materials for clothing, food, construction, etc.
• Production of raw materials for energy, such as firewood
• Production of medicines
• Socio-cultural interactions
• Soil formation
• Soil retention
• Waste regulation and supply
• Economic processes

Biotic and abiotic elements
Processes are managed to provide a particular composition and structure of ecosystem elements. Elements may be described as natural resource assets, e.g.:
• Biodiversity assets
• Land (soil/geomorphology) assets
• Water assets
• Air assets
• Energy assets</td></tr>
<tr><td>Protection from predators/disease/parasites</td><td>• Protection from predation
• Protection from disease and parasites</td></tr>
<tr><td>Benign physical and chemical environment</td><td>Benign environmental regimes of:
• Temperature (energy, includes use of fire for warming)
• Moisture
• Light (e.g., to establish circadian rhythms)
• Chemical</td></tr>
<tr><td>Socio-cultural fulfilment</td><td>Access to resources for:

• Spiritual/philosophical contentment
• A benign social group, including access to mates and being loved
• Recreation/leisure
• Meaningful occupation
• Aesthetics
• Opportunity values, capacity for cultural and biological evolution
o Knowledge/education resources
o Genetic resources</td></tr>
</table>

Appendix 2:

Glossary of Terms

Term	Suggested definition	Comment
Beneficiary	A person or group whose welfare is affected by an ecosystem service in some way.	*Welfare or well-being can be affected either positively or negatively – see 'benefit'*
Benefit	Something that has an explicit impact on or changes in human welfare.	*Examples include such as more food, better hiking, or less flooding. See Fisher and Turner, (2008). Note benefits can also be negative – in which case they can be regarded as a dis-benefit, e.g. more disease vectors in an area.*
Benefit transfer methods	A method of estimating the value of an ecosystem service based on using the results obtained in another study that is deemed comparable to the situation under investigation. (e.g., estimating the value of one forest using the calculated economic value of a different forest of a similar size and type)	*See Ranganathan et al. (2008)*
Contingent Valuation	See 'Stated preference methods' below.	
Cultural service	An ecosystem service (end-product of nature) that when combined with human or cultural capital contributes to some intellectual or cognitive benefit.	*Note cultural benefits like often recreation are joint products, arising from natural and human capital; e.g. wildlife watching or angling depend on both an ecosystem service (presence of target species) and some socio-economic 'infrastructure' or practices.*
Ecological function	The capacity or potential of an ecosystem to provide a service as a result of its structural properties or the processes its supports.	*Functions are turned into services if a beneficiary exists. Functions give rise to services – see also intermediate service.*
Ecosystem assessment	An appraisal of the state and trends of services provided by an ecosystem or ecosystems.	*Assessments can be biophysical social and value based; see Cowling et al. (2008)*
Ecosystem service	The contribution which the biotic and abotic components of ecosystems jointly and directly make to human well-being; an 'end-product' of nature.	*Thus living process <u>have</u> to be involved; services are final products used by people*

Term	Suggested definition	Comment
Environmental service	The contribution which ecosystems directly make to human well-being; an 'end-product' of nature.	*Living organisms may or may not be involved, so can cover outputs like wind power; again the outputs are final products used by people*
Functional trait	A characteristic or attribute of a species or group that determines its response to external factors (response trait) or the impact it has on other parts of the ecosystem (effects trait)	*See Luck et al. (2009)*
Intermediate service	A service that is not directly consumed by people but supports or underpins the output of other services.	*Synonymous with ecological function.*
Marketed service	A marketed service is one in which a transaction between buyer and seller can be identified and whose interaction can be used to estimate the value of the good or service.	
Non-market (Public) good or service	A service for which no formal market exists and which is often enjoyed for free by beneficiaries because their access cannot be regulated or controlled.	
Production function	The relationship which shows how changes in ecological functions, structure or processes affect the output of an ecosystem service	*Useful in helping to understand how actual or potential changes in the dynamics of ecosystems might affect the marginal values associated with service outputs*
Provisioning service	An ecosystem service (end-product of nature) that when combined with element of built capital or labour contribute to some product.	
Regulating service	An ecosystem service (end-product of nature) that affects the ambient environment of people in ways that affects their health or security, or which substitutes for the work they would have to do to control that ambient environment for themselves.	

Term	Suggested definition	Comment
Revealed preference methods	A method used to estimate values based on observing actual consumer or producer behaviour and identifying the ways in which a non-marketed good influences actual markets for some other good.	*See Beukering (2007) and Ranganathan et al. (2008)*
Safe minimum standard (SMS)	The minimum level of natural capital required to prevent ecosystem collapse and the loss of ecosystem integrity	*Below the SMS the production functions no longer apply and domain in which marginal valuation applies no longer exists.*
Service Providing Unit	The collection of individuals from a given species and their characteristics necessary to deliver an ecosystem service at the desired level	*See Luck et al. 2003, Luck et al. (2009)*
Stated preference methods	A group of methods (which includes Contingent Valuation) used to estimate values based on asking people to state their preferences for hypothetical changes in the provision of environmental goods or services. This information is then used to estimate the values that people attach to the environmental goods and services in question.	*See Beukering (2007) Ranganathan et al. (2008)*
Supporting service	An ecosystem component that is not directly consumed and which contributes the output of others which can be regarded as an 'end-product' of nature.	*Synonymous with intermediate product or ecological function*

Term	Suggested definition	Comment
Valuation	The process whereby people express the importance or preferences they have a for some benefit amongst a set of alternatives	*Valuation is usually made in monetary terms to help comparison between different kinds of benefit. However, non-monetary valuation is also possible.*
Well-being	A context- and situation-dependent state, comprising basic material for a good life, freedom and choice, health and bodily well-being, good social relations, security, peace of mind, and spiritual experience	*See MA (2005)*