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England's Ecosystem Services

A preliminary assessment of three habitat types: broad-leaved woodland, the inter-tidal zone and fresh-water wetlands

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Cover note

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English Nature would like to acknowledge that this report complements and uses a similar analysis structure to EFTEC's earlier report for Defra, 'The economic, social and ecological value of ecosystem services: a literature review' (2005). We are grateful for Defra's advice and comments on this project.

Executive summary

The concept of 'ecosystem services'

Healthy ecosystems can contribute to economic and social well-being either directly through the provision of goods, or indirectly through the provision of services that feed into and underpin economic processes. The focus of this report is on these ecosystem services, which are typically difficult to observe, and thus risk being unaccounted for in economic valuation studies.

Ecosystem services can be usefully grouped according to four broad categories as defined in the Millennium Ecosystem Assessment (World Resources Institute, 2005):

1. Supporting services, such as nutrient cycling, oxygen production and soil formation. These underpin the provision of the other 'service' categories.
2. Provisioning services, such as food, fibre, fuel and water.
3. Regulating services, such as climate regulation, water purification, flood protection
4. Cultural services, such as knowledge, recreation, and aesthetic value.

When ecological functions provide inputs to economic processes, we get e*cosystem goods*, which are the natural products harvested or used by humans. These include agricultural produce, timber, fish, game, livestock, medicinal plants, drinking water and so on. We also get *ecosystem services* which contribute to human well-being and survival more broadly through services such as purification of air and water, pollination of crops, decomposition of wastes, generation and renewal of soils, stabilisation of the climate, mitigation of droughts and floods, and protection of soils from erosion. The focus of this report is on these services and how they benefit society; however.

This report represents an attempt to join up the science and economics of ecosystem services. It aims to assist evaluation and decisions relating to ecosystem management in England, by providing:

- A first attempt at a **detailed catalogue of ecosystem services** in three priority habitat types (broadleaved woodland, terrestrialised freshwater wetlands and inter-tidal habitats) to act as a reference for future evaluation work. The point here is that we need to understand the science of ecosystem services before we can evaluate their importance to society;

- **examples and case studies of valuation work** undertaken in the UK in the past;

- **advice on the appropriate economic valuation techniques** for communicating and providing evidence of marginal changes in ecosystem service value for a range of decision-making contexts; and

- advice on the **relevant issues, challenges, opportunities and limitations** inherent in undertaking such evaluation exercises.

This report follows the earlier report for Defra on ecosystem services, mainly relating to the international context and with a focus on wetlands, forests and agricultural ecosystems (eftec, 2005).

Scientists, economists and policy makers will be interested in Section 2 of this report. It represents an initial assessment of potential ecosystem services for three habitat types in England: broadleaved woodlands, wetlands and inter-tidal zones. It summarises the ecological literature, from a human welfare perspective, distilling this into an assessment of potential ecosystem services which provide societal benefits. This assumes appropriate habitat management and sustainable harvesting. The idea is to use this as a resource for evaluation in more specific assessments. Section 3 is aimed more at the economist audience.

Key to understanding the societal value of ecosystems is to characterise and quantify the relationships between ecosystem function and provision of ecosystem goods and services, and to identify the ways in which these generate welfare improvements. Figure E1.1 demonstrates these pathways with a very simplified model.

ECOSYSTEM (1) ⇨ ECOSYSTEM SERVICES (2) ⇨ CONTRIBUTION TO HUMAN WELFARE (3) ⇨ ECONOMIC VALUE (4)

Figure E1.1 Simple ecosystem services to value pathway

Ecosystem services contribute to economic welfare (or generate benefits) in two ways – through contributions to the ***generation*** **of income and well-being**, and also through the ***avoidance*** **of damages** which inflict costs on society. The latter is characteristic of certain ecosystem services that provide insurance, regulation and resilience functions, as is explored in the main report. Both types of benefits should be accounted for in any policy-making decision, and will entail using a mix of techniques where market data is combined with non-market data.

The Millennium Ecosystem Assessment

To put this England-based study in an international context, the recently published Millennium Ecosystem Assessment, compiled by UNEP with 1,360 scientists from 95 countries, emphasises the importance of understanding ecosystem services. This assessment concludes that: the distribution of species on Earth is becoming more homogenous; between 10% and 50% of well-studied higher taxonomic groups are currently threatened with extinction; over half the 14 biomes studied have experienced a 20%-50% conversion to human use, and rapid conversion of ecosystems is projected to continue in the 21st century. The assessment also recognises the economic benefits that have resulted from ecosystem modification; but this has coincided with losses to other ecosystem services – only four of the 24 ecosystem services studied have been enhanced – 15 other services have been degraded (World Resources Institute, 2005).

The notion of ecosystem services helps us to understand a key dilemma in natural resources policy: that of ecosystem simplification. Ecosystem simplification generally involves land use and habitat change which results in an increase in the economic value of one ecosystem service eg the provision of a crop yield. However, as is now becoming apparent as we learn more, this may be at the expense of other services provided by the ecosystem, which may have an impact over a wider geographical scale and which may include public as well as private good values.

England's ecosystem services

This is a preliminary assessment of ecosystem services which may be evident in some of England's semi-natural habitats. It is not intended to be comprehensive and it is clear that the actual provision of ecosystem services is complex and will vary from site to site. This preliminary analysis identifies numerous potential services potentially provided by these habitats, of which the following are suggested as especially relevant in England and worthy of particular attention in future evaluation studies:

- carbon budget management
- water quality
- flood risk management

In some areas of England it is possible to find healthy functioning ecosystems providing significant services which merit protection. In other areas, the habitats will be modified to such an extent that while rare species remain and need to be conserved, it is difficult to detect significant provision of additional ecosystem services. In the latter cases it may be a question of considering the additional services that might be provided if the landscape were to be restored.

In order to assess the societal value of ecosystem services, the report suggests a number of steps of analysis that should be applied to each service (following the simple pathway set out in Figure E1.1). This entails employing one or several of the economic valuation techniques described in Section 3 in order to estimate the possible values attributed to ecosystem services by different groups in society.

Several approaches may be employed in order to estimate the value of ecosystem goods and services. However, it is clear that we remain in the early stages of understanding both the science and economics of ecosystem services.

This report emphasises the complex nature of ecosystems and how appropriate protection and management can deliver wider societal benefits. The problem is that this complexity makes it difficult for decision makers to evaluate the magnitude of the societal benefits of ecosystem services. It demonstrates, however, that for the case study habitat types we should be aware of a variety of potential ecosystem services in England, including potential benefits for water quality, flood control and the carbon budget.

Contents

1 Overview

England harbours a broad array of habitat types that serve valuable functions by providing inputs to our production processes, acting as sinks and treatment centres for pollution and waste, as storage houses for genetic and biological information and as buffers against potentially destabilising and catastrophic events.

Despite the contribution of these functions to our well-being, our understanding and recognition of the contributions of ecosystems to economic and social welfare is still limited. Part of the problem lies in the complexity and uncertainty surrounding the study of ecosystems in general, and part lies in the well-known failures of the market-driven economy to take account of goods and services provided by ecosystems free of charge – the so-called external or non-market goods and services.

Many decisions made daily by natural resource managers and decision-makers in England, including English Nature and other representatives of Government, would benefit from a clearer picture of both the nature and value of ecosystem goods and services. Such information would help, for example, in prioritising the delivery of funding to maintain or improve the management of ecosystems, such as woodlands and wetlands, and in deciding between competing uses of ecosystems in the best interests of society.

Appraisal and evaluation[1] of environmental policies, programmes and projects is increasingly becoming standard, and with that the recognition of the role of economic analysis, such as cost-benefit analysis, and specifically the need for valuation of non-market goods and services as inputs to this analysis.

Ecosystem functions contribute to economic and social well-being either directly through, the provision of goods, or indirectly through the provision of services that feed into and underpin economic processes. The focus of this report is on these ecosystem services, which are typically more difficult to observe, and thus often risk being unaccounted by valuation studies. Better understanding of the value

This report aims to assist economists at English Nature and elsewhere with economic appraisal and evaluation of decisions relating to ecosystem management in England, by providing:

- A first attempt at a **detailed catalogue of ecosystem services** in three priority habitat types (broadleaved woodland, terrestrialised freshwater wetlands and inter-tidal habitats) to act as a master reference for future valuation work;

- **examples and case studies of valuation work** undertaken in the UK in the past;

- **advice on the appropriate economic valuation techniques** for communicating and providing evidence of marginal changes in ecosystem service value for a range of decision-making contexts; and

[1] The UK Treasury Green Book (HM Treasury, 2003) defines appraisal as ex-ante evaluation and evaluation as ex-post evaluation. For ease, for the remainder of this document we use the term evaluation to refer to both.

- advice on the **relevant issues, challenges, opportunities and limitations** inherent in undertaking such valuation exercises.

This study is a collaboration between economists and ecologists, demonstrating the range of expertise required to approach the study of the ecosystem-economy interface. It follows on from a similarly collaborative study undertaken for Defra (eftec, 2005), which had a more international focus and particular emphasis on the role of environmental services in alleviating poverty. The aim in commissioning the current study was to give that work an English focus.

The remainder of this section explores the concepts inherent in the study of ecosystem services and their economic value. Section 2 of the report then presents the catalogue of England's goods and services for the three priority habitat types (woodlands, terrestrial freshwater wetlands and inter-tidal habitats) (a list of BAP species-habitat associations that are relevant for this Section is presented in Annex 1). The appropriate choice of valuation technique for the catalogue of services is presented in Section 3 along with a range of methodological issues surrounding economic valuation. This discussion is supported by a case study example in Annex 2. Finally, Section 4 presents recommendations and conclusions.

1.1 What are ecosystem goods and services?

Ecosystems and the diverse functions they perform provide a stream of goods and services, the continued delivery of which remains essential to our economic prosperity and other aspects of our welfare. The terms 'ecological/ecosystem function' and 'ecosystem service' are used interchangeably in the literature. However, all recognise that the contributions of ecosystems to society are the outcome of a range of conditions and processes through which natural ecosystems operate.

Ecosystem services can be usefully grouped according to four broad categories as defined in the Millennium Ecosystem Assessment (World Resources Institute, 2005) see table 1.1.

Table 1.1 Ecosystem service categories

Supporting services	**Provisioning services**	**Regulating services**	**Cultural services**
Primary production, Provision of habitat, Nutrient cycling, Soil formation and retention, Production of atmospheric oxygen, Water cycling	Food, fibre and fuel, Genetic resources, Biochemicals, Fresh-water	Invasion resistance, Herbivory, Pollination, Seed dispersal, Climate regulation, Pest regulation, Disease regulation, Natural hazard protection, Erosion regulation, Water purification	Spiritual and religious values, Knowledge, Education and inspiration, Recreation and aesthetic values, Sense of place

When ecological functions provide inputs to economic processes, we get e*cosystem goods* (or 'provisioning' services), which are the natural products harvested or used by humans such as agricultural produce, timber, fish, game, livestock, medicinal plants, drinking water and so on. We also get *ecosystem services* which input to the production of ecosystem goods and human well-being and survival more broadly through services such as purification of air and water, pollination of crops, decomposition of wastes, generation and renewal of soils, stabilisation of the climate, mitigation of droughts and floods, and protection of soils from erosion.

The focus of this report is also on the characterisation of the categories of ecosystem service, derivation of a complete list of services the three priority ecosystems generate (see Section 2) and their valuation (see Section 3). Throughout the report, these categories are employed to structure the presentation of information.

1.2 Why should we measure the economic value of ecosystem services?

Why should we measure the economic value of ecosystem services? The short answer is that information on ecosystem value will contribute to better decision-making. The UK has adopted a range of policy objectives in relation to the preservation of ecosystems, stemming from international commitments and EU and national laws, including a policy of halting and reversing the loss of biodiversity. There are bound to be tradeoffs in achieving these objectives, arising from competing land uses and other interests (eg recreation versus development). This translates into the need for assessment of the funding and policy choices involved in order to achieve policy goals *efficiently*, ie in the *best interest of society*.

The notion of ecosystem services helps us to understand a key dilemma in natural resources policy: that of ecosystem simplification. Ecosystem simplification generally involves land use and habitat change which results in an increase in the economic value of one ecosystem service ie the provision of a crop yield. However, as is now becoming apparent as we learn more, this may be at the expense of other services provided by the ecosystem, which may have an impact over a wider geographical scale and which may include public as well as private good values.

Efficient policy decisions are ones that allocate limited resources to uses that will generate the highest net benefit for society, where 'net' entails accounting for benefits minus costs. These costs and benefits include effects visible in the marketplace, such as reductions in profits, as well as non-market effects, that reflect externalities (effects not captured by markets). Positive externalities exist where ecosystem services provide benefits free of charge (eg woodlands contributing to good water quality in the catchment area), and negative externalities generally exist where resource-use decisions impose an unintentional burden on others (eg clearing of woodlands for transport infrastructure resulting in siltation of rivers downstream and costs to fishermen and drinking water suppliers). Taking account of these externalities requires:

- understanding and recognition of the processes and pathways by which ecosystems contribute to economic well-being, including the often considerable uncertainties;
- recognition of the range of stakeholders affected and the extent to which they are affected; and
- provision / estimation of the missing economic value data, ie the size of the externality.

In relation to English Nature's activities alone, the following provides some examples of the uses of economic measures of the value of ecosystem services:

- to **communicate with the public** the value of the ecosystems;
- in **deciding value for money** spent on the management of the environment, eg the appropriate amount of public money to spend to achieve and maintain ecosystem service improvements or avoid declines;
- in **choosing between competing uses**, eg the benefits lost from recreation through reduced access to sites compared with the benefits gained to wildlife conservation;
- in **assessing liability** for damage to the environment, eg for damage incurred by companies and covered by EU Environmental Liability Directive;
- to **communicate with natural resource managers**, eg in forestry, agriculture, fisheries and minerals/aggregates extraction, the economic case for sustainable management of their resources;
- in **assessing 'over-riding economic interest'**, as defined in the EU Habitats Directive, in deciding on granting licence for development on or near a conservation site;
- in **influencing national and European level policy**, by providing economic evidence of the full range of benefits and costs of policy impacts on the environment and society (ex-post and ex-ante assessments);
- in **prioritising funding** for different activities within English Nature; and
- in assessing '**disproportionate costs'** as defined in the EU Water Framework Directive, in deciding on the application of derogations/exemptions, ie achievement of lower environmental objectives, or later than 2015.

These uses for economic data will often be set within a broader economic evaluation context, such as a cost-benefit analysis, a cost-effectiveness analysis or a multi-criteria analysis. These are complementary frameworks for taking account of efficiency, equity and sustainability criteria that form part of an overall project or policy evaluation.

The level of detailed analysis required, and the selection of appropriate valuation techniques is partly dependent on the intended use of the data. For example, a project aimed at communicating ecosystem value to the public may require a less detailed approach, and therefore smaller budget, than one for assessing liability. This is discussed further in Section 3.

Finally it should be noted that the above policy concerns and hence economic value of ecosystem services that contribute to policy making work towards achieving all four of the four pillars of sustainable development as defined by the government, namely, (i) social progress which recognises the needs of everyone; (ii) effective protection of the environment; (iii) prudent use of natural resources; and (iv) maintenance of high and stable levels of economic growth and employment.

1.3 How can we measure the economic value of ecosystems?

Key to understanding the value of ecosystems is to characterise and quantify the relationships between ecosystem function and provision of ecosystem goods and services, and to identify the ways in which these generate welfare improvements. Figure 1.1 demonstrates these pathways with a very simplified model: ecosystems and their functions provide services, which generate benefits to human populations by contributing to human welfare or well-being (either through the production of goods or through other services supplied), which can then be translated into economic value using economic valuation techniques. Economic valuation is therefore a logical extension to any assessment of the services provided by ecosystems for the purpose of public decision-making. This simplified model masks the often significant difficulties in establishing the causal pathways. Nonetheless it is a useful construct to guide such assessments and identify needs for future research.

ECOSYSTEM (1)	⇨	ECOSYSTEM SERVICES (2)	⇨	CONTRIBUTION TO HUMAN WELFARE (3)	⇨	ECONOMIC VALUE (4)

Figure 1.1 Simple ecosystem services-to-value pathway

Section 2 of this report seeks to catalogue ecosystem services and how they contribute to human welfare (stages 1-3 in Figure 1.1), whilst Section 3 focuses on the estimation of economic value (stage 4). Scientists, economists and policy makers will be interested in Section 2. It represents an initial assessment of potential ecosystem services for the three habitats chosen here. Section 3 is aimed more at the economist audience.

For the purposes of informing policy choices, Figure 1.1 should be read with marginal changes in mind, reflecting the type of changes that occur to the quality and quantity of ecosystem services as a result of management decisions. For example, an improvement in river quality through an investment programme is an example of a ‘marginal’ change. It is not appropriate to talk about the economic value of ecosystems as a whole, as this could be considered infinite (as life of the planet would cease to exist without ecosystems). However, a ‘marginal’ change does not have to mean a small change. Even the loss of an entire wetland can be considered marginal at the catchment level, and even more so at the global level.

A key step in the appraisal process is in characterising the myriad ways that ecosystem services contribute to human welfare and disentangling these (steps 1 - 3). Ecosystem services can provide joint products and services that can also be competing. These considerations are important to avoid double counting. Section 3 presents these challenges with a more detailed illustration of the ‘services to value’ pathway and a discussion on double counting.

Economists have developed the total economic value (TEV) framework to characterise the ways in which ecosystems contribute to social welfare, which helps identify the links between steps 2 and 3 in the figure. The total economic value of ecosystems to society should reflect their *use value* to society as well as their *non-use value*, where TEV = use + non-use, as described below.

Use value involves some interaction with the resource, either directly or indirectly:

Direct use value:	where individuals make actual, present day use of a resource, which can be consumptive (eg commercial or recreational fishing) or, to varying degree, non-consumptive (eg hiking).
Indirect use value:	Where individuals benefit from ecosystem services supported by a resource rather than directly using it (eg nutrient cycling or carbon sequestration).

Option value: an individual derives benefit from ensuring that ecosystem services will be available for his or her own *use in the future*. In this sense it is a form of use value, although it can be regarded as a form of insurance to provide for possible future use (often associated with the potential of genetic information inherent in biodiversity to be used for research, eg pharmaceuticals; this latter aspect is sometimes termed 'quasi-option' value.

Non-use value is associated with benefits derived simply from the knowledge that the ecosystem is maintained. By definition, it is not associated with any use of the resource or tangible benefit derived from it, although users of a resource might also attribute non-use value to it. It can be split into three basic components:

Existence value: derived simply from the satisfaction of knowing that ecosystems continue to exist, whether or not this might also benefit one self or others (also associated with 'intrinsic value').

Bequest value: associated with the knowledge that ecosystems and their services will be passed on to future generations.

Altruistic value: derived from knowing that contemporaries can enjoy the goods and services ecosystems provide.

Figure 1.2 illustrates the TEV framework and provides some examples. The figure introduces an important distinction between market and non-market measures of value. For example a woodland can generate both market (or private) goods such as timber and un-priced, non-market (or public) goods such as open-access, informal recreation. Note that by changing the property rights and imposing restrictions on access, the public goods like recreation can be transformed into priced private goods (Bateman, 1999). The same applies to services where markets have been introduced, such as payments for watershed services and the carbon offset market. In fact, one of the potential uses of valuation is to estimate the correct level for service payments that will encourage sustainable use and eliminate externalities.

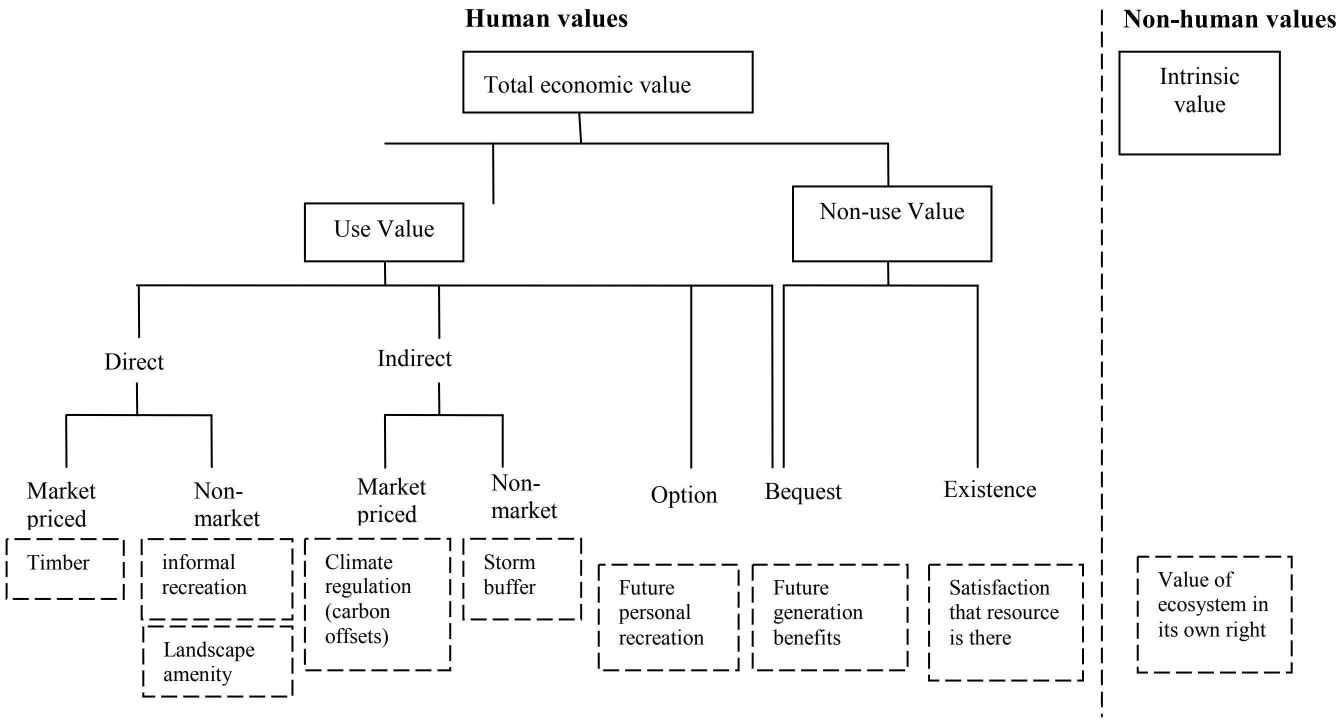

Figure 1.2 Total Economic Value Schema (adapted from Bateman (1999))

The figure also introduces the argument for a wider definition of value that is based on a moral philosophical case for consideration of preferences outside the human sphere, ie an 'intrinsic' value separate from anthropocentric existence values (eg Singer, 1993). This perspective remains outside the scope of economic valuation and analysis which rely on anthropocentric preference estimation. There is also some question about whether ethical positions about inter-generational stewardship and sustainability can be fully reflected in the preferences of the current generation. Turner also (1999) argues that all these services are to a degree contingent on maintenance of the integrity of the ecosystem as a whole, and that the TEV approach may underestimate the importance of this (the so called 'glue' value which is a necessary prerequisite for the generation of all subsequent values (Bateman, 1999)). The glue concept, is also often in practice outside of the scope of economic valuation as it cannot easily be measured. However, its importance is highlighted by the notion of provisioning and regulating services.

TEV is measured by the preferences of individuals. When goods and services are provided in actual markets, individuals express their preferences via their purchasing behaviour. In other words, the price they pay in the market is at least a *lower-bound* indicator of how much they are willing to pay for the benefits they derive from consuming that good or service. For non-market goods and services, such behavioural and market price data are incomplete or missing. In such cases, the methods of economic valuation provide several tools – grouped under the headings 'stated' and 'revealed' preference techniques) that may be employed to estimate these 'non-market' or 'external' benefits. The benefits of ecosystem services can be communicated through both market and non-market data and often elements of both are required to paint the whole TEV picture.

The common characteristic of non-market valuation techniques is that they express economic value in units of money. The measures they use for welfare changes include: Willingness to

Pay (WTP) to secure a gain or to avoid a loss and Willingness to Accept Compensation (WTA) to forgo a gain or to tolerate a loss (note that market price is an indication of the minimum WTP of buyers as mentioned above). Use of these techniques has the advantage of allowing the non-market benefits of ecosystem goods and services to be compared with financial gains from their use. The economic literature using these techniques is vast; Section 3.2 provides an overview. Regardless of whether all components of TEV can be expressed in monetary terms for a given ecosystem good or service, the concept is useful for cataloguing and characterising the many ways that ecosystems contribute to human well-being (economic welfare).

2 Ecosystem services of habitats in England: the catalogue

2.1 Introduction

Three habitats (types of ecosystem) were selected for detailed examination of services and goods provided. They are (i) broadleaved woodland; (ii) intertidal habitats and (iii) terrestrialised, freshwater wetland habitats. Selection criteria for studying these three habitats were that they (i) are well-represented in England; (ii) are multifunctional, offering a broad range of service and goods categories; (iii) provide a contrasting range of services and goods; (iv) are easily defined and evidenced; and (v) are of high relevance in the context of current policy development.

Ecosystem services are defined as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life. These were identified for the three habitats and are described in Section 2.2. A summary providing an indication of relative importance of services is provided in Section 2.3, and examples and explanations of services for each habitat are detailed in Sections 2.4, 2.5 and 2.6. The sub-categories of services and goods, presented in Table 2.1 and used as sub-headings throughout, were developed to be general enough to apply to all service categories.

2.2 Overview of ecosystem service categories, services and goods

For the purposes of this report, ecosystem services are categorised into seven categories, which are further subdivided into specific services and goods. This categorisation is taken from eftec (2005) and can be applied across all habitats including the three ecosystems covered in this report.

Ecosystem service categories:

- supporting
- provisioning
- regulating
- cultural

The services and goods provided by the three ecosystems of concern here under each of these categories are described in Sections 2.4, 2.5 and 2.6. The services and goods associated with these habitats are not presented here in any priority order and will vary depending on the location. Underlined type indicates words or processes described in the glossary at the end of this report.

Ecosystem services provided by each habitat may be subject to limiting thresholds, beyond which the service is no longer delivered. In some cases a service that is beneficial to humans may have negative side effects, or be non-beneficial under certain scenarios. Therefore, the services described for each habitat are not necessarily always delivered by healthy, functioning ecosystems. Such complexities and sources for debates are indicated in the text for each habitat. It should also be noted that the ecosystem services for each habitat type represent a preliminary assessment and are not necessarily comprehensive.

The remainder of this section provides a summary explanation of a selection of some of the more complex ecological 'services':

2.2.1 Purification and detoxification (regulating service)

Natural vegetation acts as a filter removing particulate matter from the air. Filtration of air pollution is the process of interception and decomposition of particulate and gaseous air pollution. These processes remove pollutants from the atmosphere, mitigating associated health and environmental impacts. Production of oxygen is a consequence of photosynthesis in plants, fulfilling an important role in exchanging gases with the atmosphere and oxidising anaerobic environments. This process ensures an appropriate balance of oxygen to sustain aerobic life forms (Andrews and others 1996). Filtration of water describes the removal and retention of suspended particulates in water, ie a sieve effect of soils and plants, which improves water quality. Detoxification of water and sediment includes dilution of pollutants resulting in lower toxicity, detoxification of pollutants through chemical change, decomposition or binding processes, and accumulation of pollutants in plants or sediments that effectively partitions them from the environment.

2.2.2 Cycling processes (supporting services)

Functioning cycling processes occur in healthy ecosystems, maintaining conversions of the cycled entity and availability in the different phases of the cycle. Figure 2.1 illustrates the nutrient cycle, which involves a number of processes including nutrient **fixation**. Nutrient cycling conserves nutrients (eg nitrogen, phosphorus, potassium) against loss by leaching and **volatilization** (Wild*,* 1995) and soil formation processes (the breakdown and release of minerals from rock and the accumulation of animal and plant organic matter) are particularly important in maintaining soil productivity. Translocation of water and nutrients from depth is a service provided by deep rooted plants that replenish depleted water and nutrient reserves at the surface. Nutrient retention is a useful service in situations with excess nutrients and helps to mitigate against **eutrophication** of watercourses and natural/semi-natural habitats. Vegetation plays an essential role in removing one of the main greenhouse gases, carbon dioxide, from the atmosphere. **Carbon fixation** and sequestration in the carbon cycle (Figure 2.2) leads to the retention of carbon in **sinks**. This lowers the atmospheric levels of carbon dioxide. Implications for global warming and climate change are described under regulation and stabilisation services.

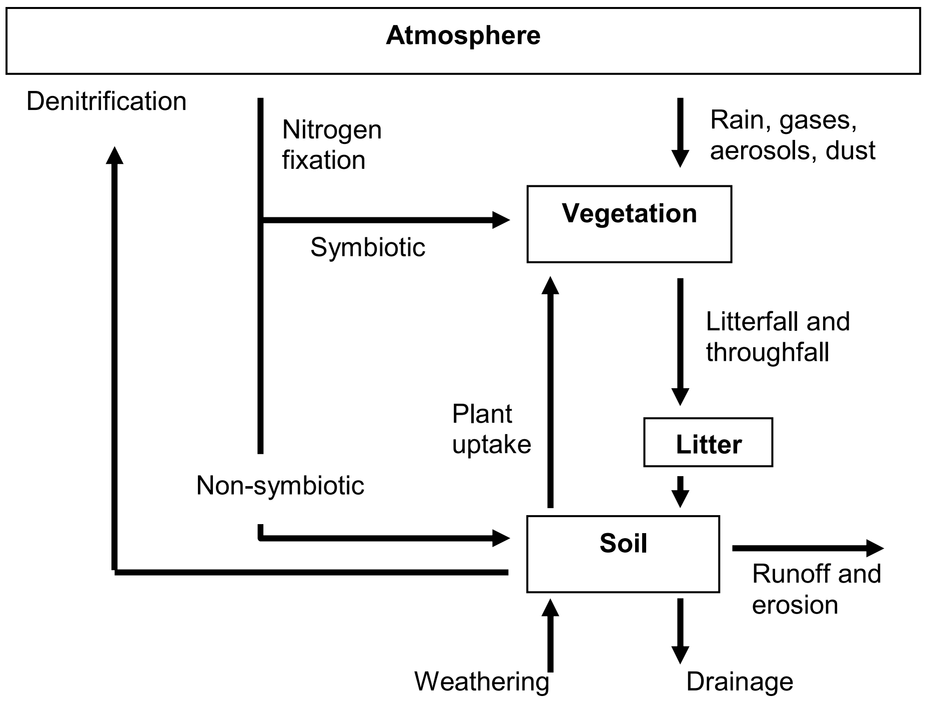

Figure 2.1 The nutrient cycle (adapted from Wild, 1995).

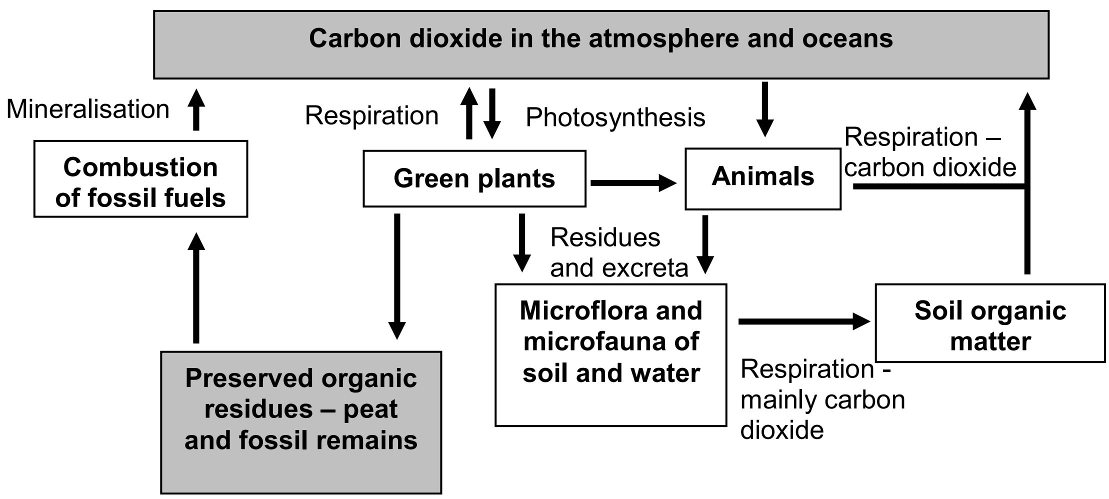

Figure 2.2 The carbon cycle. Shaded boxes indicate carbon sinks (adapted from White, 1997).

2.2.3 Regulating services

Global climate regulation is a service that mitigates against global warming and associated climate change. This is provided by any ecosystem that sequesters carbon and thereby lowers atmospheric carbon dioxide, described in the cycling processes category of services. Local climate regulation services in contrast are prevention of extreme local weather, ie temperature buffering, wind attenuation, cloud cover and precipitation regulation. Erosion control is a service provided in many different forms such as reduced impact of rainfall and overland flow, wave attenuation and shoreline stabilisation. The flood risk mitigation service is detention and storage of excess water, reducing flow rates or acting as a buffer to protect areas at risk of flooding. Maintenance of surface water stores is carried out by ecosystems with capacity to hold water or trap and direct water into water storage areas such as reservoirs and upward seepage of groundwater, and is particularly important in dry areas or at times of water deficit. Groundwater replenishment relies on water that is not evaporated or transported by surface runoff infiltrating into groundwater **aquifers**, which is assisted by slowing of surface water flow.

2.2.4 Habitat provision (supporting service)

Ecosystems provide habitats for wild plant and animal species, both resident and migratory. As such, ecosystems act as a refuge and storehouse for biodiversity, by maintaining the conditions which allow survival of the diverse array of species on the planet. Plant and animal species are a direct source of an immense number of goods and products that are harvested and used by humans for livelihood support, enrichment and welfare. Biodiversity also represents a genetic and biochemical library that underpins the flexibility and potential of much agricultural and pharmaceutical development. To avoid double-counting with other types of ecosystem service, habitat provision category is focussed upon the habitats and associated species of conservation importance. The service provided by habitats of conservation importance include; providing a high biodiversity resource, hosting important breeding or nursery grounds, and providing international migration stopover locations and internationally important over-wintering habitats. Association with species of conservation importance is a service of habitats that support rare, specialist or priority species (as defined by the UK BAP).

2.2.5 Regeneration and production (supporting and provisioning services)

Primary production drives the food chain in all ecosystems. High rates of primary production enhance the production of goods including food and hence can be an important service particularly in agriculturally-managed ecosystems. Fibre and construction products include all sustainable fibrous products used for example in buildings, furniture and clothing. Food and drink products, medicinal and cosmetic products and ornamental and other products are restricted in this report, to those sustainable goods harvested and produced on a commercial basis. Regenerative services include any service that leads to reproduction and regeneration of habitats in other ecosystems, primarily pollination or seed dispersal.

2.2.6 Information provision (cultural service)

Much intellectual development, both artistic and scientific, is influenced directly or indirectly by interaction with and inspiration from the natural environment. **Paleo-environmental data** source is a service from environments that preserve fossil and sedimentary evidence of environmental conditions, such as fossilised organisms and pollen grains. Preservation of archaeology service refers to preservation of physical evidence of past human societies, such as artefacts, burials and constructions. Historical importance in contrast refers to services providing information from less ancient history, ie documented historical times. This service includes preservation of traditional ways of life. Education and scientific research resource is the use of an ecosystem to add to scientific knowledge and dissemination of that knowledge. Uses of scientific research include biomimicry, a recent development whereby science imitates or takes inspiration from nature's designs and processes to solve human problems, eg a solar cell inspired by a leaf. Gene bank for research and development of products is a potential service in all ecosystems, and is documented here for ecosystems that are already under research in this respect.

2.2.7 Life-fulfilment services (cultural service)

Natural landscapes provide humans with recreational and exercise opportunities. Recreation and tourism here refers to non-consumptive activities that attract people to visit the ecosystem for enjoyment, and includes free and priced recreation. Physical health benefits and promotion of personal wellbeing are provided by ecosystems that can support physical activities, are thought of as tranquil or provide a link with nature (wilderness value). This also includes opportunities for community development. Historical meanings and cultural importance is a service of ecosystems linked to folklore, intellectual and spiritual traditions, art and heritage. Cultural and recreational activities in the environment are the source of much economic revenue through tourism and sport.

2.2.8 Ecosystem services summary

The potential ecosystem services described above for each of the three habitats are summarised in Table 2.1. This table provides cross-reference for comparison of services between habitats and indicates services of particular importance, either due to current environmental pressures, rarity, or uniqueness to the particular habitat. It indicates those services which may be relatively more important for each habitat type. Services of particular importance should be at the forefront of evaluation work, and may vary between areas. The table shows that most services are provided by these three contrasting habitats, although the service may be delivered in a variety of different ways, discussed in Sections 2.4, 2.5 and 2.6. The relative importance of services is indicative only and may vary in different situations. Given the complexity of ecological interactions, the extent of services in a particular situation requires case-by-case evaluation of services.

Table 2.1 Table of ecosystem services and goods for broadleaved woodland, intertidal and terrestrialised freshwater wetland habitats.

○ Service may be provided. ● Services of possible (relative) importance [Note this is a qualitative judgement].

Service Category	Services and goods	Habitat		
		Broadleaved woodland	**Freshwater wetlands**	**Intertidal habitats**
Supporting services	Production of oxygen	●	○	○
	Nutrient cycling	○	●	●
	Translocation of water and nutrients from depth	○		
	Primary production	○	○	○
	Habitat provision for species of conservation importance	●	●	●
Provisioning services	Food and drink products	○	○	●
	Fibre and construction products	●	○	○
	Medicinal and cosmetic products	○	○	○
	Ornamental and other products	○	○	○
	Renewable energy	●	○	○
Regulating services	Filtration of air pollution	●		
	Filtration of water	●	●	○
	Detoxification of water and sediment		●	●
	Carbon fixation/sequestration and global climate regulation	●	●	○
	Local climate regulation	○	○	○
	Erosion control	○	●	●
	Flood risk mitigation	○	●	●
	Maintenance of surface water stores		●	
	Groundwater replenishment		○	
Cultural services	Paleo-environmental data		●	
	Preservation of archaeology	○	●	●
	Educational and scientific resource	●	●	●
	Gene bank for research	○	○	○
	Historical and cultural importance	●	●	○
	Recreation and tourism	●	●	○
	Physical health and personal well being	●	○	○

2.3 Broadleaved woodland habitat services and goods

Broadleaved woodland habitats include all closed-canopy broadleaved and yew stands. The habitat also includes mixed stands, ie those with both broadleaved and coniferous species, with over 20% of the cover made up of broadleaved and yew trees, rather than other conifers, and associated integral features such as scrub, glades and rides. The BAP Priority Habitats included in this ecosystem type are Upland Oakwood, Lowland Beech and Yew Woodland, Upland Mixed Ash Woods, Wet Woodland and Lowland Mixed Deciduous Woodland (UK BAP, 1995; 1998). Coniferous plantations and wood-pasture and parkland are not included in this review (see Table 2.2).

Table 2.2 Location and extent of BAP Priority Habitats included in broadleaved woodland (UK BAP, 1995; 1998; Forestry Commission, 2004).

Habitat	Estimated extent in England unless stated otherwise
Total English Broadleaved woodland	745,000 ha at the 31 March, 2004
Upland Oak Woodland	Between 70,000 ha and 100,000 ha in the UK (eg in Cumbria, Devon and Cornwall)
Lowland Beech and Yew woodland	In the late 1980s the Nature Conservancy Council estimated the total extent of ancient semi-natural woodland of this type in the UK at between 15,000 and 25,000 ha. An additional 5,000 ha of recent Beech woodland brings the total area to about 30,000ha.
Upland Ashwood	67,500 ha in the UK
Wet woodland	50,000 – 70,000 ha in the UK
Lowland mixed deciduous woodland	250,000 ha in the UK (mainly England)

2.3.1 Supporting services

Production of oxygen

All plants produce oxygen as part of photosynthesis. Biomass can be used as a proxy for oxygen production, therefore woodlands, as habitats with relatively high biomass, are extremely important in this respect.

Nutrient cycling

Decomposers provide nutrient cycling services. One important group of decomposers is fungi. Woodland provides the most important habitat for fungi, which live on dead organic matter such as leaf litter and have an important role in re-cycling, converting nutrients into new forms for re-absorption or **mineralization**. In this way they prevent a build up of nutrients in the soil and loss through leaching (Sanderson and Prendergast, 2002). For example, symbiotic relationships between roots and microorganisms perform nitrogen fixation. Alder, found in wet woodlands, has an important symbiotic relationship with an actinobacterium (*Frankia alni*), which forms nodules on the tree roots and has an estimated rate of fixation at up to 125 kg N per ha per yr. As a result, alder improves fertility of the soils, which is particularly important in its role as a **pioneer** species (http://www.treesforlife.org.uk/tfl.alder.html). Woodland soils are rich in organic matter from decomposing detritus (White, 1997). However the capacity of woodlands to cope with additional nutrients is limited and there is currently concern that forest soils are becoming saturated with nitrate and that nitrate leakage is occurring (Forestry Commission, 2003).

Translocation of water and nutrients from depth

Hydraulic lift by tree roots moves water from wet layers at depth to higher dry soils, ensuring survival of trees in dry weather, and in some cases providing water for shallow rooted neighbouring plants (Richards and Caldwell, 1987). Furthermore, absorption of nutrients and minerals by roots translocates these minerals to the surface to be incorporated into plant matter (though this service is limited because most root systems are within the top 30cm of soil). Addition of nutrients to topsoil is important for food products from woodland soils, in which mineral content has been in decline with consequences for human health.

Habitats of conservation importance

Broadleaved woodlands (excluding Wood-pasture and Parkland) include six priority BAP habitats in England, receiving the highest precedence for conservation action (UK BAP, 1995, 1998). Upland Oak Woodlands, Mixed Ash Woodlands, Beech Woodlands, Yew Woodland and Wet Woodlands in the UK are included in areas notified as **SSSIs**. Several broadleaved woodland plant communities are also listed on Annex I of the EC Habitats Directive, and a number of these areas have been approved as **SACs** (UK BAP, 1995, 1998). Upland Oak Woodlands in Britain are internationally important because of their limited extent and distinct plant and animal communities. Britain and Ireland hold a substantial part of the European and world populations of some species of Upland Oak Woodland (UK BAP, 1995). Woodland landuse in lowland areas relieves some of the pressures imposed on the environment by intensive arable landuse (Forestry Commission, 2003).

Compared to most other land uses, woodlands and forests are generally rich in biodiversity. Though they only occupy 11% of the land area, they are home to about 40% of the priority species listed in the UK Biodiversity Action Plan (UK BAP, 1995, 1998) (eg the dense and varied shrub layer found in many southern mixed Ashwoods can provide suitable habitat conditions for dormice, UK BAP, 1998). The high biodiversity value of woodland arises for a number of factors. They have a diverse, multilayered structure and often have a mosaic of habitats brought about by successional sequences, **coppice** management, woodland edge and woodland rides. Areas of more open canopy tend to have more pronounced and diverse ground flora (Fuller & Warren, 1991). Often, different woodland types occur in mosaics with each other and with other types of habitat, adding to the overall diversity and species richness of the landscape (UK BAP, 1998). In wet woodland, which has a large number of invertebrates associated with alder, birch, willows, dead wood within the sites and logjams in streams, the association with water provides specialised habitats not found in dry woodland types. Woodlands on sites that have been continuously wooded since at least 1600AD – ancient woodlands – tend to be the richest (Townsend and others 2004).

Broadleaved woodlands are important as wildlife corridors. They are also important breeding sites, particularly for birds including summer migrants and rare resident species. Different assemblages of birds occur in different types, for example, upland Oakwoods are particularly noted for the occurrence of breeding wood warblers, redstarts and pied-flycatchers as well as being the stronghold of the Welsh red kite population (UK BAP, 1995).

Association with species of conservation importance

Broadleaved woodlands support many rare species, including 82 BAP priority species, listed in Annex I. Most Oceanic upland oak woods are particularly rich in ferns, mosses and liverworts and many also hold very diverse lichen communities (UK BAP, 1995). Mixed ashwoods are amongst the richest habitats for wildlife in the uplands and many rare woodland flowers occur mainly in these woods. Some rare native trees (notably large-leaved lime and various whitebeams) are also found in these woods. Beech-yew woodland can be particularly important for fungi, while wet woodland provides cover and breeding sites for otters, and may support relict species from former open wetlands on the site (UK BAP, 1998). The Lowland Mixed Deciduous woods include many of the bluebell woods for which the UK is internationally important: we have perhaps 20% of the world population of native Bluebell. The purple emperor butterfly is found exclusively in old oak woodlands, and native broadleaved woodlands also support the greatest diversity of moth species of any UK habitat (Carter, 1982).

2.3.2 Provisioning services

Fibre and construction products

The principle fibre and construction product of Broadleaved woodlands is timber, used in construction, furniture and so on. The UK Woodland Assurance Standard (UKWAS) certifies sustainable management of high forest woodland in the UK. This is an independent assessment benchmark certification in response to a growing consumer demand for credible proof that timber products come from sustainably managed forests. UKWAS has been developed by a partnership of forestry and environmental organisations. Forest certification has expanded rapidly in the UK, and there are now around 1.2 million hectares of UKWAS certified forest and woodland. This accounts for about 40% of the UK's total forest area.

Although more minor in extent (only 2% of UK woodland in 2001) and economic value, coppice management produces other construction and fibre products. These include hurdles, poles for thatching, hazel **liggers**, rose arbours, hedge laying stakes and living fences and willow baskets and furniture (Sanderson & Prendergast, 2002; Lewington, 2003). Due in part to nature conservation management, there has been a revival in coppice management and associated traditional coppice products over recent years (eg Wessex Coppice Project, Dickie and Rayment, 2001). Course (1998) estimated that approximately 1,100 people working in **green wood trades**. Opportunities exist for the increased use of coppice products in bioengineering projects such hazel or willow hurdles for riverbank restoration (Sanderson and Prendergast, 2002).

Food products

Commercially harvested food products from woodlands include pheasants (not always sustainable), domestic stock grazing, deer and fungi (Sanderson and Prendergast, 2002). Collecting fungi on a commercial scale is a relatively recent phenomenon, and of the 12,000 fungi species in the British Isles only a few reach commercial prominence. The New Forest is the base of the largest commercial operation in England, with produce going to the restaurant trade (Land Use Consultants and the Foundation for Local Food Initiatives, 2000; Sanderson and Prendergast, 2002).

Medicinal and cosmetic products

Woodlands provide the basis for a number of medical and cosmetic products. Taxol, a cancer therapy drug, is derived from yew (Nash, 1998); willow is a source of pain-killing compounds (Lewington, 2003) and charcoal is used in pharmaceuticals (Sanderson and Prendergast, 2002).

Ornamental products and other products

Traditional crafts and industries are undergoing a growth in popularity (Collins and others 2004). Ornamental and other products from coppice include pea sticks, besom handles, rustic furniture, brooms, brushes and turned products, tent pegs, walking sticks, fine joinery, tool handles, and bonfire ash used as glaze by potters (Sanderson and Prendergast, 2002). Non-coppice ornamental woodland products include wood carvings, mistletoe, wreaths and stumps. Charcoal for barbecues is predominantly imported but charcoal as an artists' material in England is produced commercially from willow (http://www.somerset/willow/Pages/Art.htm). The largest British producer of artists' charcoal supplies throughout the UK and exports to 38 countries (http://www.middlepeg.com.au/wow.htm). Other uses of charcoal are for pet food, metal smelting and filtration, gunpowder and fireworks (Sanderson and Prendergast, 2002). Willow is used to make cricket bats. Wright and Sons (Chelmsford, Essex) is a world authority on growing and grading cricket bat willow and supply more than 90% of the world's market (http://www.middlepeg.com.au/wow.htm).

Renewable energy sources

There is interest in new opportunities for energy production from sustainable woodland as a renewable biofuel for power stations. Industrial scale short rotation coppice woodland may also be used as biofuel (Sanderson and Prendergast, 2002) with a total of 669 hectares of short rotation coppice (using willow and poplar) having been agreed under the Energy Crop Scheme in England, as at September 2004 (Forestry Commission, 2004). Firewood is a major product collected from woodlands in many places both on a commercial and personal level. Sustainable charcoal burning is a traditional woodland practice complimenting coppice management (www.gloucestershire.gov.uk/index.cfm?articeid=2510).

2.3.3 Regulating services

Filtration of air pollution

It has been established that woodlands have a greater capacity for interception of particulates than shorter vegetation, open space or water. The layered canopy structure of trees provides a surface area of between 2-12 times greater than the land areas they cover (Willis and others 2003). This diverse structure increases the ability of forests to filter pollutants and fine particles, buffer and adapt to environmental change. When combined with an increased mix of species, increased biological activity in and on the soil reduces the likelihood of acid flushes. However such 'pollution scavenging' in run-off may increase local acidity, although this is less of a problem with broadleaved woodland than coniferous woodland (Forestry Commission, 2003). Filtering is important given concerns about human health implications, especially for particles less than 10 µm in diameter. Broadleaved woodlands are therefore relevant to health issues near pollution sources, ie large urban centres, industrial areas and large road networks, where they facilitate the uptake, transport and assimilation or decomposition of many gaseous pollutants (Crabtree and others 2000; Willis and others 2003).

Filtration of water

Tree cover can provide a buffering function for water courses, by attenuation of overland flow. This can help to limit the delivery of agricultural run-off and sediment to water courses. Consequently this service can improve water quality and controlling water pollution. Poor woodland management can have negative impacts on water quality, for example by increasing turbidity in streams enriching and contaminating the water (Forestry Commission, 2003). A catchment approach to control sediment inputs into Bassenthwaite Lake in Cumbria in northwest England, has identified potential conflicts over land use. For example planting of new woodland for the purpose of erosion control potentially conflicts with ecological and landscape values of important moorland habitat (Nisbet and others 2004).

Carbon fixation and sequestration

In woodlands, carbon dioxide is continually being exchanged between the atmosphere and the forest stand, and over the lifetime of a forest stand, more carbon is captured than released. Hence there is a net accumulation of carbon in the forest (Nordhaus, 1991; Brainard and others 2003; Broadmeadow and Matthews, 2003). However carbon fixing only continues if the forest is harvested for long-term use, otherwise carbon equilibrium will develop (a process taking centuries) (Broadmeadow and Matthews, 2003). Relationships between carbon sequestration and factors such as tree-species and growth-rate, thinning and rotation have been the subject of some research, but there are uncertainties about the carbon content of the soils and the proportion of carbon locked up in timber products. It is estimated that sequestration of carbon per hectare is; beech (2250 t), oak (1629 t), other broadleaf (1409 t) (Willis and others 2003). However the end use of the timber is more important than the species differences in the long term.

Forest soils act as carbon reservoirs and in the case of peat soils can contain more carbon than the trees, depending on rates of litter input and decomposition. However little broadleaved woodland in England is on peat soil and so woodland soil carbon reserves may not be greater than that held in the trees (Broadmeadow and Matthews, 2003). Average carbon stocks (tC per ha) for soils in English woodland have been recorded as 217 compared to 153 for arable and 170 for pasture (Broadmeadow and Matthews, 2003).

Global climate regulation

As a carbon sink (see Cycling Processes), woodlands have the potential to alleviate climate change. This is because accumulation of carbon and maintenance of a carbon store can prevent build up of carbon dioxide in the atmosphere and reduce global warming. This service has considerable economic benefits.

Local climate regulation

Woodlands regulate local climates by acting as windbreaks, through cooling shade effects and evapotranspiration may affect rainfall levels. Woodlands also moderate temperature fluctuations (Forestry Commission, 2003). Protection afforded by woodland is utilised to shelter livestock.

Erosion control

Woodlands can provide physical shelter from winds, helping to control wind erosion of soils. Appropriate woodland establishment can improve soil strength and stabilise soil and thus minimise erosion risks (Forestry Commission, 1998; UK BAP, 1998; Loomis and others 2000; Heal, 2002; Forestry Commission, 2003). Control of soil erosion is achieved by reducing channel flows, increasing water penetration into the soil, reducing overland flow, and reducing rainfall impact by intercepting rain in the canopy (Somerset County Council, 2005). Therefore woodland has the potential to reduce **soil erosion** at source, and act as a buffer to limit the delivery of sediment to watercourses, to protect river banks from erosion and to encourage sediment deposition within the floodplain (Forestry Commission, 2003). Use of woodland in this way may form part of an integrated approach to managing sediment problems in waterways.

Flood risk mitigation

Woodland can help attenuate water flows and provide flood mitigation services. For example, the high hydraulic roughness of wet woodlands such as alder carr retards water movement, though the benefits need to be balanced against potential loss of water from the catchment area through increased rates of transpiration and evaporation (Forestry Commission, 2003). The Parrett Catchment Project (http://www.parrettcatchment.info) aimed to identify areas where woodland establishment would have the greatest potential to reduce flooding and associated problems. Riverbank woodland planting delayed runoff into tributaries, reduced soil compaction (reduced area of intensive farming adjacent to watercourses), increased water penetration in the riparian strip and woody debris in the river, all acting to reduce river flow rates. Wider catchment planting added the service of improved soil structure throughout the catchment and increased water uptake by trees (particularly in summer) (Somerset County Council, 2005). However increased water uptake by trees may not always be beneficial, for example in areas with water deficits such as eastern England, as woodland water use can exceed that of grassland, arable crops or bare ground (Forestry Commission, 2003).

The capacity of trees to intercept rainfall may also produce benefits during storms, particularly in an urban setting. In vegetated areas only 5-15% of rainfall contributes to runoff, whereas in vegetation-free urban areas 60% of rainfall runs off into storm water drains (Bernatzky, 1983). This may cause problems as peak storm flow exceeds town drainage capacity and the water often carries higher than normal levels of pollutants washed from the streets (Haughton and Hunter, 1994). However trees in urban areas may not always act in such a beneficial way. Woody debris may block waterways, exacerbating floods.

Pollination

Woodlands can support suitable habitat and breeding grounds for a valuable resource of species such as Hoverflies, associated with pollination of crops in habitats adjacent to woodlands.

2.3.4 Cultural services

Recreation and tourism

Woodlands provide resources for (free and priced) recreation. Key locations include Castle Eden Dene National Nature Reserve, Peterlee, Monks Wood **NNR**, Cambridgeshire, Burnham Beeches NNR, Berkshire, and wood pasture sites such as the New Forest, Hatfield and Sherwood Forest. Activities include walking, cycling, and activity sports such as paintballing. A recent Forestry Commission study found that around 3% of all UK tourism was 'forestry related'. The Forestry Commission conducted a questionnaire study on local woodland use (339 people in Scotland) which showed that people were more likely to use woodlands for recreational purposes if they had childhood experience of woodlands, walked dogs or had 'a special connection to woodland'. Woodlands were more likely to be used if they were accessible (within walking distance, accessible by car, bike or bus) or had good signage and information boards.

Woodland conservation and game shooting have been linked for hundreds of years in Britain and although not all management for game is sustainable many existing semi-natural woodlands have survived clearance because they provide habitat for game species. More recently sporting interest and game conservation has been responsible for woodland planting and management outside commercial forestry. In addition, woodland is used for recreational harvesting of blackberries, fungi, nuts etc.

Physical health benefits and promotion of personal wellbeing

Forests and other natural spaces can play a key role in providing opportunities for physical activities such as walking, cycling and conservation activities such as 'Green Gyms'. This promotes health and reduces risk of illnesses such as coronary heart disease, diabetes and osteoporosis. Forest-based activities also promote mental wellbeing and reduce stress (Tabbush and O'Brien, 2003). Forests promote a calming effect and provide an escape from hectic life styles (O'Brien and Claridge, 2002; O'Brien, 2003). The life-fulfilling services of woodlands enhance local living environments, which are reflected by higher house prices (eg the Sussex Weald). Even small forests are an important resource for local communities, through volunteering or via networks of owners (eg Anglia Woodnet, Woodland Trust) and have a particular impact if they provide a sense of ownership to people (O'Brien and Claridge, 2002; O'Brien, 2003).

Preservation of archaeology

UK forests contain a diverse and rich collection of archaeology including burial mounds, fortifications, earthworks, field systems, and standing stones. Within woodland environments there are two types of archeological evidence: archaeology in woodland, where there is no relationship between the archaeological evidence and the woodland in which it occurs (eg barrows), and archaeology of woodland, where the archaeological evidence is directly related to the history and management of the woodland (eg saw pits, charcoal platforms and ancient woodland boundary banks) (Crow, 2002-2003). However trees, woodland and woodland operations can be damaging to underlying archaeology and require that good management practices are upheld to avoid such damage.

Historical and cultural importance

In the past, trees and forests have had an important role such as marking out boundary lines, and Royal Hunting Forests, although the term historical forests does not necessarily refer to trees and woodland in the modern sense (Rackham, 1998). Woodlands have helped preserve traditional methods such as the use of heavy horses to move logs because machinery is not appropriate within some woodland habitats.

Ancient trees provide important dating information for scientific and historical research especially in the science of dendroclimatology (Briffa, 2000). However the use of tree rings is mainly restricted to less ancient living trees, because the oldest trees are hollow. Some woodland species are poor colonisers of new habitat and are often used as ancient woodland indicators. Examples include wood anemone, yellow archangel*,* sweet woodruff and great woodrush (Peterken, 1974). Certain rare species of hoverfly are strongly associated with ancient woodland habitats (Stubbs (1982) devised a provisional list of ancient woodland indicator hoverfly species, however, there are limitations to dating with indicators).

Historic meanings of veteran trees and ancient forests eg ancient tree names, folklore, ‘wildwood’ myths and fairytales, contributes to our heritage and our understanding of our past (Crow, 2002-2003). Woodlands have spiritual value which the public perceive as far more important than timber production (O’Brien, 2003). They represent a link with wilderness, symbolising continuity between past and present and are a source of wonder and spiritual renewal (O’Brien and Claridge, 2002). Trees provided the focus for the works of English painters Samuel Palmer, Paul Nash, Graham Sutherland and the Babington School of Painting. Artistic works are also commissioned within woodlands (eg sculptures, carvings, greenman etc.). Woodlands are also appreciated distantly in books (eg Meetings with Remarkable Trees, Thomas Pakenham).

Education and scientific research resource

Woodland habitats provide a resource for general education and scientific research. Key woodland research centres include Wytham Woods, used for research by Oxford University; Bradfield Wood, Suffolk a National Nature Reserve which is a working wood that has been under continuous traditional management since 1252, the ancient forest of Alice Holt, managed by the Forestry Commission, and field study centres in Epping Forest and North Wales.

Gene bank for research and development of products

Woodland diversity provides a gene bank for research into the development of wood products. Various woodland plants are used to derive medicinal treatments. Currently under investigation are wood anemone and bluebell, which were traditionally used to treat tuberculosis and leprosy (Nash, 1998).

2.4 Inter-tidal habitats services and goods

The intertidal habitats included here are those that are exposed at extreme low tides and inundated at extreme high tides, occurring on a sediment substrate. This excludes rocky shores and permanently sublittoral habitats. BAP Priority Habitats included are Coastal Saltmarsh, Mudflats, Seagrass Beds, Sheltered Muddy Gravels and Saline Lagoons (UK BAP 1995; 1999).

Table 2.3 Location and extent of BAP Priority Habitats included in intertidal habitats (Davidson and others 1991; UK BAP 1995; 1999; Covey and Laffoley, 2002).

Habitat	Estimated extent in England unless stated otherwise
Overall intertidal habitats	385,000 ha of which 308,000 ha (83%) are on estuaries.
Saltmarsh (including transitional communities)	32,500 ha
Intertidal mud and sandflats	270,000 ha in the UK. There are many important sites in terms of conservation value in England, including the Exe Estuary, Maplin Sands, the Solent marshes and the Isles of Scilly.
Sheltered muddy gravels	Not clearly documented
Saline Lagoons	1,200 ha. 177 in England, the largest of which is the Fleet in Dorset (480 ha)

The need to take account of ecosystem services in marine policy is also acknowledged by the EU Marine Strategy. The approach envisaged there integrates managing land, water and living resources and promotes conservation. In response to that the aim of 'Safeguarding our Seas' (REF) aims to ensure that environmental limits are not exceeded and, where they have been, to promote their recovery.

2.4.1 Supporting services

Production of oxygen

Algal mats on the sediment surface of intertidal habitats are net producers of oxygen (Wolfstein and others 2000) and all vegetation produces oxygen in the process of photosynthesis. Studies have shown that cord-grass roots are capable of pumping oxygen into the surrounding sediment, thereby altering pH (Lee and others 1999). This process may enhance aerobic respiration and reoxidation reactions, increasing the rate of nutrient cycling (Koretsky and others 2000) and therefore increasing productivity.

Nutrient cycling

Intertidal habitats have a high capacity to recycle substantial nutrient inputs, including sewage effluent and agricultural run-off, returning nitrogen and phosphates to food chains (English Nature, 2004). This is effectively natural tertiary sewage treatment and is a result of high metabolic activity and high mineralisation rates. This capability is due to the large mass of animals and plants in estuarine ecosystems, and is driven by sunlight and large quantities of nutrients entering and passing through the ecosystem (Davidson and others 1991; de Groot, 1992). The surface of mudflats plays an important role in nutrient chemistry. In addition, tidal movements circulate clean water and decomposers which increase the recycling capacity (de Groot, 1992). The integrity of the food web (eg the role of filter feeders) is critical in nitrogen cycling (Davidson and others 1991; Wilkinson and others 1997). Too much nutrient input causes eutrophication and anoxia, resultant breakdown of the foodweb, death of the saltmarsh and potentially erosion (Davidson and others 1991). Therefore inputs should be controlled through appropriate management (English Nature, 2005). Saltmarsh can also be a major source of nutrients to estuaries, via nitrogen fixation (Davidson and others 1991).

Habitats of conservation importance

Intertidal habitats include five BAP Priority Habitats, receiving high precedence for conservation action (UK BAP, 1995, 1999). All five BAP Priority Habitats are included in some coastal SSSIs, however, the current seaward limit of SSSIs to Mean Low Water mark precludes many examples of intertidal habitat. These habitats are also designated as Ramsar sites and SPAs (including 27 major saltmarsh sites and many smaller ones), and sites listed as a Priority Habitat on Annex 1 of the EC Habitats Directive have been approved as SACs (UK BAP, 1995, 1999). Estuaries for which the conservation value has been studied in great detail include the Humber estuary (Allen and others 2003), the Essex estuaries (English Nature, 2000), the Wash and the Solway and Cumbrian coasts. The latter have 10.5% of GB saltmarsh and 13.1% of UK mudflat area, support 13 SSSIs, NNRs, a Ramsar site and a SPA, and the Solway Firth is approved as SAC, plus there are numerous other wildlife and landscape conservation sites included (eg part of the Esk estuary is within the Lake District National Park, the Inner Solway Firth is an AONB, and there are National Scenic Areas (Scotland), Buck and Davidson, 1997). The estuarine habitat resource in Britain is greater than anywhere else in Europe (Davidson and others 1991) and there are many sites of international importance, including Maplin Sands, estimated to be the largest surviving continuous population of dwarf eelgrass in Europe (covering around 325 ha).

Inter-tidal habitats (including saltmarsh at high tide) provide spawning grounds and nursery habitats for economically important species such as bass and flatfish, and also for cephalopods. In addition, estuaries and seagrass beds act as safe refuges for many juvenile fish such as cod, herring, skate, and species of flatfish – many of them commercially important (UK BAP, 1995, 1999; Elliott and others 1990; Laffaille and others 2001; Stevenson, 2002). For example, juvenile Dover sole remain in the Tamar estuary for two years as a nursery area, during which time they seem to restrict themselves to a single mudflat, and are therefore susceptible to localised disturbance (Coggan and Dando 1988; Davidson and others 1991). Marine opportunists drift into estuaries as larvae from eggs spawned in coastal waters, and when young, take advantage of the rich benthic food sources (Little, 2000), before emigrating to the open ocean as recruits for adult populations (Stevenson, 2002). In addition to use by fish populations, saltmarshes around Britain support high densities of breeding birds with sometimes over 100 pairs per square kilometre (Davidson and others 1991). At least one-third of the British common seal population has recently bred on estuaries (Davidson and others 1991). The saltmarshes and associated dunes of the Inner Solway Firth (Cumbria/Dumfries and Galloway), and the Esk and Duddon estuaries are extremely important for natterjack toads, supporting about 50% of the UK breeding population (Davidson and others 1991; Buck and Davidson, 1997).

Intertidal habitats form vital links in the migratory route of birds and fish species, *eg* salmon and trout (Davidson and others 1991). Migrating waterfowl depend on the mosaic of mud and salt flats, saltmarsh and adjacent pools and pastures, for feeding, roosting, refuges in cold weather, moulting sites, and migrating staging areas (Davidson and others 1991). Saltmarshes act as high tide refuges for birds feeding on adjacent mudflats, and as a source of food for passerine birds particularly in autumn and winter (UK BAP, 1999). The Inner Solway Firth supports the entire Svalbard (Spitzbergen) breeding population of the barnacle goose (Buck and Davidson, 1997).

Use of these habitats for over-wintering is particularly important for birds and juvenile fish. In January over 1740000 waterfowl are present on British estuaries many with internationally important populations (Davidson and others 1991). Eelgrass beds provide an important source of food particularly for overwintering brent goose and wigeon. When this resource is exhausted the birds move on to saltmarsh vegetation and then on to arable and pasture (Rodwell and others 2000). The Humber estuary is a significant nursery area in winter for juvenile cod spawned off Flamborough Head in February (Rees and others 1988; Davidson and others 1991).

Association with species of conservation importance

There are 26 priority species associated with saline lagoons, coastal salt marsh and sheltered muddy gravels (Annex 1). Intertidal habitats support both characteristic fauna that is sedentary and also migratory species of birds and fish (Davidson and others 1991). Highly mobile sediments and varying salinity creates harsh conditions which require specific adaptations, therefore there are relatively few benthic species living in estuaries compared to freshwater rivers and truly marine habitats (Davidson and others 1991). Saline lagoons support a number of other rare species and lagoonal specialists (UK BAP, 1995). In sheltered muddy gravels the most diverse communities occur under fully saline conditions, although priority species such as the native oyster occur under reduced salinity (UK BAP, 1995). Mudflats especially support characteristic estuarine invertebrate animals notably crustacea, molluscs and worms, on which fish and waterfowl feed. Although species numbers are low, species biomass of these benthic species is twice as great as in freshwater and marine sediments (eg the laver spire shell snail can occur in densities of over 10,000 animals per m^2 (Davidson and others 1991). Ten nationally rare plants are entirely dependent on estuarine habitats (Davidson and others 1991). Tidal flats, creeks and lower saltmarshes support seven nationally rare and 10 nationally scarce species, whilst mid and upper saltmarshes support three nationally rare and nine nationally scarce species (Davidson and others 1991). Areas of high structural and plant diversity where there are transitions from fresh to brackish conditions, are particularly important for invertebrates (UK BAP, 1999).

High rates of primary production

Rates of primary production in intertidal habitats are often very high (eg Carter (1989) quotes net values between 500g and 1500g carbon per m per year). Dry live-weight varies from 153 to 2722 g per m^2 (Hussey and Long, 1982 and Davidson and others 1991). Estimates of gross primary production for the Dutch Wadden Sea totals an average of ca 1450g of organic matter (dry weight per m^2 per year), of which 750g is produced in saltmarshes and mudflats (de Groot, 1992). High productivity in the coastal margin provides the basis of energy for fishery production worldwide (Thom and others 2001). Productivity also allows salt marshes to be used as grazing land for sheep and cattle (eg Morecambe Bay, and around 2,130 ha on the North Norfolk Coast, Posford Duvivier Environment, 1996). In turn, grazing provides animal products. However, marketability of ‘saltmarsh lamb’ may potentially threaten saltmarshes with problems associated with overgrazing. Grazing of intertidal habitats by wildfowl reduces their impacts on adjacent arable land and associated loss of crops.

Regenerative services

Intertidal vegetation typically undergoes cycles of erosion and regeneration. Regeneration of saltmarshes is vital to all other services and products (Davidson and others 1991; Rodwell and others 2000; Bird, 2000).

2.4.2 Provisioning services

Food products

Intertidal habitats provide many fish (eg sea bass, eels etc.) and shellfish products (eg cockles, mussels etc.), though many of these activities are currently unsustainable. For example, clam dredging in Southampton Water has severely disrupted this habitat. Improved management of the coastal zone and fisheries by creating sanctuary areas may increase the long-term sustainability of the fishing industry (English Nature, 2005). The greatest biomass in estuaries is usually in mussel beds, (eg those on the Ythan estuary in northeast Scotland produce 268 g dry flesh weight per m^2 per year (Milne and Dunnet, 1972; Davidson and others 1991). Salmon are harvested as they migrate through estuaries on their way to freshwater breeding grounds (Davidson and others 1991). Many seaweed products are used in the food industry, however due to the highly competitive international market, relatively very little seaweed harvesting takes place today in Britain (Milliken and Bridgewater, 2001). Seaweed species used for food and condiments include purple laver, sea lettuce and dulse, tangle, knotted wrack, carrageen and alginates from brown seaweeds, however, these are associated more with rocky shores than intertidal sediment habitats (Indergaard and Østgaard, 1991; Sanderson and Prendergast, 2002). Marsh samphire (eaten as a salad plant, pickled, or boiled) has been commercially harvested for generations around the coasts of Essex, Norfolk and Lincolnshire and Morecambe Bay, though in 2002 Norfolk had no more than 100 samphire harvesters (Mabey, 1996; Posford Duvivier Environment, 1996; Sanderson and Prendergast, 2002).

Fibre and construction products

Few jobs are associated with the traditional exploitation of wild species for construction in intertidal habitats (Sanderson and Prendergast, 2002), although limited cropping of reeds does occur (eg North Norfolk coast, Posford Duvivier Environment, 1996). Other construction products associated with intertidal habitats include extraction of aggregates. Environmentally friendly practices are being promoted by Defra (http://www.defra.gov.uk/environment/waste/aggregates/delivery.htm#2b).

Medicinal and cosmetic products

Dulse, tangle, knotted wrack, and carrageen seaweeds are used to produce cosmetics (Sanderson and Prendergast, 2002). There are a small number of cottage industries in Scotland using local seaweeds in the production of medicines, health products and veterinary products (Sanderson and Prendergast, 2002). Brown seaweeds contain alginates, which have a range of applications in the pharmaceutical industry (Indergaard and Østgaard, 1991), however this is not currently supplied by UK sources (Sanderson and Prendergast, 2002).

Ornamental products and other products

Ornamental resources include white weed from Maplin Sands (for aquaria), sea urchins from the Isles of Scilly (English Nature, 2002b), shells and driftwood (English Nature, 2004). Other products of intertidal habitats include seaweed used for animal feed supplements and soil improvers (Sanderson and Prendergast, 2002). Alginates from brown seaweeds have a range of applications in the paper and textile industries (Indergaard and Østgaard, 1991), although not currently supplied by UK sources (Sanderson and Prendergast, 2002). Cropping of turf occurs at Morecambe Bay, and bait digging can be commercial, however, quantitative data for this activity is lacking (Gray, 1972; Posford Duvivier Environment, 1996; Rodwell and others 2000). Estuaries have a plentiful supply of water for industry (Davidson and others 1991).

Other natural coastal products

The coast also provides a resource for harvesting natural products which no longer have significant markets, but which remain very important as social products because they represent a particular way of life. These include the gathering of samphire, shellfish, baits etc., fishing and wildfowling. Recent conservation management agreements, such as at The Wash, have recognised these local rights (English Nature, 2002b).

Renewable energy sources

Intertidal habitats have the potential to provide tidal and wave power, however, to lessen the impacts on the coastal zone (and therefore be a sustainable energy source) these are generally positioned offshore, beyond the intertidal zone. For example, the world's first electricity generating tidal turbines are around 1.5km off the coast of Lynmouth, Devon.

2.4.3 Regulating services

Filtration of water

Saltmarshes filter, purify and disperse water flows from inland (Woodroffe, 2003). Intertidal sediments trap estuarine suspended particles, especially when they are colonized by plants (Widdows and others 2000; Abril and Borges, 2004). Filter feeding organisms also act to filter organic matter and pollutants from the water column (Wilkinson and others 1997).

Detoxification of water and sediments

During sediment deposition processes and the formation of mudflats, contaminants such as heavy metals and **radionuclides** are removed from the water column and trapped within the sediment (Covey and Laffoley, 2002), therefore sediments act as a sink for these pollutants. Processes involved include **coagulation** of heavy metals, which relocates and partly neutralises them (de Groot, 1992). Heavy metals and other pollutants are known to accumulate in plant tissues such as eelgrass in intertidal areas, trapping them and effectively preventing them polluting the habitat (Langston and others 1997). In areas receiving pollution, organic sediments sequester contaminants and may contain high concentrations of heavy metals (UK BAP 1995, 1999). Eelgrass is known to accumulate Tributyl, tin and possibly other metals and organic pollutants, which may become concentrated through food chains resulting in shellfish becoming unfit for human consumption (Davidson and others 1991; UK BAP 1995; Bradley, 1997; Covey and Laffoley, 2002). Therefore this is a service providing better water quality and ensuring safety of food products. However several heavy metals and organic substances have been shown to reduce nitrogen fixation, which may affect the viability of the plant, particularly in nutrient poor conditions.

Radionucides adsorb onto particle surfaces to some degree so that their distribution is linked to that of bottom sediments. Sediment type and geographical factors control radionuclide concentrations (Garland and others 1989). In estuaries, the high currents and rapid changes mean that tidal flats and marshes exchange sediment, water and porewater with the adjacent subtidal areas at tidal, fortnightly and seasonal timescales, ie sediment is only a temporary sink for pollutants (Abril and Borges, 2004). Therefore, to prevent eventual harm to intertidal ecosystems, input of toxins should ideally be limited to background levels (English Nature, 2005).

Degradation processes carried out by microbes living in sediment can be utilised in bioremediation of oil spills. This natural process can be more successful than artificial clean-up methods, although success depends upon many factors, including the tolerance of saltmarsh plant species (IPIECA, 1994; Hester and others 2000; English Nature, 2004).

Nutrient retention

Saltmarsh can act as a nutrient sink because nutrients are often associated with sediment, accumulating in a saltmarsh as sediment is deposited. This service removes nutrients from the water column where it may cause eutrophication. The nutrients are effectively trapped by tidal circulation and assimilate in the marsh. They may be transformed by chemical and biological processes or be taken up by wetland vegetation which can then be harvested and effectively removed from the system. Intertidal habitats also accumulate drift litter, which releases nitrogen that is then taken up in the vegetation. Sea rush saltmarsh communities normally have an appreciable accumulation of organic matter in the top 10-20cm of the soil and superficial litter trapping may be considerable (Rodwell and others 2000), and newly developing marshes generally accumulate nutrients (Boorman, 2003).

Carbon fixation and sequestration

Coastal margins are an important component of the oceanic carbon cycle due to high productivity rates and their coverage of the earth surface. Owing to large spatial heterogeneity, estimates of carbon and methane emissions from intertidal habitats suffer from large uncertainties (Abril and Borges, 2004). However this system is highly relevant to the global carbon budget, and to the effects on atmospheric carbon and global warming (Thom and others 2001).

Although carbon buried in sediments may be recycled and mineralized (the net mineralization of organic carbon from inner estuarine waters, tidal flats and marsh sediments leads to high CO_2 atmospheric emissions, 10 – 1000 mmol per m^2 per day, ie 44 - 44 000mg per m^2 per day (Abril and Borges, 2004)), globally, tidal marshes appear to be slightly autotrophic (Gattuso and others 1998; Abril and Borges, 2004). Therefore tidal marshes are generally a net sink of atmospheric CO_2 with a net burial of organic matter in the sediment (Gattuso and others 1998; Goni and Thomas, 2000; Delaune and Pezeshki, 2003; Abril and Borges, 2004). Estimates of rates of burial of carbon in coastal marsh systems vary widely, with 0.2 to 1 cm per year representing a range for most marsh systems. In the order of 25% of the mass of the accreting material may be organic (forming peat), with accumulation rates of ca. 4 gC per year (Thom and others 2001; Thom, 1992). Estimates of tonnes of carbon stored each year are subject to considerable uncertainty and are dependent upon sedimentation rates and area of mudflats and saltmarsh available. Modelling has shown that extension of the area of intertidal habitat may provide enhanced storage capacity (Shepherd and others 2005).

Global climate regulation

As a carbon sink (see Cycling Processes), absorbing and trapping excess carbon dioxide that would otherwise contribute to the greenhouse effect (see Cycling Processes), intertidal habitats help to slow global warming and climate change (English Nature, 2004).

Local climate regulation

The volume of water in intertidal habitats means that they regulate microclimates, particularly at high tide. Water absorbs heat and buffers the temperature of coasts, and vegetation of saltmarshes attenuates wind power. Relatively high evaporation from shallow coastal waters, saltmarsh pools and saline lagoons contribute to the global water cycle, and therefore is a critical link in supply of cloud cover and precipitation (de Groot, 1992).

Erosion control

Saltmarsh vegetation diminishes wave heights by up to 70% and wave energy by over 90% (Bird, 2000), and seagrass beds can reduce wave heights by up to 40% and wave energy by up to two thirds (Fonseca, 1996; Bird, 2000). This has positive implications for sea defence (see flood risk mitigation below). For example, waves only have 20% of their energy left 180m into open-coast marshes on the north Norfolk coast, (Moeller and others 1996; Shi and others 2000; Woodroffe, 2003). Studies have shown that the most rapid reduction in wave heights occurs over the most seaward 10 metres of permanent saltmarsh vegetation. Observed wave height attenuation shows a seasonal pattern which appears to be linked to the cycle of seasonal vegetation growth (Möller and Spencer, 2002).

Deposition and vertical accretion processes in upper estuaries and around salt marshes act to counter erosion processes (Pethick, 1984; Boorman, 2003). Accretion of material has been found to vary between depths of 0.5 and 10cm per year and at the higher rates approximately 5 m per ha per year of material is deposited, and may depend upon local climate, tidal pattern and the seasonality of flora (Ranwell, 1964; Bird and Ranwell, 1964; Ranwell 1972; Bird 2000; Rodwell and others 2000; Woodroffe, 2003). The Mersey estuary accumulated 68 million tons of marine-derived sediments between the 1960s and the 1980s. However there is a threshold to this process and excessive mud deposition rates can blanket and kill saltmarsh (Perkins, 1974; Pethick, 1984; Davidson and others 1991; Bird, 2000). **Sedimentation** increases with catchment soil erosion, channel dredging increase sediment in suspension, and where dredgings are dumped on or near marshes (Bird, 2000). Saltmarsh can spread rapidly (eg the estuaries of the Wash gained 47 000 ha of saltmarsh from sediment deposition over the past 1700 years (although landclaim and **coastal squeeze** also occur), Perkins, 1974; Pethick, 1984; Davidson and others 1991). Accretion rates increase when mudflats are sufficiently elevated to be colonised by vegetation (eg glassworts or cord-grass). This is due to the leaves and stems slowing currents at high tide, in addition to build up of plant litter building up (Pethick, 1984; UK BAP 1995, 1999).

Common cord-grass is very effective at trapping sediment and in some places can act as a pioneer plant as a precursor to saltmarsh, such as in the Dee estuary. It has been planted in the past as a method of stabilizing and land-claiming tidal-flats in estuaries (Bird, 2000; Rodwell and others 2000) including at least 39 estuaries in the UK (Davidson and others 1991), and in some places continues to expand by colonisation. Landclaim is a service in terms of protecting land from flooding to create new agricultural land, however it results in the loss of more valuable salt marsh and tidal feeding grounds for waterfowl (Davidson and others 1991). Land-claim has affected at least 85% of UK estuaries and about one-third of British intertidal habitat and half of saltmarshes have been claimed since Roman times (Davidson and others 1991, UK BAP, 1999). For example, enclosure of saltmarsh has led to 32000 ha of agricultural land being created in The Wash, and 4 340 ha in Essex and North Kent (Boorman and Ranwell, 1977; Davidson and others 1991; UK BAP, 1999). Intertidal flats and saltmarsh are in dynamic equilibrium (Davidson and others 1991) because eel-grass and cord-grass beds have cyclic expansion and die-back, exemplified by processes in Poole Harbour (Rodwell and others 2000; Bird, 2000). The complex interactions of cord grass with other species and the intertidal environment are described in Lacambra and others (2004). However, coastal squeeze has resulted in UK saltmarshes being lost to erosion at a rate of 100 ha a year (UK BAP, 1999).

Flood risk mitigation

Saltmarshes act as soft engineering sea defence by minimising impacts of storms by reducing wind action, wave attenuation (see above), and erosion control (see above) (Brooke and others 1999; English Nature, 2004). Use of saltmarsh in **managed realignment**, relieves the destabilising impacts of coastal squeeze on hard sea defences (eg Tollesbury in Essex) (UK BAP, 1999; Covey and Laffoley, 2002; Boorman, 2003). It has been recognised that in a number of circumstances working with coastal processes has greater benefits for society, the economy and the environment than hard engineering coastal defence (English Nature, 2005). For example, it has been estimated that an 80m depth of saltmarsh in front of the defensive structure can roughly save £4,600 per metre in additional wall protection (Empson and others 1997). The most effective use of saltmarsh for flood defence depends on biological characteristics of plant species used and may include engineering works designed to ensure physical conditions suitable for vegetation establishment, including offshore barriers and beach recharge (Brooke and others 1999; UK BAP, 1999).

With climate change increasing storminess and precipitation, along with sea level rise, will increase the importance of saltmarsh habitat for this buffering service will increase (Ramsar, no date). However the effects on coastlines remain speculative due to limited monitoring and the imprecision of available models (Bird, 2000). On coasts with wide bordering mudflats such as Bridgwater Bay, saltmarsh may well be maintained as the result of shoreward drifting of muddy sediment as the sea level rises (Bird, 2000).

Pollination

Several species of hoverflies, which are particularly important crop pollinators, breed on saltmarshes.

2.4.4 Cultural services

Preservation of archaeology

The intertidal zone is rich in archaeology such as wrecks and coastal settlements, reflecting Britain's maritime heritage (Roberts and Trow, 2002). Sediments preserve archaeological artefacts very well, such as Seahenge which was discovered in 1999 in Norfolk (Watson, 2004).

Education and scientific research resource

Scientific research will ensure an increased understanding of coastal and marine environments, their natural processes, the impact that human activities have upon them, how to minimise those that have an adverse effect and improve the quality of decision-making in intertidal habitats (English Nature, 2005). England's coast provides a very important educational resource for worldwide study of coastal processes, coastal defence, fisheries, waterfowl and ecology. Prime examples include Durlston Head, Lyme Bay, and Cleethorpes Discovery Centre. Thanet is used internationally as a resource for understanding the importance of seaweeds, and Morecambe Bay is extensively researched by Lancaster University and others (Posford Duvivier Environment, 1996). Observations of England's estuarine bird life provide information for global monitoring. Developing species indicators for ecosystem health can provide information on the integrity of the habitats to provide ecosystem services (Laffoley and others 2003). Research on the functioning of coastal ecosystems will be invaluable in proposed future marine spatial planning and in identifying Marine and Coastal Protected Areas (English Nature, 2005).

Gene bank for research and development of products

Coastal environments could also have possible pharmaceutical and genetic resources, with opportunities for cross-breeding and engineering (Posford Duvivier Environment, 1996; English Nature, 2004). For example, the skate and ray fish are being investigated for their anti-aging properties and the sea pink plant was once used in treatments for tuberculosis and leprosy, and is being investigated in the UK (Nash, 1998; Lewington, 2003).

Recreation and tourism

Promoting and encouraging the use of natural resources in a sensitive manner is seen as a useful strategy to ensure long-term environmental, social and economic benefits (English Nature, 2005). The natural coast provides people with a diverse recreational resource for fishing, walking, sailing, birdwatching, whale, seal and dolphin watching, boat trips, and wild fowling etc. Other activities such as water sports and angling may take place over the mudflats at times of high tide (eg Morecambe Bay, Davidson and others 1991 and Posford Duvivier Environment, 1996). Boat mooring takes place over mudflats in bays and estuaries, which negates the need for purpose built marinas that interfere with sediment movements etc. but may cause sediment disturbance (Davidson and others 1991). Wildlife attractions include wildfowl grazing and waders feeding and roosting on saltmarshes and mudflats, and seals hauling out onto tidal flats.

Physical health benefits and promotion of personal wellbeing

Recreation in coastal areas has physical health benefits and 'sea air' is often referred to as a tonic. Contact with nature is good for the mind and the tranquil wilderness of intertidal areas is an escape from busy lifestyles. In addition, quality of life depends on the health of our coasts and seas (English Nature, 2004).

Historical meanings and cultural importance

Many historical events have occurred in coastal areas, particularly given Britain's island heritage. Examples include the Norman landing at Pevensey and King John's disastrous crossing of the Wash in the mid 12^{th} century when he reputedly lost the crown jewels in the tidal flats (Davidson and others 1991).

People's appreciation of England's natural coastline is reflected in the very high desirability of many coastal residential areas. Our coastal environment has huge cultural and historic significance to a country whose economic base grew up on its seafaring activities. As an island nation the British people have a strong sense of identity with the coastal environment, with a rich maritime history and nautical heritage, fundamental to the national and cultural identity (Covey and Laffoley, 2002). These intertidal habitats are appreciated as an atmospheric and desolate landscape, providing a resource for artistic inspiration. Examples include the artistic community that has developed in North Norfolk in recent years, the St. Ives painters, bird artists such as Scott and Tunnicliffe, and novelists such as Du Maurier, Stevenson, Buchan and E.M. Forster. Du Maurier features estuaries as places of haven and romance, whereas other literature describes estuaries as wild and thrilling landscapes as well as awesome places (eg Dicken's Great Expectations, Davidson and others 1991). Habitats such as salt marshes have spiritual and cultural values, related to religion and folklore (English Nature, 2004).

2.5 Terrestrialised freshwater wetland habitats services and goods

Terrestrialised wetlands are habitats with a permanent or periodically high water table, excluding open water, ranging from wet grassland to **swamp** vegetation. BAP Priority Habitats included in this ecosystem type are lowland raised bogs, **blanket bogs**, purple moor grass and rush pastures, fens, reedbeds and coastal and floodplain grazing marsh (UK BAP, 1995; 1999). There are also interfaces with other groups of habitats through wet woodlands, wet heath, wet grassland, brackish areas and sand dune slacks.

Table 2.4 Location and extent of BAP Priority Habitats included in Terrestrialised freshwater wetland habitats (UK BAP, 1995; 1999).

Habitat	Estimated extent in England unless stated otherwise
Lowland raised bogs	500 ha
Blanket bog	Uplands. Figures for the extent of blanket bog vegetation are currently under review in the Upland Inventory. England has some 215,000 ha of blanket peat soil (in the main >0.5 m deep). However significant proportions of peat soil, probably in excess of 10%, no longer support blanket bog vegetation *i.e.* do not provide the ecosystem services of blanket bog
Purple moor grass and rough pasture	5281 ha. Culm measures, Dartmoor and the Blackdowns
Fen	The calcareous rich fen and swamp of Broadland covers an area of 3,000 ha, however total extent of different types of fen are currently not known. Different types of fen have geographical strongholds. Groundwater-fed valley fens are common in north-east Norfolk, Anglesey, the New Forest and further west in England. Basin fens are frequent in lowland Cumbria, the West Midlands, and parts of Norfolk. Floodplain fens are widespread, but best represented in the Norfolk Broads and other scattered locations.
Reedbed	6,500 ha in Britain (mostly in England).
Coastal and floodplain grazing marsh	200,000 ha, however only 5,000 ha is semi-natural supporting a high diversity of native plant species

2.5.1 Supporting services

Production of oxygen

Although all vegetation produces oxygen as a by-product of photosynthesis, healthy wetland systems are a net source of oxygen production, with oxygen production exceeding consumption. For example, a shallow water wetland (pond) measured by Odum (1971) had a gross production of 8grO_2 per m^2 per day and a community respiration of 6grO_2 per m^2 per day, leaving a net oxygen production of 2grO_2 per m^2 per day.

Nutrient cycling

Nitrogen fixation is a vital link in the nitrogen cycle, returning atmospheric nitrogen to the soil/plant system and consequently increasing productivity. In wetlands nitrogen fixation is carried out by microorganisms that can convert atmospheric nitrogen into ammonia and often form symbiotic associations with wetland plants. Flooding increases soil's capacity to fix nitrogen biologically. This is because blue-green algae living free or in association with water fern thrive in the floodwater and on the soil surface, aerobic nitrogen fixers function at the aerobic-anaerobic interface in the soil and anaerobic bacteria flourish in the anaerobic layers of soil (Ponnamperuma, 1984).

Excess nutrients such as nitrogen and phosphorus cause problems in the eutrophication of waterways and, in the case of nitrates, cause problems with drinking water supplies. These are derived from sewage effluent and fertilizers (Fink and Mitsch, 2004). Wetlands, particularly reedbeds, provide a service by retaining nutrients and treat sewage as effectively as sewage treatment works. This is by transporting oxygen to the root zone through the thick root-mass. Oxygenation aids microbial digestion, developing a complex microbial population, which competes with and eliminates human pathogens and removes organic nutrients. Horizontal reedbeds are particularly useful for denitrification, which completes the nitrogen cycle (http://www.ecoflo.ie/howreedbedswor.php). Denitrification, removing nitrogen from the system, in flooded water meadows has been measured at 430-460kg N per ha per year in sandy soils where water infiltration is greater, and 220kg N per ha per year in peaty soil, however these values depend on the nitrogen loading of flood waters (Davidsson and Leonardson, 1998). For example, Seffer and others (2000) reported that the Morava floodplains (Slovakia/Austrian border) remove around 430t of nitrogen per year making the restoration of lost wetland area most cost-effective way of reducing nutrient loads in the Danube.

Wetland processes assist in soil formation and increase soil fertility by slowing the passage of water and encouraging the deposition of nutrients and sediments. This nutrient retention makes wetlands among the most productive ecosystems recorded, rivalling intensive agricultural systems (Costanza and others 1997). Traditional land management of grazing marsh and water meadows includes warping. This can enrich and improve the agricultural productivity (soil fertility) of the land (Sheail, 1971; Mayled, 1998). Peat soils form because uninterrupted water availability continually produces organic matter and soil bulk accumulates due to slow decomposition rates in anaerobic waterlogged conditions (Ponnamperuma, 1984).

High rates of primary production

Wetlands can be very productive which is why they have such a large number of products associated with them and why they are vulnerable to drainage for arable land use. Studies have shown that above ground primary production in wetlands such as peat bogs, fens, and sedge meadows can be as high as 1,026g per m^2 per year. Many floodplain grazing marshes produce hay and silage (UK BAP, 1995), and spring flooding of grazing marsh can increase production rates by warming the soil, inducing early growth, a process utilised in water meadow systems (Sheail, 1971; Mayled 1998). However the productive soils of wetlands are attractive for agriculture and therefore are vulnerable to drainage for arable land use.

Habitats of conservation importance

Terrestrialised wetlands include six BAP Priority Habitats in the UK, receiving highest precedence for conservation action (UK BAP, 1995, 1999; Newbold, 1998). All six Priority Habitats include sites designated with statutory protection such as SSSIs, NNRs, SPAs, SACs and Ramsar sites (UK BAP 1995, 1999; Sanderson and Prendergast, 2002). The UK is thought to host a large proportion of the fen surviving in the EU (UK BAP, 1995). Blanket bogs are an important habitat for a wide range of species including internationally important populations of breeding waders (English Nature, 2001c).

Terrestrialised wetlands can be extremely species rich. Fens in particular include a diverse range of habitats with a variety of vegetation types according to the topographical situation of the fen (eg whether it occurs in a floodplain, valley, water-fringe, basin or at a spring) the water source (eg ombrotrophic, surface water, ground water) and the water chemistry (nutrient rich or poor, base rich or poor). Fens can contain up to 550 species of higher plants (a third of our native plant species); up to and occasionally more than half the UK's species of dragonflies, several thousand other insect species, as well as being an important habitat for a range of aquatic beetles (UK BAP, 1999). Fens are an ideal habitat for small mammals supporting a diverse assemblage and are particularly rich in shrews (Perrow and Jowitt, 2003). Over 400 vascular plants have been recorded at Wicken fen (Mountford and others 1996), as well as some 121 species of Red Data Book invertebrates (Friday, 1999; http://www.wicken.org.uk). Although less species-rich, complex microtopographical mosaics in bogs and the variety of habitats associated with grazing marshes and purple moor grass and rush pastures, mean that these habitats host a diversity of species assemblages, enhancing biodiversity of the habitat as a whole (UK BAP, 1995, 1999).

Reedbeds support a distinctive breeding bird species assemblage including six nationally rare Red Data Book birds (UK BAP, 1995; Townsend and others 2004), and are also important breeding grounds for amphibians (Millet, 1997). Grazing marshes are particularly important for the number of breeding waders (UK BAP, 1995). Blanket bogs also support important densities of breeding populations of birds (eg Thorne and Hatfield Moors in South Yorkshire) (UK BAP, 1999).

Water birds particularly make use of wetlands during migration (Wetlands International, 2002), using wetlands for feeding, roosting, and sheltering from adverse weather. For example, reedbeds provide roosting and feeding sites for migratory species including the globally threatened aquatic warbler (UK BAP, 1995), and serve as pre-migration roost sites for swallows (Millet, 1997).

Grazing marshes are important over-wintering habitats for internationally important bird populations because the range of sward heights and frequent winter and spring flooding provides ideal feeding conditions (UK BAP, 1995; Townsend and others 2004). Reedbeds are used as roost sites for several raptor species in winter (UK BAP, 1995), and small populations of wintering birds of prey also hunt over the open moorland including blanket bog (Millet, 1997).

Association with species of conservation importance

There are 78 priority species associated with these wetland habitats (Annex I). Important or protected species include mammals, birds, plants and invertebrates (UK BAP 1995, 1999; Wiggington, 1999). Insectivorous plants overcome the nutrient deficiency of ombrotrophic bogs by adaptations to trap and digest insects. Seasonal pools in wetlands are home to a distinctive community of unusual plants and animals and contain approximately one quarter of protected wetland plants, and more than 40% of rare plants (Vines, 1999). Blanket bogs and their associated pools support a specialised flora and fauna, including a number of rare and scarce invertebrates (English Nature, 2001c).

2.5.2 Provisioning services

Food and drink products

Production enables Blanket Bogs to be used for rough grazing, although this is generally not required to maintain the habitat, as is the case in Coastal and Floodplain Marsh. These grazing activities produce meat and other animal products.

Fibre and construction products

Reeds are used as a thatching material as they are resistant to decay and a well-thatched roof can last for many years (Millet, 1997). Some 365ha of reedbed are harvested in England, predominantly from Norfolk and Suffolk (Rayment, 1995). The popularity of thatched roofs is increasing (Hawke & José, 1996, Collins and others 2004) and it is estimated that UK production would need to increase by approximately 1.5 million bundles per year in order to meet all domestic demand (Sanderson and Prendergast, 2002). Due to its flexibility, saw-sedge is used as a thatching material for the ridges of thatched roofs (Friday, 1997), and is currently harvested commercially on the Cambridgeshire and Norfolk Broads fens (Sanderson and Prendergast, 2002).

Medicinal and cosmetic products

Wetland species have been extensively used in the medicinal industry (Constanza and others 1997), for example the white willow was the original source of compounds used in the pain-killing drug aspirin (Lewington, 2003). The medicinal leech is applied to reduce blood pressure and to restore blood circulation following tissue grafts. In addition, leech saliva contains antibiotics and anticoagulants that may prove useful in surgery (de Groot, 1992).

Ornamental products and other products

Traditional crafts and industries are undergoing a growth in popularity (Collins and others 2004). Other reed products are garden screens and wind breaks, and reed seed harvested for the propagation of plants used for wastewater treatment (Sanderson and Prendergast, 2002). Club rush is used for plaiting and weaving to produce rush-panelled screens, lampshades, floor matting, bags and shoes and as a sealant in whisky casks (Sanderson and Prendergast, 2002). Potentially **fen litter** can be used as a general soil improver, an ingredient in a blended organic growing medium and as pet bedding (Andrews, 2000). Marsh hay is harvested commercially on the Norfolk Broads (Marren, 1994; Sanderson and Prendergast, 2002) and provides a low quality fodder (Andrews, 2000).

Renewable energy sources

Although peat can provide a source of fuel (eg in Ireland peat resources provide approximately 8% of the country's commercial energy demand, de Groot, 1992), this is not renewable and therefore is an unsustainable energy source and releases carbon into the atmosphere contributing to global warming. Fen litter has a calorific value similar to wood (Andrews, 2000) and the viability of marketing fen litter biofuel (eg in a gasified form or briquetted) has been identified by The Broads Authority (Andrews, 2000). A small market already exists for wood chip biofuel (Dickie, 2001).

Regenerative services

Flood drift through wetland habitats can provide and transport propagules within and between habitats, which is particularly useful for regeneration in fragmented landscapes (Cellot and others 1998). Invertebrates which breed in wetlands, such as drone flies, provide vital pollination services in other habitats.

2.5.3 Regulating services

Filtration of water

Wetlands act as natural filters, providing valuable supplies of clean water fit for human use. Water extracted from reservoirs with active blanket bog catchments has less discolouration than water from upland catchments with degraded blanket bog. Discoloration is expensive and difficult to remove, a problem being tackled by the Moors for the Future Partnership (http://www.moorsforthefuture.org.uk). Wetland vegetation can bind and filter sediments, clearing fine sediments and particulate matter from the water column. There is also some evidence that vegetation can 'scavenge' sediment directly from flood waters (Merritt, 1994; Brown and Brookes, 1997). This improves water quality downstream from the wetland.

Detoxification of water and sediment

The net storage of fine sediment in wetlands leads to toxicant retention. High levels of nutrients are also toxic, however, wetlands can be used to improve the quality of water returned to the environment after human use or subject to diffuse water pollution, and to improve the potability for human consumption. Excess nutrients can be stored or transformed in wetlands, therefore reedbeds and constructed wetlands can be used to treat sewage, chemical outflows, industrial waste and other pollutants (see Cycling Processes). Reed bed schemes are a cost effective and sustainable form of sewage treatment (Merritt, 1994; http://www.ecoflo.ie/howreedbedswor.php). One of the most effective species for treating contaminated water is club rush (Speight, 1995). Groundwater draining large intensively cultivated catchments collects diffuse dissolved nutrient pollution from a range of sources including agricultural fertiliser such nitrates and phosphates. This water is often received by natural fen systems in which vegetation effectively removes the pollutants by taking them up via roots (eg in common reed) or shoots (eg in rigid hornwort) (Mainstone and others 1993).

Freshwater flowing through wetlands aids in the dilution of pollutants and helps to keep water quality parameters at levels safe for humans, fish and other aquatic organisms. Without this natural dilution service the economic cost of keeping water pollution at tolerable levels would greatly increase (Daily, 1997).

Heavy metals can accumulate in wetland plants having been taken up by the roots, effectively trapping them in the wetland system (http://www.ecoflo.ie/howreedbedswor.php). Some wetland plants (eg water hyacinth and some reedmace and reed species) have been found to accumulate heavy metals in their tissues at 100,000 times the concentration in the surrounding water, thus detoxifying certain kinds of effluent (Costanza and others 1997).

Carbon fixation and sequestration

All plants fix carbon from the atmosphere and peat forming wetlands sequester carbon, acting as valuable carbon sinks and helping relieve the process of global warming (see Regulation and Stabilisation). Plants absorb carbon dioxide during photosynthesis and subsequently release this carbon back into the atmosphere when plants die and decompose. Anaerobic, waterlogged conditions slow decomposition of plant material, which leads to an accumulation of peat, in which the carbon is retained and stored (Ponnamperuma, 1984; UK BAP, 1995, 1999). For example, in Northern Ireland peatlands cover only 12% of the land area but account for 53% of the soil carbon pool. Deep lowland raised bogs were found to have stored carbon levels in excess of 5000tonnes per ha (http://www.peatlandsni.gov.uk). A catchment scale study by Worrall and others (2003), incorporating fluvial export of carbon in the carbon budget estimation, showed that upland peat in the North Pennines represented a net sink of 15.4 ± 11.9 gC per m^2 per year and estimates for the carbon budget of all British upland peat suggests a net carbon sink of between 0.15 and 0.29MtC per year. It is estimated that wetlands may act as carbon sinks for as much as 40% of global terrestrial carbon. Although covering only 3% of the world's surface, peatlands are estimated to store over 25% of the soil carbon pool (Costanza and others 1997). In UK lowland raised bogs the thickness of the peat varies but can exceed 12 metres. In blanket bogs the depth of peat is also very variable, with a typical average of 0.5-3 m but depths in excess of 5m is not unusual (UK BAP, 1999).

However, active raised bogs release methane into the atmosphere and climate change may increase the rate of release. This is the second most important greenhouse gas after carbon dioxide contributing to around 10% of the UK's total emissions of greenhouse gases in 1990. It has 21 times more potential for global warming than that of carbon dioxide over a 100-year time horizon. However, it has a relatively short turnover rate of 12 years in the atmosphere and reductions in total emissions result in a rapid reduction in atmospheric concentration (Defra, 2000). Drainage of wetlands and extraction of peat also releases carbon into the atmosphere, so maintenance of peatlands in their natural state is likely to have a beneficial effect on the carbon sequestration service provided.

Global climate regulation

Peat formation (see Cycling Processes) and the benefits associated with accumulating and maintaining a carbon store are truly global. This is due to implications for global warming mitigation, and hence has considerable economic benefit (Coles, 1995; UK BAP, 1999)

Local climate regulation

Wetlands assist in the stabilisation of local climatic conditions, particularly rainfall and temperature moderation by the volume of water (Bardsley and others 2001). Evapotranspiration from wetlands makes an important contribution to the water cycle (Busch and Lösch, 1999).

Erosion control

Wetland vegetation reduces wind, wave and water current action, and protects the land from storm surges. The roots especially help to hold the sediment in place (Costanza and others 1997), helping to ensure shoreline stabilisation and erosion mitigation by reducing the impacts of wave action and water movements on riparian and coastal land (Bardsley and others 2001).

Flood risk mitigation

Wetland habitats aid the process of flood alleviation by storage of floodwater lessening peak floodwater flow and slowing water discharge rates following severe storm events. This is by functioning as natural reservoirs storing water in their soils or on the surface, reducing runoff and releasing water gradually. Therefore this service of naturally operating floodplains alleviates flooding and reduces the need for expensive engineering structures (Merritt, 1994; English Nature, 2001b). It is particularly important given that around 5 million people are at risk of flooding in England and Wales. Washlands are semi-natural floodplain habitats that are deliberately designed for flood control purposes, and are used during times of high flow to reduce flooding in other parts of the catchment. Examples where washlands are used for flood defence are the River Calder, W. Yorkshire; the River Witham, Derwent Ings on the River Derwent in East Yorkshire, River Trent and Beckingham Marshes in Lincolnshire, and the Nene and Ouse washes in Cambridgeshire (English Nature, 2001d). Using the actively managed washlands approach to mitigate flooding represents a fully integrated, economically robust, living and sustainable water system (English Nature, 2001b).

Maintenance of surface water stores

Wetlands contribute to the maintenance of surface water stores by retention and slow release of water, and upward seepage and discharge of ground water through wetlands such as fens. For example, during dry weather, peatlands provide a more reliable supply of water than many mineral soils. The top peat layers (to around 40cm depth) interact with the local water movement and hydrologists believe that it can slow water movement. This means that in their natural state peat bogs typically contain 85-95% water, held in *Sphagnum* mosses, with the ability to store water into summer (UK BAP, 1999). Blanket bogs cover large catchment areas for important reservoirs. Storing water in peatlands may become even more important in the future if predicted climate changes, including increased rainfall in Western Europe, occur.

Groundwater replenishment

Goundwater recharge may be fulfilled by wetlands, which detain water allowing infiltration into aquifers (Tiner and Burke, 1995). The groundwater store helps to maintain the flow or level of surface water bodies during the dry season when surface run-off is not available. This is important in maintaining the water table in the soil and to keep soils saturated, and to maintain habitats that depend on high groundwater levels. Maintenance of groundwater near the coast also prevents saline intrusion, which has potential impacts on water extraction and productivity of arable land.

2.5.4 Cultural services

Paleo-environmental data source

Peatland environments are important historical archives that act as extremely sensitive indicators of environmental change since the last glaciation. They preserve environmental datable deposits of pollen, invertebrate remains and atmospheric deposits such as volcanic ash from which it is possible to assess historical patterns of vegetation and climate change (Long and others 1999; UK BAP, 1999; Langdon and others 2004). This information is of international significance and could possibly assist in predicting future climate changes. Peat accumulation also preserves a unique and irreplaceable archive of plant and animal remains due to slow decomposition in the anaerobic environment (English Nature, 2001c).

Preservation of archaeology

Peat soils are renowned for preserving the organic and inorganic remains of settlements, including tombs, farms, trackways, implements and bog bodies (with important genetic material). Complete upwards time sequences of deposits can only be guaranteed in ombrotrophic bogs (lowland and upland) as fens may have experienced periods of erosion and redistribution of sediments. Examples include Stonea Camp in Cambridgeshire (an Iron Age fortification), the Sweet Track in Somerset, Lindow Man in Cheshire and Shapwick Heath NNR in south west England where records of human activity were found dating back to circa 4000-500 BC (English Nature, 2002a). Such finds generate considerable public and media interest.

Education and scientific research resource

There are many wetland education centres (eg Slimbridge WWT, SW England, Martin Mere WWT, NW England) that provide the general public and school children with a better understanding of the functions and values of wetland ecosystems, biodiversity issues and other environmental matters. Wicken Fen NNR is amongst the best-studied nature reserves. Important work that has been carried out at Wicken Fen includes the relationship between cropping cycles, hydrology and the natural processes of fenland succession, in determining the structure of vegetation (Friday and Colston, 1999). Pan-European research is continuing into utilising wetland functioning for the benefit of water quality (Maltby and others 1998). In addition, Britain is a 'type' location for Blanket bogs, a globally rare habitat, therefore the UK holds an international responsibility for their conservation. These bogs are highly valued internationally for ecological research. The value of scientific research lies in the utility of information obtained, such as indicators of pollution or climate change.

Gene bank for research and development of products

Continued studies of the peat bog environment may lead to an increased knowledge of the uses and potential medicinal benefits of native plants. For example, bog myrtle was under development in the 1990s as a midge repellent (Simpson and others 1996; Nash, 1998).

Recreation and tourism

The natural beauty and diversity of animal and plant life make wetlands ideal locations for ecotourism, and form the basis for important recreational and tourist economies. Many wetlands protected as National Parks, Ramsar Sites or designated protected sites are able to generate considerable income from tourist and recreational uses, such as boating, birdwatching and fishing.

The revenue derived from recreational activities involving consumptive use of a wetland area (eg fishing and wildfowl shooting) can provide substantial contribution to local economies through club membership subscriptions (Murray and Simcox, 2002).

Physical health benefits and promotion of personal wellbeing

The psychological effects of urban living identifies that visiting 'wild' places is good for mental health. Wetland landscapes offer opportunities for public enjoyment of the countryside, tranquility and a link with nature (English Nature, 2001b; English Nature, 2002b).

Historical meanings and cultural importance

In a preliminary survey of world Ramsar sites, over 30% of a sample of 603 recorded some religious, historical, archaeological or cultural significance at the local or national level (Constanza and others 1997). For example, the Mosslands of the Mersey Basin were a barrier to development of the railways during the industrial revolution, fen habitats in East Anglia have strong cultural resonance and the Somerset Levels and Moors has attained the status of Cultural Landscape through many years of management by farmers, drainage boards, and other local and national agencies. Folklore has developed around wetland species such as the attractive snake's head fritillary plant species (Oswald, 1992). The aesthetic properties of wetlands such as unique landscapes that have inspired the work of artists (eg 'The Wind in the Willows' by Kenneth Grahame and Waterland by Graham Swift, English Nature, 2001b; English Nature, 2002b). Also the nature of wetland habitats provides characteristic sounds (eg calls of curlew and red grouse on upland bogs). Meadows in particular evoke appeal and have inspired artistic works (Marren, 1995).

Traditional management techniques have been preserved in the difficult conditions of wetland environments. For example, in wetlands the reed cutting and thatching industry has continued and is undergoing a revival (Collins, and others 2004). Also the historical practice of winter flooding to replenish nutrients particularly phosphorus is now being viewed as an alternative to artificial fertiliser (Sheail, 1971; Mayled, 1998).

3 Valuing ecosystem services: approaches and issues

This section sets out the possible approaches to valuing ecosystem services and recommends broad classes of technique for each service type. Examples from the valuation literature are provided to illustrate the options and issues. Section 3.1 begins by setting the context for valuation, highlighting factors other than ecosystem service type that will contribute to the choice of valuation technique. Section 3.2 provides a brief overview of the techniques available and touches on some broader evaluation considerations, such as identifying the relevant stakeholders or affected populations. One of the main shortcomings of any evaluation exercise will be lack of available scientific data, which in turn will affect the certainty that can be attached to valuation results. This section also highlights the inherent uncertainties attached to the use of valuation results, specifically where benefits transfer is involved. Section 3.3 contains the discussion of technique by service type providing examples from the economic valuation literature, and finally Section 3.4 sets out the main issues and opportunities in taking forward research in this area.

3.1 The policy and appraisal context

3.1.1 General economic considerations

The valuation of ecosystem services cannot happen in a policy vacuum. While the total economic value framework is useful in understanding the full range of values produced by ecosystems, it makes little sense to estimate the total economic value of an entire ecosystem as this would be infinite. The appropriate use of economic valuation is one which is focused on **discrete and measurable changes**, such as the implications of losing half the area of a woodland ecosystem or doubling nutrient inputs to a wetland. It is also impractical from the standpoint of designing and undertaking an economic valuation study to measure value in the absence of a context, such as a credible threat or policy choice. The distinction here essentially boils down to valuing a stock, ie an ecosystem, versus valuing a flow, ie services. In valuing a stock, say of the world's wetlands, the marginal value of the last units of that stock will approach infinity as the stock declines. The marginal value of another wetland therefore depends on the size of the remaining stock. However, it still stands that the total value of the stock is infinite.

In framing the policy question to be answered by the overall appraisal, the appropriate approach is one in which both **'with' and 'without'** (or 'policy-on' and 'policy-off') scenarios are developed. For example, what is the stream of benefits and costs if we preserve, say, 10 hectares of a forest versus if we convert it for agriculture? The difference in the state of the world between the with and without scenarios identifies the change in ecosystem services that is to be valued. This framework applies equally to both the scientific (identification of services affected) and economic (valuation) stages of the analysis. When applied to the economic analysis the difference between the 'with' and 'without' scenarios is equivalent to the incremental net benefit (or net cost) of the policy decision. In fact, this 'with and without' principle is the basis of cost benefit analysis. This process is presented in more detail in Section 3.1.2.

Approaching the valuation of ecosystem services in this way is particularly useful in illustrating an important distinction about the value of ecosystem services. Namely, that ecosystem services contribute to economic welfare in two ways – through contributions to the

***generation* of income and well-being**, and also through the ***avoidance* of damages** which inflict costs on society. The former recognises positive contributions to production processes, such as acting as a wastewater treatment facility or providing for soil fertility. The latter is characteristic of certain ecosystem services that provide insurance, regulation and resilience functions, as is explored in the section below. The latter also recognises that damage to these services entail costs. In turn, the benefit of any action that reduces such damage is equal to the avoided costs. Both types of contribution to social welfare should be accounted for in any policy-making decision, and both may entail using a mix of techniques where market data is combined with non-market data in order to capture the range of economic benefits provided by each service.

The allocation (or re-allocation) of limited resources is inherent in any policy choice. The advantage of economic appraisal tools, such as economic valuation, is that the trade-offs between competing uses of resources can be made explicit and compared using a common unit, ie in monetary terms. Economic valuation measures not only the direction of the preferences of different stakeholders, but also the strength of these preferences. Thus, the decision about whether to convert or conserve an ecosystem can be informed by measuring and valuing the benefits and costs to the various **stakeholders** – or **winners and losers**. Economists would advocate a decision where the benefits outweigh the costs, or the winners can compensate the losers and still be better off. Failure to adequately identify the affected population will result in an incomplete picture of the benefits of ecosystem services.

Recognition of the complex interactions between an ecosystem and the wider environment is necessary for establishing the **spatial scale** of reach of services and hence the appropriate population (or beneficiaries) to identify, and the nature of these impacts. As mentioned in Section 3.1.4 below, an ecosystem function in England can have effects on the other side of the globe. Identifying the nature and extent of these impacts is a matter first for the scientific assessment and then for the economic analysis. In most cases it will be very difficult to assess that extent, but the first step – of identifying the existence of an effect – should be a useful input to the decision-making process.

The impact of an ecosystem service, which in some geographical locations is positive may be negative in a different location. For example, the water retention ability of certain woodlands, which in some areas may be considered a benefit, may lead to losses in areas further downstream where low flow in rivers is an issue. The existence or expansion of woodlands may exacerbate the low flow problem resulting in loss of river-based recreation, amenity, adverse impacts on river-based species and their diversity and possibly increased cost of drinking water supply due to the need to find other sources of water. Taking account of location specific factors is important, especially where values are transferred from different contexts (see benefits transfer discussion in Section 3.2.3).

3.1.2 The impact – pathway approach for ecosystem services

Before embarking on a description of all of the possible techniques for valuing ecosystem services, it is important to step back for a moment and examine the larger picture. Section 2 of this report undertook to catalogue ecosystem functions and services, by focusing on how these services contribute to human welfare. The catalogue of services produced (Table 2.1) provides a useful checklist for any decision-maker setting out to estimate the total economic value of a particular ecosystem or the value of impacts arising from a decision regarding an ecosystem.

In order to assess the economic value of those services, the following steps of analysis should be applied to each service (following the simple pathway set out in Figure 1.2).

A General Note that applies to all of the following steps: In undertaking this analysis, consideration needs to be given to the potential overlaps, complementarities and potential conflicts between services and how these impact upon economic endpoints. This is to ensure that there is no double counting where services combine to produce the same economic benefit or to avoid including the benefits of two competing or mutually exclusive services.

1. *Assess which services are provided by the ecosystem in question*

   This is a mainly qualitative assessment that involves establishing the spatial scale of reach of services and potentially affected populations by comparing what's on the ground with the service catalogue in Table 2.1. Some examples:

   - The wetland provides flood control services for the catchment area, which is densely populated.
   - There is a major river adjacent to the woodland that receives erosion control services from the woodland.
   - There is no air pollution being filtered by the forest.
   - There is no wastewater or other pollution being filtered by the wetland.

2. *Determine the **extent** to which the ecosystem provides that service, and how the service would be affected were the ecosystem to be removed ('the with and without scenario'). Alternatively, if the policy decision implies a specific discrete change (eg loss of x hectares), determine how this change would affect the service.*

   This is a quantitative assessment, and may require the use of modelling to answer the question satisfactorily, or may just require expert judgement based on past experience. Some examples:

   - About 80% of all rainfall and runoff is captured by the wetland and released slowly. If the wetland were to be drained for development local stream and river levels would rise by 0.5m during heavy storms.
   - In the absence of the woodland along the river banks, it is estimated that sedimentation would raise the river bed by 1ft annually, and that water quality would be reduced by a GWQ level from good to poor, with resulting impacts on the ecological health of the river along a 20 km length, possibly endangering the survival of a priority species of crustacean.

In assessing the extent of provision of ecosystem services, it is also important to take note of the capacity of the ecosystem to provide services. What is the threshold at which, for example, the ability of a wetland to act as a nutrient sink is overloaded and leads to adverse effects?

3. *Identify the potential benefit to society of this contribution*

   This entails identifying the groups of people in society who benefit from ecosystem services (or will be suffering a loss when they are removed, degraded or destroyed), and how each are affected by the provision of the services or would be affected by the changes to this provision. Some examples:

- Of the four villages that are at risk from flooding if the wetland were to be drained, it is likely that 30% of dwellings and businesses would flood to at least 2 ft once every 5 years. This will result not only in financial loss in terms of damage, but in pain and suffering inflicted by the flood on residents.
- Multiple uses of the ecosystem services of a river could include the following, which would all be affected by a change in these services (albeit to different extents): (1) The river is sourced for drinking water and increased sediment in the river will increase treatment costs to water companies and customers, (2) the river is also used for navigation, which over time will require increased dredging to remove excess sediment with environmental and economic costs associated with dredging, (3) the river is used for recreation and contributes to the landscape value of the area, thus a decline in water quality will reduce the value of recreational experiences, and (4) residents of the UK and future generations may suffer from the loss of an endemic species.

4. *Estimating economic value, where feasible*

This entails employing one or several of the economic valuation techniques listed in the next section in order to estimate the possible values attributed to ecosystem services by different groups in society. It should be noted that it is not always possible to estimate all economic values associated with a single service or a single resource that provides a multitude of services. However, this step of the analysis is implemented on the basis that 'any number is better than no number'. Some examples:

- The financial damage costs of flooding can be estimated, as well as the residents' willingness to pay to avoid pain and suffering from flooding.
- Financial costs of water treatment and dredging can be estimated, as well as resident and visitor willingness to pay to avoid (or willingness to accept to tolerate) the multitude of effects of decline in river water quality.

While the above analysis is straightforward in principle, in practice there are many uncertainties and missing data and links at each step. In fact, the examples provided here demonstrate that an economic analysis is only the last stage of an often very detailed qualitative and quantitative impact assessment. The examples also show how one service may give rise to a number of different benefits and provide for different beneficiaries. What the examples are not able to show is how several services may contribute to the same benefit and as mentioned at the outset this needs to be monitored throughout the assessment to avoid double-counting when adding up across different services.

Double counting pitfalls also arise in the application of economic values and are most likely to be an issue when using benefits transfer, ie when using the results of existing studies to estimate the value of ecosystem service changes in a new assessment (see Section 3.2.3). This type of double counting is addressed further in Section 3.4, and can be avoided through careful study of the literature used for benefits transfer or careful design of new valuation studies where original work is commissioned.

Figure 3.1 sets out to illustrate the interactions between services and their endpoints, using a few wetland functions as an example. The list of impacts/effects is incomplete and so is the list of benefits. The figure is for illustration of the complexity of the interactions rather than to provide a full picture of these interactions.

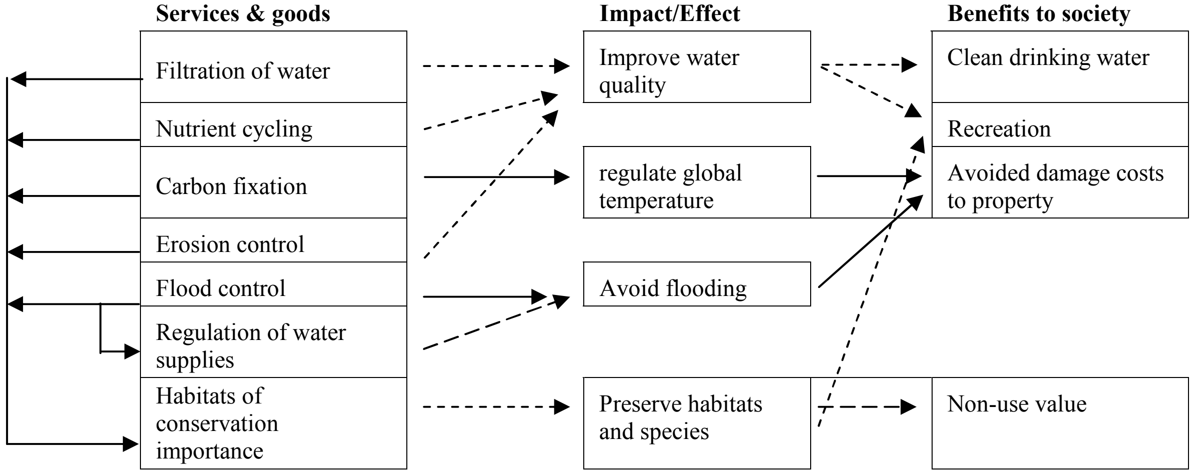

Figure 3.1 Some wetland function interactions

The figure shows that there are various ways to demonstrate the interactions between service, impact and benefit. Ultimately, the extent and nature of this interaction will be location specific and thus establishing these interactions should form part of the impact assessment.

Thus, overall it may make little sense to talk about the value of an individual ecosystem service. Rather the points at which values are ascribed are the end-points or impacts of that service (eg we can talk about the value of storm protection to property, the value of storm protection to crops, the value of storm protection to forests). Depending on demographic and geographically specific factors these values will be different for each location. In addition, we can talk about the *combined* value of services in contributing to end-points of value (eg the contribution of a woodland to clean drinking water or recreation). As mentioned earlier, cataloguing services is a useful tool for understanding the range of potential values of an ecosystem, but this does not require that an individual value is ascribed to each.

3.1.3 Managing for ecological risk

Ecosystem dynamics – key considerations

As mentioned earlier on, our understanding of ecological functions and the provision of goods and services is limited. The framework here is a gross simplification, which necessitates a brief discussion of the complexities of the study of ecosystem function, and how ecosystems bring about services to humankind. Any study of ecosystem dynamics and interactions with human systems needs to recognise the following characteristics of ecosystems (as reported in eftec, 2005):

- Thresholds are a typical feature of the relationship between human pressure on the environment and ecosystem function. In some cases humans can regulate the pressure imposed on systems to achieve optimal overall welfare benefits that combine economic and ecological values, whereas in others the response to stress is discontinuous and there is a sudden and catastrophic change in ecosystem conditions at some level of environmental stress. At this point the functioning of the ecosystem is shifted to an alternative stable state which is very often massively detrimental to human interests. Crucially, we currently lack sufficient understanding of ecosystem dynamics to identify thresholds *a priori*, and consequently it is difficult to implement informed policy. It is therefore particularly important to be able to identify thresholds where they exist within any model of ecosystem-economy interaction, in order to avoid unexpected catastrophic changes that could severely impinge upon human welfare;

- Declining species diversity simplifies ecosystems, which may in turn affect the stability of ecosystems in the face of disturbance, and thereby the capacity to deliver ecosystem functions that support human welfare. Species diversity, or at least the diversity of species comprising functional groups, provides ecological insurance, in that if some species are lost others are available to fill their functional roles. Declining biodiversity potentially erodes this ecological insurance until species 'redundancy' is reduced to a degree where continued species loss results in the catastrophic failure of ecosystem services. In rare cases some species may not have functional counterparts and their loss may contribute disproportionately to ecosystem failure. Loss of such 'keystone' species has been shown to have large impacts at local scales; and

- Ecosystem functionality interacts across habitats, ecosystems and scales. Landscapes consist of several functionally integrated ecosystems such that disturbances to one ecosystem have complex and indirect effects on other ecosystems within the landscape. These effects may be expressed through either physical or biological processes, and make it difficult to isolate any one ecosystem when studying ecosystem dynamics. When dealing with whole landscapes it is therefore imperative that we understand how multiple functions interact across ecosystems and how to properly ascribe the contributions of various landscape elements to the functioning of the whole. The geographical scale of such interactions can be very large. For example, every year in the Pacific Northwest of the United States and Canada, oceanic salmon (*Oncorhynchus* spp.) migrate great distances along rivers inland to spawn and subsequently die. This mass migration represents a significant input of marine-derived nutrients into coastal ecosystems and riparian forests. The observed decline in salmon abundance may have substantial implications for the future structure and composition of terrestrial forests.

These complexities, make it even more important for decisions to be taken with due account of their impacts on ecosystems in an integrated way from the start, as the ultimate consequences of not doing so are largely unknown but could be catastrophic. Risk assessment and resource economics are thus essential components to the management of ecosystems.

3.2 Overview of valuation techniques

This section presents an overview of economic valuation techniques (3.2.1), pricing techniques (3.2.2), and benefits transfer (3.2.3). It then concludes with some general comments about the preferred application of each technique (3.2.4).

3.2.1 Valuation techniques

While all techniques described in this report can be called valuation techniques, revealed and stated preference methods are generally what are referred to as economic valuation.

Stated preference methods

These methods directly elicit individuals' preferences for non-market goods, through the use of questionnaires that allow respondents to trade off goods and services against money thereby stating their preferences. These methods are the only way to gather quantitative evidence about the non-use component of TEV to be estimated. In the case of ecosystem services non-use value may be significant, particularly for irreversible impacts.

There are two types of stated preference methods:

- **Contingent Valuation (CV)** employs a questionnaire format where respondents are asked how much they would be willing to pay or willing to accept compensation for a specified gain or loss of a given good or service. Economic value estimates yielded by CV surveys are 'contingent' upon the hypothetical market situation presented to respondents and allows them to trade off gains and losses against money. WTP/WTA questions may be asked in a number of ways, including open-ended, where the respondent states their maximum WTP or minimum WTA, and dichotomous choice, where the respondent is required to answer 'yes' or 'no' to a 'bid' (eg are you willing to pay £x?). Typically in CV studies the attributes of the good or service are valued together as a bundle.

- **Choice modelling (CM)** approaches involve respondents making choices between goods which are described in terms of their various attributes, offered in different amounts, or levels. There are two main choice formats: contingent ranking and choice experiments. In a contingent ranking exercise, respondents rank a set of alternative scenarios of good or service provision in order of preference. In a choice experiment, exercise respondents are presented with a series of scenarios and asked to choose their most preferred. One of the attributes is always price or cost so that by ranking the alternatives or choosing their most preferred, respondents implicitly trade goods and services against money and hence their WTP or WTA can be inferred through their choices. Choice modelling is a technique borrowed from market research and typically provides more data on individuals' preferences than CV techniques for a similar sample size.

Revealed preference methods

These methods infer individuals' preferences by observing their behaviour in markets in which a given environmental good or service is indirectly purchased (eg recreation) or markets where the price of a man-made good is influenced by environmental goods and services (eg the property market).

There are two main variants of revealed preference methods:

- **The Travel Cost Method (TCM)** enables the economic value of recreational use (an element of direct use value) to be estimated. The method requires the costs incurred by individuals travelling to recreation sites to be surveyed, in terms of both travel expenses (fuel, fares etc.) and time (eg foregone earnings). The basic assumption is that these costs of travel serve as a proxy for the recreational value of visiting a particular site. The difference between the amounts people spend getting to different sites can also be modelled against site characteristics to estimate the value of those characteristics (eg landscape types or amenity features such as visitor centres etc, see for example Bergin and Price, 1994).

- **Hedonic Pricing** may be applied to the valuation of environmental goods such as landscape amenity, air quality and noise. It is based on the assumption that like structural and neighbourhood characteristics, the surrounding environmental quality also affect the price of a property so that identical houses fetch higher prices in eg quieter areas with better air quality. The technique involves isolating the effect of these services on the demand for a marketed good. In most cases price data from the housing market are used. Analysis of the data estimates the implicit price which individuals are willing to pay for the relevant environmental characteristics.

3.2.2 Pricing techniques

The following are the set of pricing techniques, ie those techniques employing market data:

- **Market Price** data from ecosystem goods and services that are actually traded, either in local or international markets offer perhaps the most visible indication of value. Products such as timber and crops are obvious examples. The correct indicator is the 'real' price that is net of all transfer payments, ie government subsidies or taxes, so that the market price should be adjusted for these.

- **The Opportunity Cost** approach estimates the benefits that are forgone when a particular action is taken. For example, forgone revenues from timber sales and the loss of benefits from forgoing other forest products may be viewed as the opportunity cost of a forest conservation project that prevents the harvest of timber and/or other products. In the strictest sense, opportunity cost should be viewed as the next best alternative use of a particular resource.

- **Mitigation Behaviour / Preventive or Avertive Expenditure** approaches analyse the cost incurred, or prices paid, in order to defend against the negative impacts of environmental degradation (eg the cost of building sound-proof windows in the case of noise pollution or the cost of buying pollution masks to protect against urban air pollution).

- **The Substitute Goods / Cost of Alternatives** approaches entail estimating the cost of provision of an alternative resource that provides the function of concern. A wetland service that provides protection against flooding could, for example, be valued, at the very least, on the basis of the cost of building man-made flood defences of equal effectiveness. Another example may be the cost of fertiliser to replace the natural productivity of soils that have been eroded.

- **Shadow Project Costs** consider the cost of providing an equal alternative resource or ecosystem at an alternative location. Such an approach may also be termed as a 'replacement cost' approach, which measures environmental value by applying the cost of reproducing the original level of benefit. The market in wetlands in the USA is an example of such a system in practice. The regulatory system facilitates the market by allowing, say, developers to drain a wetland if they create or protect a replacement wetland elsewhere. The replacement cost technique is likely to be employed in the implementation of the EU Environmental Liability Directive, where issues surrounding the identification of ‘equivalent (shadow) projects’ and determination of ‘excessive cost’ are not yet resolved. However, theoretically speaking the use of shadow or replacement costs is a poor measure of economic value, as it may cost much more to rebuilt some habitats than they are actually worth; or the cost of rebuilding the habitat may be a tiny fraction of its value to society. Ideally, the cost of rebuilding the habitat should be compared with a more correct measure of value in order to aid the decision of whether or not to rebuild it.

- **Production Function Methods** estimate the direct and indirect use value of ecosystem goods and services via their contribution to marketed outputs. An input-output approach is used, which involves measuring the change in quantity or quality of a good or service input and the resulting change in marketed output. The change in physical quantities is valued in monetary terms using the market price. This approach is most suited to ecosystem services that contribute in various ways towards economic outputs (eg the filtration of water is beneficial for recreation, drinking water, fisheries production and so on). Using the production function the portion of this contribution to each economic end point can be ascribed.

3.2.3 Benefits transfer

Benefits (or ‘value’) transfer is the process of taking information about benefits from one context (the 'study site') and applying it to another context (the 'policy site'). Essentially this means reviewing the literature of original valuation studies and selecting those results that correspond best to addressing the policy question at hand. The case study in Annex 2 demonstrates how benefits transfer can be applied, albeit in the most simple way. Annex 3 presents some examples of original valuation work that could eventually be applied using benefits transfer to inform English Nature’s work.

3.2.4 ‘Valuation’ vs ‘Pricing’ techniques

While valuation techniques have a greater theoretical appeal compared to pricing approaches, there are certain cases where it may be more practical and relevant to use pricing techniques to estimate economic value. Pricing approaches are less controversial in the sense that market data reflect the public’s preferences as actually demonstrated in the market and therefore does not suffer from some of the uncertainties that are inherent in the hypothetical markets created through stated preference surveys. Revealed preference data are also less controversial, although all techniques employing market data will be underestimates of actual willingness to pay, for the reasons described previously. Besides, market data are not without its own problems related to the imperfect functioning of markets (issues that are not relevant for stated preference studies which collects it own preference data).

Another consideration is that, broadly speaking, different techniques will capture preferences associated with individuals’ different roles in society. As stated preference techniques are able to capture non-use values, including altruistic and bequest values, they lean towards capturing the preferences of the citizen; whereas pricing techniques will tend to capture the preferences of the consumer, where goods are mostly valued independently of the ecosystem context from which they are derived (see Bateman, 1999).

Many ecosystem services are generally unobserved by individuals and as such would rarely enter into the set of preferences of the citizen. These include micro-climate regulation, water and air purification and detoxification, and regulation of water flows. While some would argue that a stated preference survey would be capable of providing information to the respondents, there is a limit to how much new information can be provided in a single questionnaire. For example, the service of pollination of crops (within regeneration and production) is much easier to value using pricing approaches as these services are more relevant to crop producers rather than using valuation techniques applied to individuals who may find it difficult to assess the indirect (but significant) contribution these services make to their own wellbeing. In the case of pollination services, production function can be used to value the contribution of pollination to the overall yield value or the service can be valued through the cost of substitutes such as artificial pollination methods. This should not imply that pricing approaches are simpler. They still require the - at times - very complex relationships to be identified and measured between ecosystems and their functions and services.

There are also examples of ecosystem services, such as all of the life-fulfilling services, for which stated preference techniques are preferred. The next section considers each of the services in turn presenting some examples from the economic valuation literature and recommending general approaches for future work.

3.3 Selecting techniques for valuing ecosystem services

This section looks at each service type in turn and advises on the most suitable technique for each type. Essentially, most valuation techniques could be applied to at least one aspect of benefit in each category of service, however some are better suited than others[2]. As explained previously, ecosystem services embody for the most part the indirect use value component of the total economic value of ecosystems. This section explores the economic valuation techniques that are most suited to valuation of the different ecosystem services described in this report.

Section 3.3.1 outlines some general criteria for selecting economic valuation techniques, while Section 3.3.2 provides some suggestions for each service type and examples from the economic valuation literature (it is not intended to be a complete review of all valuation studies on ecosystem services in the UK).

3.3.1 General criteria for selection of techniques

Four main criteria can be identified which will inform the selection of appropriate valuation techniques. These are:

[2] Turner et al (2005) undertakes a similar exercise for wetlands and presents a wide range of techniques as being suitable for almost all ecosystem services. The treatment of the subject is more detailed in that report than it is here. However, the approach taken here is to provide a stronger steer to decision-makers, rather than a complete menu and literature review.

1. Whether or not the benefit to society is a market or non-market benefit:

Particular ecosystem services may provide either or both market and non-market benefits to society, reflecting different uses and beneficiaries. As presented above, market benefits can be valued using pricing techniques and non-market benefits using valuation techniques. Where both market and non-market benefits are in evidence, then these should be valued separately and added together. For example, the value of water purification services includes both the financial value of the service provided to water companies (who would otherwise have to spend more to treat the water) as well as the value of the contribution to water quality to informal recreational users. Double counting should be avoided. For example, if avoided treatment costs to water companies are used, these cannot be added to WTP of households to receive good quality water.

2. What the expected response to the change in ecosystem service provision will be:

In selecting between different techniques, the decision should be informed by the expected human response to the change in ecosystem service provision. This boils down to detailing the 'with and without' scenario and is especially the case when considering the use of different pricing techniques. To give an extreme example, the evaluation of the wetland service of water purification for drinking water provision is considered in different legislative contexts. In the first context, where water companies are legally required to take on the extra burden of water treatment when the wetland becomes degraded or lost, the cost to the water companies would be the valid measure. In the second context, where no legal requirement exists or where no water company would replace the ecosystem service, the result would be increased illness from consuming the poorer quality drinking water - here the cost of illness (or willingness to pay to avoid illness) would be the relevant measure. Alternatively, we may expect that people would purchase bottled water, in which case the appropriate technique is avertive expenditure[3]. Note that these techniques do not estimate the total economic value of clean water, only the economic cost of one of the outcomes of declining water quality.

The same applies in choosing between non-market techniques. For example, if a woodland providing recreation and landscape services is cut down to make room for new housing the local community stands to lose both services. However, if there is another woodland nearby that offers similar recreational opportunities, and it is expected that the resident and visitor populations would simply use this second woodland as a substitute for the first then it may be that there is no net loss in recreational services (if we ignore the potentially different travel costs of getting to the second woodland instead of the first one). If the only remaining service lost is the landscape benefit of the woodland to local residents, this may be best captured using the hedonic pricing technique, which would measure the value of current landscape as reflected in house price differentials. This value can then be assumed as lost if woodland is lost. Note that the hedonic pricing technique could include an element of recreational benefits to residents but would not capture the value of woodland recreation to visiting populations.

[3] Pricing techniques need not be mutually exclusive, and several may be employed to evaluate the different outcomes of damaging or losing an ecosystem service. A mix of avertive expenditure techniques, production function, replacement cost and opportunity cost may be employed to capture the value of one ecosystem service. The important point is to avoid double counting in defining the benefits and effects.

3. *The pros and cons of the techniques themselves, including the availability of data and resources to employ the technique:*

While stated preference techniques can in principle be applied to any context, they are often limited by the cognitive ability of respondents to understand the nature of the service being valued or more precisely by the lack of information on the precise impacts of ecosystem services of relevance to respondents. Eliciting preferences for ecosystem services, such as 'carbon sequestration, water regulation and regulation of local temperatures' has the problem of insufficient prior knowledge or even scientific information for true preferences to be revealed (which is why some surveys have been unsuccessful in eliciting responses for ecosystem services, see Christie and others 2004). However, some argue that many economic decisions, ie private purchasing, are made on the basis of little information, which does not make them less valid. Questionnaires should identify at the very least what this means for the surveyed population, eg an increase in local temperatures of 5 degrees or decrease in local water supplies leading to a reduced water level in the local river. Finally, each of these impacts can be so complex that it may merit a separate valuation study for each so as not to overburden respondents. This is where it may become practical to use benefits transfer for some impacts, and new valuation work for others.

Availability of data on the physical measure of ecosystem services is a concern for all valuation techniques. While one of the benefits of stated preference work is that it serves to collect economic data, it relies on accurate representations of physical impacts for its own validity. In the absence of economic data, such as time series data on house prices, hedonic pricing is not possible. Travel cost requires data that can be collected if a survey of visitors can be implemented increasing the cost and time requirement of the method.

Given data, the time and resources required for different techniques is another consideration. Benefits transfer can be applied in a matter of weeks but is constrained, for example, by the limited coverage of some aspects of ecosystem service function, and by its insensitivity to site specific characteristics. Stated preference and revealed preference studies can take between six months or even more than a year to implement, at much greater cost. The cost and resource requirements of any valuation approach should not, however, be assessed in isolation from the needs of the evaluation, which is the next point.

4. *The needs of the policy evaluation:*

The more important the ecosystem and the more significant the outcome of its loss or degradation, the greater the need for as comprehensive an analysis as possible. As mentioned earlier, benefits transfer can uncontroversially be used to indicate the magnitude and direction of ecosystem benefit, but – depending on the sophistication of the benefits transfer technique employed a more detailed assessment, involving at least some original valuation work, is required where significant policy decisions are going to be taken. An example may be where a strong case is required to oppose a powerful development interest, or an accurate estimate is required to estimate the correct level of an environmental service payment.

While conceptually desirable, it may not always be necessary to estimate the economic value of all goods and services of an ecosystem or the entirety of the change in TEV that is caused by a change in the ecosystem. So long as a benefit threshold is exceeded, a valuation exercise would not always need to go any further, unless a number of projects need to be ranked, eg according to their cost benefit ratio. The benefit threshold is determined by the cost of the policy. For example, the benefit of conserving an inter-tidal wetland would be compared to the (opportunity) cost of conservation and so long as even an impartial analysis shows that benefits exceed costs, evaluation should conclude that conservation should go ahead.

Finally, it may be the case that economic valuation is not required at all, and that given a comprehensive and quantitative scientific assessment measuring how ecosystem services contribute to different economic end points, the case made for conservation of the ecosystem is strong enough.

3.3.2 Preferred technique by ecosystem service category and examples

Table 3.1 provides an overview of preferred category of valuation techniques for each of the service types. The ensuing discussion provides examples from the literature of work undertaken mostly in the UK. Note that in most valuation contexts more than one technique will likely be employed, as is demonstrated by the examples here and the case study in Annex 2. Also note that the mention of different techniques for each service or even the separate mention of each service do not imply that the economic values of services are additive.

Table 3.1 Techniques for valuation of ecosystem service categories

Service Category	Services and goods	Technique		
		Pricing	Valuation	Comments
Supporting services	Production of oxygen	●		These are best valued through production function pricing approaches, but typically data are not available.
	Nutrient cycling	●		
	Translocation of water and nutrients from depth	●		
	Primary production	●		
	Habitat provision	●		Pricing techniques can be used to estimate the contribution of habitat provision to products sold in the market. Valuation techniques: only stated preference techniques are capable of capturing the non-use values of habitats, which can be a significant proportion of their value.
Provisioning services	Food and drink products	●		
	Fibre and construction products	●		
	Medicinal and cosmetic products	●		
	Ornamental and other products	●		
	Renewable energy	●		

Service Category	Services and goods	Technique		
		Pricing	Valuation	Comments
Regulating services	Filtration of air pollution	●	●	**Pricing techniques** can be used for, eg avoided health costs, costs of water treatment works etc. **Valuation techniques** can be used to estimate the contribution to eg recreation (but need to avoid double counting)
	Filtration of water	●	●	
	Detoxification of water and sediment	●		
	Carbon and global climate regulation	●		**Pricing techniques** can be used to estimate avoided damage to property, replacement costs (eg sea walls), production inputs to agriculture from erosion control, price of water supply, etc. **Valuation techniques** can measure the health and psychological effects of natural disasters.
	Local climate regulation	●		
	Erosion control	●		
	Flood risk mitigation	●	●	
	Maintenance of surface water stores	●		
	Groundwater replenishment	●		
Cultural services	Paleo-environmental data	●		**Pricing techniques** are most relevant using a production function to estimate the contribution of ecosystem services to the value of research outputs, education, etc. **Stated preference** can be used to estimate the use and non-use value of cultural heritage.
	Preserving archaeology	●	●	
	Historical and cultural importance	●	●	
	Educational and scientific resource	●		
	Gene bank for research	●		
	Recreation and tourism	●	●	Both **pricing and valuation techniques** can capture the contributions made to the economy through tourism as well as the consumer surplus of informal recreation and non-use value of ecosystems.
	Physical health and personal well being	●	●	

The remainder of this section considers possible economic approaches to evaluate some of the more complex ecosystem services, together with some example studies.

3.3.3 Support services

Cycling and other support processes contribute to the provision of other ecosystem services, such as regeneration and production, habitat production and life-fulfilling services. As such, it is difficult to value these services independently, as they work together with other processes to produce goods and services that are valued by humans.

Habitat provision

Habitats and species provision, when viewed independently of the other ecosystem services that accompany habitats, is a non-market service best estimated using stated preference techniques which can capture both the use and non-use components of value. Some valuation studies have focussed on the value of conserving a particular species (eg Langford and others (2001) for the Mediterranean monk seal and Hanley and others (2002) for wild geese), others on biological diversity[4] provision per se, as some examples presented below illustrate, and others on particular habitat types. However, valuation studies of particular habitat types generally capture the value of a whole range of ecosystem services offered by those habitats (including recreation, landscape, and non-use values) and therefore are not presented here.

Valuing biodiversity is notoriously difficult, mainly because it is a complex concept little understood by the general public, but also because there appears to be no one definitive measure of biological diversity. The most recent study relevant to this ecosystem service is Christie and others (2004) which set out to assess whether it is possible to develop a framework to enable meaningful and robust values for biological diversity in the UK. They conclude that it is possible and some of the results are presented below. However, the authors undertake benefits transfer tests within the study and conclude that based on the results, the transfer of the WTP estimates to other contexts is not recommended, although they imply that further research may overcome the problems encountered in their work.

There are many examples of such studies; two are referred to here as examples. Christie and others (2004) seek to elicit WTP using contingent valuation, in Cambridgeshire and Northumberland, for a number of policies that would avoid or reduce biodiversity decline. One of the policies described is a habitat re-creation scheme in Northumberland that would enhance biodiversity by creating new wetland habitats on existing farmland. The new wetland is described as providing habitats for a wide range of plants, insects, small mammals and birds, including a number of rare species; as well as ecosystem services such as flood protection and enhanced water quality. Households were willing to pay just over £47 per year for five years for this policy, which equates to £6.21 million per year. There are clearly areas of overlap between what is captured in these results and what is captured in studies presented under other ecosystem service headings in this report.

Christie and others (2004) also developed a choice experiment study to assess the value of four attributes of biodiversity: familiar species of wildlife, rare unfamiliar species of wildlife, species interactions within a habitat and ecosystem services (focused on biodiversity's role in preserving the health of ecosystem processes). With regard to the values found for 'ecosystem processes' attribute with direct impacts for humans was highly valued in both Cambridgeshire and Northumberland (£53.62 and £105.22 per household per year respectively). However, the 'ecosystem processes' attribute was not significant in Northumberland. The authors state that the reason for this finding appears to stem from the fact that generally there was a lower level of understanding of this attribute and therefore people valued it less consistently. They conclude that attempts to value ecosystem functions and services will be difficult, particularly with methods (such as stated preference methods) where respondents are required to state a preference based on the description of the good in question.

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[4] From the 1992 UN Conference on the Environment and Development: "Biological diversity" means the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems

Garrod and Willis (1997) examine the biodiversity benefits of woodlands using the contingent valuation technique to survey a random sample of households across the UK. The results provide WTP for four different forest management standards for achieving different levels of biodiversity that could be adopted in a specific, largely inaccessible, 300,000 ha area of coniferous forest. This ranges from £0.2 to £0.6 (£, 2001) per household per year. Aggregated across the population of Great Britain, this equates to about £15 to £48 per hectare of coniferous forest.

3.3.4 Regulating services

Filtration and purification are 'sink' services, where pollutants, toxic materials and other waste products are stored in sediment or biomass, thereby cleaning the air, water or land resources in the process. Alternatively ecosystems can convert pollutants chemically rendering them less harmful. The distinction is important as stored pollutants can still present a liability, especially where ecosystems are disturbed and pollutants then released. A valuation study may want to differentiate between these two types of service by incorporating a measure of risk associated with accumulation and potential release (through various pathways) of these pollutants in the future.

Storage of pollutants by wetlands has the effect of improving water quality downstream. In the case of woodlands, storage of air pollutants has the effect of improving local and regional air quality. In inter-tidal areas, the storage of pollutants will reduce the pollution flowing into the marine environment. Typically, a valuation exercise would seek to identify the avoided damage to human health and the environment, and assess society's willingness to pay to avoid this damage (or willingness to accept the damage).

The starting point of the analysis would be the amount of pollutant filtered from the environmental media (air, water, land) and/or the resulting change in concentration of the pollutant. This information then needs to be interpreted in terms of the avoided impact on human health and on the wider environment (an environmental pathway and/or dose-response analysis). The former can be valued using pricing techniques, such as avoided costs to the health service (eg days spent in hospital due to respiratory illness from air pollution) or lost days at work, as well as stated preference techniques (eg WTP to avoid suffering from illness). Impacts on the wider environment may include water quality decline in a river downstream as a result of a damaged wetland that no longer provides filtration services. The value of changes in water quality can be estimated using stated preference techniques which reflect changes in amenity and recreational benefits, among others, as well as using pricing techniques to reflect for example the increased costs to water companies required to clean the water in place of the wetland. Care needs to be taken to ensure no double counting with the life-fulfilling service categories, such as recreation.

Table 3.2 below provides some examples of valuation approaches to purification and detoxification services provided by woodland, wetland and inter-tidal ecosystems.

Table 3.2 Example valuation studies

Mortality and morbidity benefits of air pollution absorption by woodland (Powe and Willis, 2002)	
Benefits transfer using pricing techniques (avoided health costs) and stated and revealed preference techniques (value of statistical life).	1. The net effect of dry pollution deposition from trees was determined by the woodland pollution absorption minus that of heather or grass seen as the alternative land use. 2. The change in health effect (mortality or morbidity) was calculated based on net reduction in pollution due to forest foliage, and the dose response coefficients for each pollutant's impact on human health, population density and baseline health. 3. The reduction in economic costs was calculated by multiplying the number of deaths brought forward and hospital admissions by the costs noted above adjusted to 2002 prices. 4. Results: The net pollution costs forgone or net benefits of having trees, instead of another land use, for Britain was estimated to be somewhere between £222,308 and £11,213,276. A broad range dependant on the extent of dry deposition on days with more than 1mm rain and how early the deaths brought forward occur.
The value of investing in wetlands for nitrogen abatement (Gren, 1995)	
Input-output model, using a mix of pricing techniques and contingent valuation.	This paper calculates the value of marginal investment in wetlands for nitrogen purification, in Gotland, Sweden. It uses an input-output model to compare the value of three nitrogen reducing policies: (i) investment in sewage treatment plants, (ii) investment reducing nitrogen pollution from agriculture and (iii) investment in wetland restoration. Nitrogen abatement capacity of restored wetlands is assumed to be 215kgN per ha in the first year, rising to 500kgN/ha after ten years. The model estimates the marginal value of changes in nitrate abatement from the current level. Wetlands restoration is found to be four-times more valuable than investment in sewage treatment works, and over 100 times more valuable than reducing nitrate from agriculture.
Economic values of Danube Floodplains (Gren and others 1995)	
Benefits transfer (based on Gren, 1995)	The value of the Danube Floodplains as a nutrient sink is about £194 per hectare per year.

Global climate regulation

The role of ecosystems as carbon sinks contributes to regulation of the global climate, by removing a potentially harmful greenhouse gas, carbon dioxide, from the atmosphere (or avoiding its release), as described in Section 2. The first step in a valuation exercise involves assessing the extent to which the ecosystem is acting as a store for carbon. In the case of wetlands there is a need to know whether the wetland is a net emitter or store of greenhouse gases, as the methane gas emitted from wetlands has a much higher global warming potential than the carbon stored. For the UK it is impossible to generalise, so site-specific assessment is required (Parkes, 2003). For woodlands, the type of tree, age of the forest, soil characteristics and management of the woodland are important determinants in assessing the extent of carbon sequestration.

Estimates of the economic value of accumulating and maintaining a store of carbon are based on the avoided costs of damages of climate change, estimated per tonne of carbon. This is one of the most globally applicable instances of benefits transfer as a tonne of greenhouse gas emitted anywhere in the world has the same effect. Damage costs refer to the monetisation of world-wide impacts of sea level rise and extreme weather events resulting from anthropogenic production of greenhouse gases, including impacts on human health, agriculture, water resources and ecosystems. Climate models link emissions of greenhouse gases to changes in ambient concentrations to changes in global temperature to sea level rise and resultant impacts. Estimates of damage cost per tonne of carbon vary between £5 and £70 depending on various assumptions. The UK Government's current recommendation for valuing avoided climate change damages is to adopt a range of £35 to £140 per tonne of carbon for sensitivity analysis around a central estimate of £70 (Clarkson and Deyes, 2000).

Brainard, Lovett and Bateman (2003) provide a detailed assessment of the economic value of carbon sequestration and storage in British woodlands. Employing GIS models and taking into account soil types and various geological factors, they estimate carbon sequestration rates per hectare of different type of woodland. Table 3.3 presents results for England only, based on the £70 per tonne recommended by Clarkes and Deyes (2000) and using a 3.5% discount rate (as recommended in the UK Treasury's Green Book for Appraisal).

Table 3.3 NPV estimate (£millions) of the social value of carbon in woodland in English regions. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031, using a 3.5% discount rate

	NW	E. England	SE	SW	E. Midlands	W. Midlands	Yorks and Humber
FC Beech	2.02	7.44	80.18	33.44	4.68	5.05	2.20
FC Oak	1.78	6.77	62.59	29.20	16.95	7.89	2.66
FC Sitka spruce	529.13	0.01	1.06	71.38	1.24	4.36	49.29
Other FC broadleaf	14.67	20.05	77.67	49.04	32.06	17.94	17.98
Other FC conifer	37.76	218.43	155.51	147.09	65.41	66.63	68.59
WI broadleaf	600.99	950.31	2,684.03	1,875.33	667.00	816.92	644.66
WI conifer	311.05	224.90	408.42	492.03	114.10	225.85	273.17

Notes: Woodland Inventory (WI); Forestry Commission Estate (FC)

Local climate regulation

The extent to which ecosystems, such as woodlands, influence the local climate will depend in part on the extent of their coverage. Effects such as shading and cooling will be appreciated by local visitors and will contribute to the economic value of recreational visits.

Woodlands acting as a windbreak could provide valuable services to local farmers, protecting crops from the brunt of wind burning, and of salt when in coastal areas. In order to value the windbreak effect, analysis is required at a local level to assess what the absence of woodlands near farms (or the effect in the change of woodland cover being evaluated) would entail for crop productivity: the economic endpoint of the analysis being the value of crops, hence requiring a production function approach.

The benefit of woodlands in regulating temperature is evident in the species and habitats that this cooling effect helps to maintain. For example, where woodlands shade watercourses they regulate the temperature of the water, which otherwise might overheat in summer leading to lethal temperatures for fish and contributing to the growth of weeds. All of these effects need to be quantitatively estimated and the contribution they make to ecosystem health assessed. The economic end-points in this example are potentially the commercial value of fish and the value of formal and informal recreation. However, where these effects impact on habitats, all of the values of these habitats are relevant, both use and non-use values. While marketed impacts such as commercial fish catch can be estimated using pricing approaches, non-market effects such as informal angling and non-use values will require the application of stated preference techniques. Note however that these are separate service categories and thus shouldn't be valued twice when estimating the value of a change in a particular ecosystem.

On a larger scale, local climate regulation by ecosystems is evident in the difference in temperature between rural and urban areas, which can be as much as 5%. However, the value of ecosystems in regulating local climates has not yet been a subject of economic research.

Erosion control

Evans (1996) estimates the total cost of soil erosion in the UK to be approximately £9.2 million (mostly incurred through dredging of stream channels, but also including the effect on traffic accidents - from the wash up of sediments on roads - and property damage). However, Willis (2002) reports on a lack of data on the economic value of the soil erosion reduction provided by woodlands. If it were possible to estimate the extent that woodlands contribute to avoiding overall soil erosion, then a portion of the cost estimate by Evans could be apportioned as the benefit of that woodland service.

The loss of soil to the waterways and oceans will also have implications for the productivity of remaining soils. This could be valued by reduced crop productivity over time. However, there is no physical impact or economic data to quantify this benefit.

Flood risk mitigation

Flood risk mitigation is an important service provided by ecosystems in England given the sizeable economic burden that flooding imposes on the country. Annual damage from flooding in England and Wales has been estimated at £1.04 billion in 2003 (Evans and others 2004), possibly rising to £20 billion per year by the 2080s in a worst case scenario.

Clearly, in order to assess the potential benefits of flood alleviation from wetlands, woodlands and inter-tidal habitats, the analysis has to begin by providing an estimate of the frequency and severity of expected increases in flooding that would arise from a change in the coverage of the ecosystem – or in the scenario where the quality of the ecosystem is degraded. The market costs of flooding on properties and other infrastructure (railways, roads, etc) can be calculated using the financial costs of repair and rebuilding. The Flood Hazard Research Centre's 'multi-coloured manual' on the benefits of flood and coastal defence (Penning-Rowsell and others 2003) provides 'look up' data tables on the average damage costs to property based on the height of a flood.

In addition to the financial costs of flooding damage, there are the non-market costs (also referred to as the intangible costs of flooding). These include the psychological trauma associated with being a victim of flooding, the health impacts experienced, as well as the value of 'priceless' personal effects damaged by floods, such as photos and personal keepsakes. RPA (2002) estimates the human related intangible costs of flooding using a contingent valuation survey. The results indicate that the overall mean willingness to pay to avoid such impacts was of the order of £200 per property per year for those with recent experience of flooding and some £150 per household per year for those who have not experienced flooding but are in an 'at risk' area. These estimates should be considered additional to financial losses.

Woodward and Wui (2001) undertake a meta-analysis of wetland valuation studies in order to estimate the value of individual wetland services. They find that the value of maintaining wetlands for their flood defence function is estimated at £1,279 per hectare per annum (£2001) and storm defence function value is estimated at £722 per hectare (£2001). However, they also conclude that the prediction of a wetland's value based on previous studies remains highly uncertain and recommend site-specific valuation efforts. Another meta-analysis by Brouwer and others (1997) estimates that the value of the flood control function of wetlands is £97.36 per household per year (£2001), which would require further analysis to convert it to a per hectare per year equivalent.

The use and non-use benefits of avoiding flood damage of intertidal habitats and wetlands are estimated in Klein and Bateman (1991) in a valuation study of the Cley Marshes in Norfolk; and in Bateman and others (1992) in a valuation study of the Norfolk Broads. In both studies, the benefits of avoiding further damage to habitats from coastal flooding, in terms of use (landscape amenity and recreation value) and non-use values are estimated with contingent valuation. Results for the Cley Marshes found the WTP of households to be about £51 per year (£2001), whilst results for the Norfolk Broads found that users of the site were willing to pay £66 per household per year, and non-users £26 per household per year. The latter study provides a clear distinction between use and non-use value, where users are assumed to express both values and non-users only non-use value. Note that these studies, while demonstrating the value of flood defence, are mostly focusing on the recreational, landscape and biodiversity values of the wetlands and thus there is a clear need to avoid double counting when assessing recreational and other service values later on.

Regulation of water supply

Regulation of water supply refers to keeping the water supply at a relatively constant level throughout the year.

In Willis (2002) replacement and mitigation costs are employed to measure the impact of forests on water supply. They argue that this is the appropriate economic measure for this ecosystem service as customers already pay water companies for the service of finding water supply. The cost of replacing the supply of water taken up by forestry in England is estimated to be in the order of £52 million and is based on long run marginal costs of supplying water.

Note that this is not a benefit of the forest ecosystem, but rather a cost. The amenity and recreation impacts from reductions in flows in rivers has been estimated most recently by eftec (2002) for the River Ouse, which found that median willingness to pay to avoid reduced water levels of 5cm was £0. Four other valuation studies examine the benefits of alleviating low flows in rivers (eg in terms of recreation, amenity and non-use values) (ERM, 1998; Garrod and Willis, 1996 and JacobsGibb, 2002). The results of these studies may prove useful, but ultimately – because of the units they are presented in - they require that the level of impact on the river (by the woodland) can be established before these studies can be applied to value this service.

Willis (2002) concludes that a more accurate valuation still needs to be undertaken on a range of water supply externalities to permit a more definitive assessment of whether, on balance, the net economic impact of all forestry impacts on water supply is positive or negative (a cost), or simply zero. Thus, it is necessary to proceed with caution here.

Protection from storms

Coastal wetlands provide protection from severe weather events to inland ecosytems and properties. A study from the US estimated the value of this service in relation to four hurricane events in Louisiana (Farber, 1987). The study reports the costs of increased wind damage to properties associated with the loss of a one mile wide band of coastal wetlands along the Gulf of Mexico coast of Louisiana. Although not directly relevant to the UK context, the study is interesting to examine because of its approach, particularly in trying to estimate the incremental effect of the wetland using the impact-pathway approach. Hurricane damage per property was modelled as a function of the wind speed of the storm at landfall, the distance of the county in which the property was located from the nearest coastline, the distance of the county in which the property was located from the storm path, and the inland distance of the county in which the property was located inland times the wetland area traversed by the storm. The net present value of wind storm protection of wetlands discounted over 100 years is \$3.7 million using a 3% discount rate (\$, 1980).

3.3.5 Provisioning services

Regeneration and production services give rise to many goods that are consumed by humans, such as food, medicinal and ornamental products, fibre and contribution products and renewable energy generation. Where these are sold in the market, the value of the ecosystem service contribution would be determined through pricing techniques, such as the market prices and production function. Where these are harvested as part of consumptive (informal) recreation at no financial cost (eg fishing, berry picking, etc) then non-market techniques such as travel cost or stated preference could be employed to establish the value of the recreational consumption of those goods, or market values for similar goods could be used as proxies.

For the most part, valuation of this service category translates to the valuation of ecosystem goods. A simple inventory of goods and their market value (where markets exist) can be used to arrive at a lower-bound estimate of value. This approach is most defensible where the ecosystem is actually harvested for ecosystem goods (such as willow for artists' charcoal), but could also be used to estimate the potential for capturing economic value or the opportunity cost of alternative management regimes. Any assessment of value based on market prices of ecosystem goods needs to recognise the sustainable harvesting limit, so that value is not ascribed to goods harvested at unsustainable levels which incur more damage to the ecosystem than they are worth. See Table 3.4 for an example.

Table 3.4 Example of using production function method

A production function model to value inter-tidal salt marsh creation as an input to the fisheries catch in Scotland (Stevenson, 2001)	
A production function estimates the output as a function of the inputs used producing it. In this application the function has too inputs: human effort and the area of inter-tidal salt marsh in Scotland.	1. Function used to test the effect of managed realignment (the controlled breach of flood defences as a management strategy to counter rising sea levels) on the fish catch and price. 2. Data on the human effort (number of fishermen), catch data (in tonnes) and salt marsh area (ha) were collected at the level of the Scottish fishing districts. It was assumed that the salt marsh area in a given district has effect on the fish catch by the boats registered in this district. This is a necessary simplifying assumption and excludes factors from outside a given district on the activity in that district. 3. Three different product functions are used. Depending on the function, the net increase in the consumer surplus (due to increase in the area of salt marsh) was estimated to be between around £26,000 and £500,000 per year which translated into between £750-14,300 per ha of salt marsh per year.

For consumptive recreation, a number of studies in the UK and Europe have examined the economic value of angling (Davis and O'Neil, 1992; Green and Willis, 1996; Spurgeon and others 2001) and hunting (Casini and Romano, 1998; Maragon and Rosato, 1998), although no known studies have looked at the value of other forms of consumptive recreation, such as gathering of wild foods. However, these goods which are either marketed or have marketed substitutes are straightforward to value using market price data.

3.3.6 Cultural services

This category of service contains the largest proportion of benefits that can be classified as non-market. A first useful division to make is between use and non-use values. Where use values are entailed then a range of techniques can be employed. Only stated preference techniques, however, are capable of providing a measure of non-use value. Many of the services that fall under this category can be defined broadly as recreational enjoyment of nature. Although health benefits and landscape amenity may be treated separately. Whether individuals visit particular sites (wetlands, woodland or inter-tidal habitats) in order to paint; to walk to improve their health; to fish or collect fruit; or to observe wildlife - these can all be described as recreational activities. In addition, recreational activities are rarely limited to enjoyment of one aspect of the ecosystem. For many of these activities, individuals value a whole bundle of services provided by the ecosystem – the landscape, the fresh air, the sound of birds, the opportunity to swim and an appreciation of the cultural heritage associated with the site among others. Therefore, it is often very difficult to disentangle the various elements of the life-fulfilling function of ecosystems, and the risk of double-counting when employing benefits transfer is high.

Education and scientific research resource

The contribution of ecosystem services to marketed outputs such as TV broadcasts (eg nature documentaries) can be measured using pricing techniques. Attributing that value to a particular habitat or ecosystem type will be difficult, except where specific products can be identified (such as visitors' centres or TV broadcasts on native woodlands, etc). Where those educational services are provided for free, estimates of the value of education could be made using the cost of provision (although this is less than ideal, as the true value will be much higher, but little other data exist). The value of information in research and in providing for future needs is more difficult to assess, and is the subject of a growing literature.

Biomimicry is a relatively new field of scientific research that studies nature's functioning and then imitates or takes inspiration from the designs and processes of natural organisms or systems to solve human problems, (eg, a solar cell inspired by a leaf). The advantage of biomimicry is that it is non-extractive and therefore does not have sustainable management issues. Perhaps the most well-known example of biomimicry is velcro which was developed from the observation of the function of barbs on weed seeds. Other examples of biomimicry include study of the abalone mussel shell coating to develop lightweight but fracture-resistant materials for windshields and bodies of solar cars, airplanes; the development of super filters such as desalination and chemical separation devices through study of cell membrane functions; and the study of prairies to develop natural systems of agriculture, which would hold the soil, fertilise themselves, and protect themselves against pests (http://www.biomimicry.net/intro.html).

Identifying the potential existence and value of biomimicry in particular ecosystems in England will have to be based on either (1) the known existence of a studied process or organism for biomimicry (although only where the maintenance of the ecosystem is essential for continued research) and (2) pure conjecture about the potential benefits for future biomimicry (the option value). In both cases knowledge of the extent and value of such research can be assessed to give clues as to the potential value of a particular site (eg the commercial value of velcro could provide a possible upper limit if the value of other inputs to the velcro production process can be assumed to be zero). However, estimates derived in this way need to be treated with considerable caution and would only be defensible as illustrative examples.

Preservation of archaeology

This is not always going to be a benefit of ecosystem services, as some habitats (eg woodlands) might actually work to damage buried history. That said, with good management practice damage to archaeology can be prevented and woodlands can serve to protect this heritage, where alternative land uses would see them damaged or destroyed. Macmillan (2002) undertakes a benefits transfer exercise to estimate the non-market benefits of managing UK forests to protect archaeology. The data sources are two studies of the Environmentally Sensitive Area (ESA) programme in England and Scotland (Garrod and Willis, 1995 and Hanley and others 1998). The latter study estimates WTP for special management services related to the protection and management of archaeology in agricultural lands. The former relates to ESA schemes in general, but is used for its geographical coverage. The results of the benefits transfer exercise give a value to this service of £0 - £247 per hectare of forest. The results are subject to considerable uncertainty, but reflect the available knowledge on the subject.

No similar studies are available for wetland or intertidal contexts, but in a similar way to the approach taken in Macmillan (2002) the results from the agricultural context could be transferred to a wetland context. The difference may be in the accessibility to sites between wet and dry habitats.

Gene bank for research and development of products

The value of ecosystems as an input to pharmaceutical products has typically been valued according to the market value of these products and the likelihood of a particular input ending up in a particular product (as not all inputs are developed into products), rather than the ability of the products to relieve pain and suffering (or even death), and this is usually examined in a developing country or global context (see Pearce and Pearce, 2001 and Pearce and Puroshothaman, 1995 for a review). The world markets in pharmaceutical products derived from genetic resources, is valued at around US$500-800 billion (ten Kate and Laird, 2000). In the pharmaceutical context, the relevant economic value is the contribution that one more species makes to the development of new pharmaceutical products.

The fundamental equation elicited by Simpson and others (1996) is given below.

$$\max WTP = \frac{\lambda.(R-c)e^{\frac{-R}{R-K}}}{r(n+1)} \qquad [3.6]$$

where λ is expected number of potential products to be identified (10.52); n is number of species that could be sampled (250,000); c is the cost of determining whether a species will yield a successful product ($3,600); r is discount rate set at 10%; e is the natural logarithm (2.718); K is expected Research and Development cost per new product successfully produced ($300 million) and R is revenues from new product net of costs of sales but gross of R and D costs ($450 million). Substituting the estimates above into equation [3.6] gives a maximum willingness to pay (WTP) of $9410 for the marginal species.

Recreation

A large number of stated preference studies have been undertaken in the UK to estimate the value of recreation in different policy contexts as well as geographic contexts. Techniques used are market prices (for entrance to national parks), the travel cost and stated preference techniques.

Bishop (1992) presents the results of a contingent valuation study that estimates WTP for the landscape, wildlife, and recreational amenities of two woodland sites, Derwent Walk and Whippendell Wood in England. The valuation questions asked how much people were willing to pay per visit, the maximum amount they would pay per visit, and the amount they were willing to invest annually in a private forestry company guaranteeing unlimited access to the site. Mean individual WTP for a visit to Derwent Walk ranged from £0.42 to £0.97, and from £0.54 to £1.34 for Whippendell Wood. Total annual user benefits ranged from £289,830 for Derwent Walk (or £1,789 per hectare) to £109,904 for Whippendell Wood (or £1,596 per hectare).

Scarpa (2003) provides the value of the recreational function of woodlands in the UK based on data from the most extensive valuation study of woodland recreation, the European Union funded CAMAR study conducted in 1992 by Ni Dhubhain and others (1994) with sampling in six woodland sites across England. The findings were that a minimum of £1.66 pounds per visit to a maximum of £2.78 per visit is the compensating variation required for forgoing a woodland visit (the range arises from the use of slightly different methodologies). The study provides aggregate annual values of woodland recreation in the different tourist regions in the UK which range from £1.16 million in Cumbria to £90.47 million in East Anglia, using the lower bound estimates. The range of estimates for each of the tourist regions in England is provided in Table 3.5.

Table 3.5 Aggregate benefits of woodland recreation by tourist region (£ million/year) (£2003)

Estimated WTP per visit	£1.66/visit	£2.78/visit
English Tourist Regions		
Cumbria	0.77	1.95
Northumbria	3.54	8.90
North West	33.65	84.51
Yorkshire & Humberside	47.49	119.26
Heart of England	43.17	108.42
East Midlands	35.31	88.68
East Anglia	60.33	151.51
London	23.07	65.44
West Country	38.30	96.19
Southern	36.09	90.63
South East	40.18	100.91

Wetland recreation has also been extensively studied, and the best results now come from meta-analyses that draw on up to 40 different studies to estimate the value of different wetland services. The studies covered use a mixture of stated preference and travel cost methods for informal recreation. Woodward and Wui (2001) examine a number of different recreational services, and find the value per hectare of wetland for recreational fishing is £1,161, for bird-watching £3,944, and for bird hunting £244 (£,2001). Clearly, the latter two activities are potentially in conflict with each other, but the study shows which is the most highly valued by the studies covered, which is an immediate aid to decision-making.

Market price data can also be used to provide a lower bound estimate of the value of recreational services to the economy. For example, in 1998/99, RSPB reserves attracted over 1 million visitors with an estimated annual local expenditure of £11.8 million. In rural and remote areas, impact of bird-watching can be significant (Rayment and Dickie, 2001).

Landscape

The value of the wooded landscape in different geographical settings is estimated by Garrod (2002) using a choice experiment survey, a type of stated preference technique. The total value of views of urban fringe woodlands in England was found to be over £3.5 billion (capitalised value) or £150 annual net present value. These aggregate results are based on average household willingness to pay of £226 per year for access to woodland views on journeys (eg car, train, etc), and WTP of £269 for views from homes.

Garrod and Willis (1994) similarly estimate the value of a waterside location on housing prices using the hedonic price method. The sample considered individual property sale prices for Greater London and the Midlands over a five-year period (1985-1989). The explanatory variables for the house price opportunity function were environmental and socio-economic characteristics of the neighbourhood, and structural characteristics of the property. The estimations rendered for properties located on the waterside a premium of £2,689 for Greater London and £2,238 for the Midlands (£, 2001).

An example of the potential for double counting would be adding the value of increased property prices (representing both landscape and recreational access value) to results of a study that estimate recreational use without netting out the recreational value to resident populations.

Health

The health benefits of the countryside in general are widely appreciated, although no valuation studies have focused solely on this benefit. It is likely that in the valuation studies on recreational benefits respondents consider the health benefit of their recreational visit as part of the overall value of recreation. However, another way to approach the valuation of this service would be to take as a starting point the increased life expectancy of people in rural areas. The State of the Countryside 2004 (Countryside Agency, 2004) finds that according to standard health outcome indicators, on average, rural residents live longer and have better health during their lives than their urban counterparts. Taking this difference in life expectancy and multiplying it by the value of a statistical life year could provide a useful indicator of health benefits of rural areas. However, it would be difficult to attribute this to a particular ecosystem or even ecosystem type.

Historical meanings and cultural importance

The value of the historical importance of habitats, will be captured in part by valuations of archaeological preservation services described above. They may also be captured in valuation studies that elicit willingness to pay to preserve habitats against conversion to other land uses, where respondents' preferences for protection of the habitat could include a sense of history and cultural identity with the habitat (eg for ancient woodlands). No economic valuation work to date has focused on this aspect of value stemming from ecosystems (a widening literature exists on the value of cultural moments and other cultural/historical assets, see eftec (forthcoming) for a review).

The contribution that ecosystems make to the market value of cultural heritage in the UK would be very difficult to measure (eg the contribution made to the value of Turner paintings from inter-tidal habitats), as so many other factors also contribute to that value. No attempts to establish such contributions are known of in the literature. It is probably preferable to qualify these benefit categories rather than quantify them.

As discussed above under 'information' the non-market value of these contributions, as perceived by the population, is likely to be wrapped up in valuation study results relating to particular habitats (eg in WTP for preservation of a habitat).

Any quantitative assessment should consider historical value only once to avoid double counting with historical value in the information service category.

3.4 Issues and opportunities

3.4.1 Issues

In considering the economic valuation of ecosystem services in practice, a number of important issues need to be borne in mind.

The spatial scale

The benefits of ecosystem services are often manifest well beyond the borders of the ecosystem itself (eg with flood alleviation benefits being felt far downstream of a wetland). Establishing the appropriate scale of analysis is determined by (1) the extent of reach of the service itself (is it influencing systems locally, regionally or globally?) and (2) the population affected by the particular service.

The extent of the reach of the service is established at the stage of the scientific assessment. The difficulty lies in assigning a physical impact across a broad geographical scale. Presuming that can be done (regardless of the accuracy), an economic assessment can accompany that judgement. For example, if the maintenance of ecosystem services in a habitat in England means that populations of migrating birds are maintained, then the public in other countries enjoying those birds should also be accounted for. However, only a portion of the value that the public in other countries ascribe to bird-watching should be accounted for in the English study (as other factors, such as the maintenance of their own ecosystems will also be accounted for in their willingness to pay). The portion of value to account for will follow on from the scientific assessment.

Establishing the affected population is of course related to the extent of the reach of the service. However it is also influenced by the uniqueness of the ecosystem or ecosystem service. Generally speaking, where an ecosystem has few substitutes or is unique in other ways, it is likely to affect a large non-user population. For example, while few people in England are likely to come across a great crested newt, many would be willing to pay to protect the newt because of its rareness and association with the unique natural heritage of Britain. For less unique aspects, distance decay[5] can be applied to establish the size of that non-user population.

In practice, a pragmatic accounting stance has to be adopted in specifying the scale, where the gains in accuracy are balanced against the costs of spreading the scale wider.

Scope and scarcity

Somewhat related to the issue of spatial scale above is the ability of marginal estimations of value from stated preference work to reflect the behaviour of a demand curve at the extremes. For example, one would expect that the willingness to pay for a hectare of wetland would be greater as the total stock of wetland declines, or as the use of wetland functions approaches a threshold point where there is a risk of ecosystem collapse. These aspects can be addressed in stated preference work by varying the scope of the change being estimated at various points in the questionnaire, and by asking WTP for changes in risk of ecosystem collapse. Most

[5] The tendency for WTP to vary (e.g. decrease) as the respondent's distance from the resource in question increases.

stated preference work only estimates values for one or a few points along the demand curve, and future work aimed at estimating a demand curve could be very useful as it would collect data for a wider range of policy outcomes and address some of the aspects of ecosystem dynamics that a single estimate cannot.

Aggregation and double counting

Double counting is an issue that has been brought up throughout this report, particularly in this Section. In general, double-counting needs to be thought of at least at three stages of analysis. These are described below. Overall, while double-counting is an issue, it can be avoided with careful thought. The outcome may be that the resulting estimates are under-estimates, but it is preferable to have a conservative result than one that could be dismissed because of poor accounting.

Generally speaking double counting will be more difficult to avoid with the use of benefits transfer as a valuation technique compared to undertaking original valuation work, both are dealt with below.

1) Identification of economic benefits

In order to avoid double counting in the aggregation of ecosystem services attributable to one ecosystem, the scientific analysis needs to consider only the combined effect of all ecosystem services and/or attribute and apportion benefit to each ecosystem service. The analysis needs to be aware of (a) interactions between services that provide the same end benefit; and (b) the possible incompatibility between the provision of different services, (eg provision of water for extraction and maintenance of groundwater supplies). The risk of double counting is greatest when ecosystem services are valued in the absence of a particular policy context and impact analysis, which would make trade-offs between services clear by modelling the 'with' and 'without' scenario.

2) Identification of affected population

One way to avoid double counting is to check that the same population is not being used for aggregation of economic values. Typically local, resident populations near an ecosystem will be impacted by changes in ecosystem service provision differently to those further downstream. By identifying an affected population for each welfare impact area of potential overlap will become evident where the same population is affected by a number of different welfare impacts. It is only at these points of overlap that there is risk of double-counting. This double counting can be avoided by careful examination of the extent that the transferred estimates (or new study design) value more than one welfare impact (see below).

3) Application of benefits transfer

One difficulty in benefits transfer is that either the good or service itself or the change in the good or service and the context will rarely be exactly the same in the study site as in the policy site. Even when it appears that these are a good match, further examination of the original study (eg precise wording of the survey questionnaire, which is not always made publicly available) may show that respondents were in fact considering additional or fewer environmental benefits than the study description implies.

By their very nature some valuation studies estimate results which are difficult to entangle. Contingent valuation studies will typically estimate the value of a number of the services of a particular ecosystem altogether (as a 'bundle'). On the surface it may appear that only landscape benefits are being estimated, for example. However, careful examination of the original study will reveal that the landscape has been described as maintaining a certain level of biodiversity and that the people surveyed were actually using the area for recreation. Thus, adding recreational value and biodiversity value to this study's results on 'landscape' value would be double counting.

On the other hand, there are certain services, such as climate regulation, that do not tend to interact with the economic values produced by other services of the same ecosystem and can thus be valued separately (eg from recreational values of forests), with little risk of double counting. This is because, for example, in this example, the carbon sequestration benefits of forests are manifest in the avoided damage costs of climate change which are (1) suffered by a different and/or much larger population than that of the forest visitors, and (2) the value of forest recreation is unlikely to be affected by knowledge that the forest is acting as a carbon sink (although this could change as climate change awareness rises).

4) Design of a new study

Where stated or revealed preference techniques are the preferred option for valuing an ecosystem service, undertaking original work will always provide more robust estimates of the welfare impacts of changes in ecosystem service provision. A new study will collect data on the exact change that is being valued and will survey the actual population affected. However, as stated previously in this report, use of both pricing and valuation techniques will likely be required to arrive nearer the total economic value of a change in an ecosystem and the range of affected ecosystem services. Thus, a new valuation study needs to be carefully designed with this in mind. Where it is preferable to use either market data or benefits transfer to estimate certain ecosystem services (see earlier in this section), then the remaining services valued in a stated preference study will need to remind survey respondents not to think of those other services and only to focus on the services that require valuation. In this way one is sure to avoid double counting where the survey results also include elements of other services valued through separate techniques. This was the approach used in the RPA (2002) study on the intangible costs of flooding where respondents were asked to focus only on the psychological stress suffered (and loss of personal effects of no financial value, but of high emotional value) and not to focus on the financial costs which were reimbursed through insurance.

Allocation over time

It is frequently necessary to choose between options for ecosystem management that differ in temporal patterns of costs and benefits, or that differ in their duration. Discounting provides a common matrix that enables comparison of costs and benefits that occur at different points in time.

Risk and uncertainty

In an economic evaluation, risk and uncertainty are associated with both physical outcomes and their economic consequences. On the physical side, the lack of scientific understanding or adequate monitoring data to inform models can be a barrier to understanding potential future outcomes of ecosystem loss and degradation. Also, with economic analysis, our understanding of human behavioural responses to ecosystem change is also fraught with uncertainty. Such uncertainties can influence projected benefits and so also need to be incorporated into any evaluation of options. Being transparent about all the assumptions made and undertaking sensitivity and scenario analyses and validity checks where possible will lend more credibility to the analysis.

Data limitations

It is inevitable that some of the data required for an economic appraisal will not be readily available. This includes physical impact data as well as economic data. Budgetary constraints often limit extensive collection of original data. Where data are limited, this should be acknowledged and the measures taken in response to this limitation clearly specified. The results and recommendations should be made explicitly conditional on these limitations. The various techniques used to value non-market goods and services are each associated with specific data limitations.

3.4.2 Opportunities

The opportunities presented by the continued use of economic valuation to inform policy decisions for ecosystem management are that in so doing we develop our knowledge base.

- By undertaking appraisal of ecosystems using the service-to-value pathway approach (Figure 1.2), scientists and economists can add to our understanding of the extent to which ecosystem services impact upon economic well-being. This would add to the current literature, providing more 'rules of thumb' in relation to different ecosystem types and services (eg as in Table 3.3 which shows the contribution of different woodlands to carbon sequestration services).

- By undertaking stated preference studies, we are collecting new economic data and therefore filling gaps in our understanding about (1) how we expect economic actors to respond to ecosystem change; (2) the preferences of different populations for quality and quantity of ecosystems; and (3) attitudes towards ecosystems that inform valuations and decisions. This information can be used to improve future benefits transfer exercises, for example, and also shape future information campaigns.

4 Recommendations and conclusions

While it may be possible to value some ecosystem services on their own, for the most part ecosystem services interact to produce combined benefits that are evident in the quality of water, air and land resources, or are only evident through their absence when flooding, erosion or biodiversity loss result. The catalogue of services by ecosystem type presented here is a useful tool which can help in the process of characterising and quantifying these interactions and contributions from a particular site. Using the catalogue as a checklist for identifying those services which have significant effect on human wellbeing by habitat type is a useful first step in the valuation process.

Applying a cost-benefit framework, which compares the value of ecosystem services 'with' and 'without' a given action, is the recommended way to approach economic valuation of ecosystem services. This requires identifying the affected populations, the winners and losers, and making assumptions about their behavioural responses to ecosystem service loss. Whether the result of ecosystem service loss is increased expenditure to replace ecosystem services and/or loss of well-being from loss of irreplaceable services, these can be estimated with economic valuation and pricing techniques. The selection of the most appropriate technique will depend on whether the effect is manifest in the marketplace, on the availability of data, the need for accuracy of results, the decision-making context and the amount of time and resources that are available for the assessment.

However, it is important to recognise that economic valuation is only the last step in a detailed impact assessment that requires scientific understanding of ecosystem processes interactions. This so-called 'services-to-value pathway' approach should provide quantitative data on the extent of service provided as an input to economic valuation at the final stage. The four steps set out in this report in Section 3.2.1, if followed through for each service should help to avoid double-counting and add to the rigour of the analysis. In tracing through the effects of ecosystems on the broader environment, interactions (conflicts, trade-offs and complementarities) between services should become apparent. What is valued with economic valuation techniques is not the service itself, but the various impacts of the service on the broader environment and beneficiaries.

The total economic value concept that underpins the economic valuation techniques is a useful tool for identifying the many aspects of value that an ecosystem can harbour and the ways that these are manifest (eg through direct use of the ecosystem, or because of non-use related reasons – such as bequest value). TEV is also useful for selecting appropriate valuation techniques (eg only stated preference techniques can capture non-use value). Where ecosystem services provide direct input to the economy, and where these effects can be measured using price data, then pricing techniques are preferable. While some services may generate only market or only non-market benefits, most are likely to generate both types of benefits (eg (avoided) the financial costs of flooding and the pain and suffering of flooding on victims). Thus, a mix of pricing and valuation techniques will be required in order to get the whole picture.

This report provides a number of examples under each ecosystem service type of valuation work undertaken in the UK. This should prove useful for understanding the methods involved and possibly for use in benefits transfer to make assessments of the magnitude of value of ecosystems. However, for most policy applications some original work will be required at the valuation stage. The case study presented in Annex 2 provides an example of how original valuation work and benefits transfer can be combined to answer a policy question.

The research needs in this field are for more studies to be undertaken which closely link ecological and economic assessment. Of particular value would be work focussed on estimating the economic benefits of different management scenarios in order to be able to estimate the effect of marginal changes and to encourage better management of the natural environment by resource owners. Where the benefits of good management accrue to others (eg to water companies, shipping companies), then a case could be made for payment for ecosystem service maintenance to resource managers from beneficiaries.

Another further research area is about understanding people's preferences much better than we do at present. While there is a growing literature containing original valuation work for ecosystems, it is not always clear what exactly were included in the WTP estimates. This is especially relevant for revealed and stated preference techniques rather than pricing approaches. It would be interesting to know how many of the ecosystem services are already known by individuals and to what extent, which ones of these are taken into account when preferences are sought and how much information can feasibly be provided. Such information can be obtained through additional questions in a stated preference questionnaire or by conducting valuation workshops that allow time for presentations and discussion. The benefit of learning more about the construction of such preferences is that we could make better decisions about which technique to use and how to use them when estimating the economic value of ecosystem services and to avoid omissions or double-counting.

5 Glossary

Aquifer An underground layer of rock, sand or gravel which can hold significant quantities of water (Allaby, 1998).

Autotrophic More organic matter is produced by plants than is remineralized (Abril and Borges, 2004 – from Gattuso and others 1998).

BAP UK Biodiversity Action Plan.

Benthos (adj. benthic) In freshwater and marine ecosystems, the collection of organisms attached to, resting on, or burrowing into bottom sediments (Allaby, 1998).

Blanket bogs Blanket bogs form a mantle of peat not only in wet hollows, but also over large expanses of the undulating land surface. Their only source of water and nutrients is rainfall. The vegetation is dominated by Sphagnum bog mosses and heath species (UK BAP, 1999).

Coagulation The clumping together of **colloidal** particles to form a large mass (Allaby, 1998).

Coastal squeeze Reduced width of the intertidal zone caused by rising sea levels raising the low water mark whilst the high water mark is held in place by the presence of hard sea defences (Burd, 1995).

Colloidal matter A suspension of fine-grained material (Andrews and others 1996)

Consumptive recreation activities that involve the extraction of habitat resources, eg. Fishing.

Coppice Coppicing is the art of cutting of trees and shrubs to ground level allowing vigorous regrowth and a sustainable supply of timber (Sanderson & Prendergast, 2002).

Denitrification The conversion of nitrate or nitrite to gaseous products (Allaby, 1998).

Eutrophication The process of nutrient enrichment in aquatic ecosystems, stimulating algal blooms. On death, bacterial decomposition of the excess algae may seriously deplete oxygen levels (Allaby, 1998).

Fen litter Litter comprised of a mixture of species including grasses, sedges, and scrub (Sanderson and Prendergast, 2002).

Fixing/fixation A soil process by which certain nutrient chemicals required by plants (eg. nitrogen, carbon) are changed from a soluble and available form into a much less soluble and almost unavailable form (Allaby, 1998).

Flocculation A process in which clay and other soil particles adhere to form larger groupings (Allaby, 1998). Salt flocculation is a process whereby salt water causes clay particles to stick together, increasing their effective particle size and accelerating their settlement (Davidson and others 1991). Organic flocculation occurs where particles are organically bound, eg faecal pellets can form significant components in sediment, binding particles together with mucus (Woodroffe, 2003 – from Ginsburg, 1975).

Green wood trades The many different skills involved in coppicing are communally called green wood trades eg woodland managers and owners and those commercially producing products such as charcoal, hurdles, spars (Sanderson and Prendergast, 2002).

Liggers Split rods used for the ridging on thatched roofs (Sanderson and Prendergast, 2002).

Maërl Collective name for calcareous red seaweeds (UK BAP, 1999)

Managed realignment Setting back the line of actively maintained defence, or promoting intertidal habitat between the old and new defences (Burd, 1995).

Mineralisation The conversion of organic tissues into an inorganic state as a result of decomposition by soil micro-organisms (Allaby, 1998).

National Nature Reserves (NNRs) SSSIs managed by English Nature, or approved partners, specifically to conserve their wildlife features, and to allow people to experience nature at its best (Townsend and others 2004).
Ombrotrophic A mire system that is fed by rainwater only (Allaby, 1998).

Paleo-environmental data Data on the 'ancient' environment from fossil and sedimentary evidence (Allaby, 1998).

Pioneer A species which occurs early in succession (Allaby, 1998).

Primary production Biomass produced by photosynthetic autotrophs (mainly green plants) in the form of organic substances, some of which are used as food materials (Allaby, 1998).

Radionuclides Radioactive particles.

Ramsar sites Internationally important wetland areas designated under the 1971 Ramsar Convention on 'Wetlands of International Importance, especially as Waterfowl Habitat (Townsend and others 2004).

Sedimentation Is the deposition of sediment which occurs in intertidal habitats because steep ionic gradients destabilise colloidal matter, causing it to flocculate and sink (Andrews and others 1996), whilst in saltmarshes it is aided by adhesive algal mats on the surface and by flocculation of clay by the salt exuded from marsh plants (Pethick 1984; UK BAP 1995, 1999; Bird 2000). Sediment removal from the water column can also be biologically mediated, eg. by phytoplankton (Ayukai and Wolanski, 1997; Woodroffe, 2003).

Sites of Special Scientific Interest (SSSIs) Sites selected by English Nature and protected under the Government's wildlife legislation, strengthened by the Countryside & Rights of Way Act 2000. They form a nationally important series of the best and rarest examples of our wildlife and geological features (Townsend and others 2004).

Special Areas of Conservation (SACs) Sites classified under European Union Directive 92/43/EEC known as the 'Habitats Directive'. This promotes the conservation of important, rare or threatened habitats and species across Europe. It lists 168 natural habitat types for conservation by designation as SACs, and 632 species whose conservation requires designation of their habitat as SACs. Those habitats and species at greatest risk are given ‘priority’ status (Townsend and others 2004).

Special Protection Areas (SPAs) Sites classified under the European Union Directive 79/409/EEC, known as the ‘Birds Directive’, to conserve the habitats of certain migratory or rare birds. Together, SACs and SPAs form a network of protected sites that make up the Natura 2000 series. The UK Government has made a formal commitment to maintaining these sites in ‘favourable conservation status’ (Townsend and others 2004).

Sink A natural reservoir of energy or materials that can receive energy or materials without undergoing change (Allaby, 1998).

Sublittoral The shore zone lying immediately below the intertidal zone, extending to about 200m depth or to the edge of the continental shelf (Allaby, 1998).

Swamp An area normally covered by water through out the year (Allaby, 1998).

Volatilization Passing into a gaseous phase (Allaby, 1998).

Warping A practice of opening sluices to flood land and deposit sediments (Sheail, 1971; Mayled, 1998).

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Annex 1 BAP species-habitat associations

(English Nature, 1999). 'P', 'S' and 'x' signify the habitat as being primary, subsidiary or less important to the species respectively. A question mark indicates where there is some uncertainty over the affinity of a species to a particular habitat.

Woodland

Scientific name	Common name	Taxon	Upland Oak	Lowland Beech and yew	Upland Mixed Ashwoods	Wet Woodland
Vertebrates						
Triturus cristatus	Great crested newt	Amphibian	x	x	x	x
Muscicapa striata	Spotted flycatcher	Bird	S	S	S	S
Tetrao tetrix	Black grouse	Bird	S		S	
Turdus philomelos	Song Thrush	Bird	S	S	S	S
Barbastella barbastellus	Barbastelle bat	Mammal		x		x
Lutra lutra	Otter	Mammal				x
Muscardinus avellanarius	Dormouse	Mammal			x	
Myotis bechsteini	Bechstein's bat	Mammal		S		x
Myotis myotis	Greater mouse-eared bat	Mammal		S		S
Pipistrellus pipistrellus	Pipistrelle bat	Mammal		S		x
Rhinolophus ferrumequinum	Greater horseshoe bat	Mammal				S
Rhinolophus hipposideros	Lesser horseshoe bat	Mammal		S		S
Scirius vulgaris	Red squirrel	Mammal	x		x	
Invertebrates						
Formica lugubris	Hairy wood ant (Northern)	Ant	x		x	
Formica rufa	Southern wood ant	Ant	x	x		
Formicoxenus nitidulus	Shining guest ant	Ant	x	x		
Osmia parietina	A mason bee	Bee	x			

Scientific name	Common name	Taxon	Upland Oak	Lowland Beech and yew	Upland Mixed Ashwoods	Wet Woodland
Byctiscus populi	A leaf-rolling weevil	Beetle				x
Carabus intricatus	Blue ground beetle	Beetle	P			
Crytocephalus decemmaculatus	A leaf beetle	Beetle				P
Crytocephalus sexpunctatus	A leaf beetle	Beetle	x			
Lucanus cervus	Stag beetle	Beetle		S		
Melanapion minimum	A weevil	Beeltle				?P
Oberea oculata	A longhorn beetle	Beetle				?
Procas granulicollis	A weevil	Beetle	?P			
Rhynchaenus testaceus	A jumping weevil	Beetle				?P
Lophopus crystallinus	A freshwater bryozoan	Bryozoa				x
Argynnis adippe	High brown fritillary	Butterfly	P		P	
Boloria euphrosyne	Pearl-bordered fritillary	Butterfly	P		P	
Carterocephalus palaemon	Checkered skipper	Butterfly	P		P	
Hammerschmidtia ferrunginea	A hoverfly	Fly			?	P
Lipsothrix ecucullata	A cranefly	Fly				P
Lipsothrix errans	A cranefly	Fly				P
Lipsothrix nervosa	A cranefly	Fly				P
Lipsothrix nigristigma	A cranefly	Fly				P
Cosmia diffinis	White-spotted pinion	Moth	x			
Epione paralellaria	Dark bordered beauty	Moth				P
Eustroma reticulata	Netted carpet	Moth				P
Hydrelia sylvata	Waved carpet	Moth		x		
Jodia croceago	Orange underwing	Moth	x			
Minoa murinata	Drag looper	Moth		x		
Rheumaptera hastata	Argent and sable	Moth	S			

Scientific name	Common name	Taxon	Upland Oak	Lowland Beech and yew	Upland Mixed Ashwoods	Wet Woodland
Schrankia taenialis	White-line snout	Moth				P
Trisateles emortualis	Olive cresent	Moth		P		
Xestia rhomboidea	Square-spotted clay	Moth	x	x		
Vascular plants						
Cypripedium calceolus	Lady's slipper orchid	Vascular plant			x	
Linnaea borealis	Twinflower	Vascular plant	S			
Melampyrum sylvaticum	Small cow-wheat	Vascular plant	x		x	
Sorbus leyana	Ley's whitebeam	Vascular plant			x	
Trichomanes speciosum	Killarney fern	Vascular plant	x			
Lower plants						
Boletus regius	Royal bolete	Fungi		S		
Boletus satanus	Devil's bolete	Fungi		P		
Hericeum erinaceum	A hedgehog fungus	Fungi		P		
Hydrinoid fungi (14 species)	Tooth fungi	Fungi		P		
Hypocreopsis rhododendri	An ascomycete	Fungi	S			
Microglossum olivaceum	An earth-tongue	Fungi	S			
Arthothelium dictyosporum	A lichen	Lichen	x			
Bryoria smithii	A lichen	Lichen	x			
Catapyrenium psoromoides	Tree catapyrenium	Lichen			x	
Enterographa elaborata	A lichen	Lichen		x	x	
Graphina pauciloculata	A lichen	Lichen	x			x
Pseudocyphellaria norvegica	A lichen	Lichen	x			x
Acrobolbus wilsonii	Wilson's pouchwort	Liverwort	x			
Lejeunea mandonii	Atlantic lejeunea	Liverwort	x			
Pallavicinia lyellii	Veilwort	Liverwort				x

Scientific name	Common name	Taxon	Upland Oak	Lowland Beech and yew	Upland Mixed Ashwoods	Wet Woodland
Buxbaumia viridis	Green shield-moss	Moss	x			
Campylopus setifolius	Silky swan-neck moss	Moss	x			
Sematophyllum demissum	Prostrate feather-moss	Moss	x			
Weissia multicapsularis	A moss	Moss	x			
Zygodon forsteri	Knothole moss	Moss		x		

Intertidal *This column includes data for habitats that are not included in the ecosystem services analysis.

Scientific name	Common name	Taxon	Salt Marsh/Seagrass beds/Mudflats/Sheltered muddy gravels	Seagrass beds/Maerl beds/Saline Lagoons/Mud in deep water/ *Serpula vermicularis* beds*
Vertebrates				
Bufo calamita	Natterjack toad	Amphibian	P	
Triturus cristatus	Great crested newt	Amphibian	x	
Alauda arvensis	Skylark	Bird	S	
Carduelis cannabina	Linnet	Bird	S	
Emberiza schoeniclus	Reed bunting	Bird	S	
Invertebrates				
Amara strenua	A ground beetle	Beetle	P	
Anisodactylus poeciloides	A ground beetle	Beetle	P	
Dyschirius angustatus	A ground beetle	Beetle	x	
Melanapion minimum	A weevil	Beetle	S	
Paracymus aenus	A water beetle	Beetle	S	P
Gammarus insensibilis	Lagoon sand shrimp	Crustacean		x
Tenella adspersa	Lagoon sea slug	Mollusc		P
Vertigo angustior	Narrow-mouthed whorl snail	Mollusc	P	
Thetidia smaragdaria maritima	Essex emerald	Moth	P	
Clavopsella navis	A hydroid	Sea anemone		x
Edwardsia ivelli	Ivell’s sea anemone	Sea anemone		x
Nematostella vectensis	Starlet sea anemone	Sea anemone		P
Orthotylus rubidus	A plant bug	True bug	P	x
Armandia cirrhosa	Lagoon sandworm	Worm		x

Scientific name	Common name	Taxon	Salt Marsh/Seagrass beds/Mudflats/Sheltered muddy gravels	Seagrass beds/Maerl beds/Saline Lagoons/Mud in deep water/ *Serpula vermicularis* beds*
Vascular plants				
Cochlearia scotica	Scottish scurvygrass	Vascular plant	P	
Euphrasia heslop-harrisonii	An Eyebright	Vascular plant	x	
Limonium (endemic taxa)	Sea lavender	Vascular plant	x	
Lower plants				
Chara baltica	Baltic stonewort	Stonewort		P
Chara canescens	Bearded stonewort	Stonewort		P
Lamprothamnium papulosum	Foxtail stonewort	Stonewort		P
Tolypella nidifica	Bird’s nest stonewort	Stonewort		P

Terrestrialised freshwater wetland

Scientific name	Common name	Taxon	Grazing Marsh	Purple moorgrass and rush pastures	Fen	Reedbed	Raised Bog	Blanket Bog
Vertebrates								
Bufo calaminta	Natterjack toad	Amphibian	P				S	S
Rana lessonae	Pool frog	Amphibian			S			
Triturus cristatus	Great crested newt	Amphibian	x	S	S		x	x
Acrocephalus paludicola	Aquatic warbler	Bird			S	P		
Acrocephalus palustris	Marsh warbler	Bird				S		
Alauda arvensis	Skylark	Bird	S	S			S	
Botaurus stellaris	Bittern	Bird	S		S	P		
Emberiza schoeniclus	Reed bunting	Bird		x	S	P		
Miliaria calandra	Corn bunting	Bird				x		
Arvicola terrestris	Water vole	Mammal			x	x		
Lutra lutra	Otter	Mammal			x	x		
Myotis myotis	Greater mouse-eared bat	Mammal	x					
Pipistrellus pipistrellus	Pipistrelle bat	Mammal	x		x			
Rhinolophus ferrumequinum	Greater horseshoe bat	Mammal	x					
Invertebrates								
Amara strenua	A ground beetle	Beetle	P					
Anisodactylus poeciloides	A ground beetle	Beetle	P					
Badister peltatus	A ground beetle	Beetle	P		S			
Bembidion humerale	A ground beetle	Beetle					P	
Bidessus unistriatus	A diving beetle	Beetle			?			
Cryptocephalus decemmaculatus	A leaf beetle	Beetle					P	

Scientific name	Common name	Taxon	Grazing Marsh	Purple moorgrass and rush pastures	Fen	Reedbed	Raised Bog	Blanket Bog
Cryptocephalus exiguus	A leaf beetle	Beetle			P			
Curimopsis nigrita	Mire pill-beetle	Beetle					P	
Donacia aquatica	A reed beetle	Beetle			P	?		
Donacia bicolora	A reed beetle	Beetle	x		P			
Dromius sigma	A ground beetle	Beetle			P	P		
Hydrochara caraboides	Lesser silver water beetle	Beetle	P					
Hydroporus rufifrons	A diving beetle	Beetle	x		x			
Laccophilus ponticus/poecilus	A diving beetle	Beetle	P		P			
Melanapion minimum	A weevil	Beetle			S		S	
Oberea oculata	A longhorn beetle	Beetle			P			
Panagaeus cruxmajor	A ground beetle	Beetle	P		x			
Pterostichus aterrimus	A ground beetle	Beetle			P	x	?	
Synaptis filiformis	A click beetle	Beetle	P					
Carterocephalus palaemon	Checkered skipper	Butterfly		P				
Eurodryas aurinia	Marsh fritillary	Butterfly		P	P		x	
Lycaena dispar	Large copper	Butterfly			P			
Stethophyma grossum	Large marsh grasshopper	Cricket			P		S	
Odontoymia hydroleon	A soldierfly	Fly			P			
Anisus vorticulus	A snail	Mollusc	P					
Segmentina nitida	Shining rams-horn snail	Mollusc	P					
Vertigo angustior	Narrow-mouthed whorl snail	Mollusc			S			
Vertigo geyeri	A whorl snail	Mollusc			S			
Vertigo moulinsiana	Desmoulin's whorl snail	Mollusc			P			
Athetis pallustris	Marsh moth	Moth	P		S			

Scientific name	Common name	Taxon	Grazing Marsh	Purple moorgrass and rush pastures	Fen	Reedbed	Raised Bog	Blanket Bog
Hemaris tityus	Narrow-bordered hawk-moth	Moth		P	P		P	P
Hydraecia osseola hucherardi	Marsh mallow moth	Moth	P			S		
Mythimna turca	Double line	Moth	P	P				
Rheumaptera hastata	Argent and Sable	Moth		P				S
Schrankia taenialis	White-line snout	Moth		S	P			
Xylena exsoleta	Sword-grass	Moth		P				
Clubiona rosserae	A spider	Spider			P			
Dolomedes plantarius	Fen raft spider	Spider	P		P			
Hydrometra gracilenta	Lesser water measurer	True bug	P		P			
Chrysis fulgida	A ruby-tailed wasp	Wasp			x			
Hirundo medicinalis	Medicinal leach	Worm			S			
Vascular plants								
Apium repens	Creeping marshwort	Vascular plant	x					
Calamagrostis scotica	Scottish small-reed	Vascular plant		P	x			
Carex vulpina	True fox-sedge	Vascular plant	P					
Euphrasia rivularis	An eyebright	Vascular plant		x				
Leersia oryzoides	Cut-grass	Vascular plant	P					
Liparis loeselii	Fen orchid	Vascular plant			P			
Lycopodiella inundata	Marsh clubmoss	Vascular plant		x				x
Mentha pulegium	Pennyroyal	Vascular plant	x					
Pilularia globulifera	Pillwort	Vascular plant			x	x		
Potamogeton compressum	Grass-wrack pondweed	Vascular plant	S					
Saxifraga hirculus	Yellow marsh saxifrage	Vascular plant			P			x
Sium latifolium	Greater water-parsnip	Vascular plant	S		P			

Scientific name	Common name	Taxon	Grazing Marsh	Purple moorgrass and rush pastures	Fen	Reedbed	Raised Bog	Blanket Bog
Spiranthes romanzoffiana	Irish lady's-tresses	Vascular plant		x				x
Lower plants								
Armillaria ectypa	An agaric	Fungi			P			
Jamesoniella undulifolia	Marsh earwort	Liverwort			x			
Laphozia rutheana	Norfolk flapwort	Liverwort			x			
Pallavicinia lyellii	Veilwort	Liverwort					x	
Hamatocaulis vernicosus	Slender green feather-moss	Moss			P			
Leptodontiumscens	Thatch moss	Moss		x				
Sphagnum balticum	Baltic bog-moss	Moss					P	S
Chara curta	Lesser bearded stonewort	Stonewort			x			
Nitella tenuissima	Dwarf stonewort	Stonewort			P			
Tolypella prolifera	Great tassel stonewort	Stonewort			x			

Annex 2 Case study

Introduction

This annex illustrates by means of a case study how an appraisal of the ecosystem services provided by a Community Woodland could be applied to a decision-making process. The case study describes a decision by a hypothetical donor to provide greater financial incentives to farmers to plant a Community Woodland on their land. Wantage in Oxfordshire is one of the potential sites considered by the donor.

Community Woodlands are open access woodlands intended to provide recreational opportunities for those living in urban areas or villages and to improve the landscape around such areas. Under the Forestry Commission's Community Woodlands Scheme (CWS), one-off payments of £950 per ha are given to landowners in a ten-year contract in which the applicant grants access to the public. In order to qualify, such woodlands must be within five miles of a village, town or city edge, and there must be few other woodlands available for recreation.

Wantage is a small market town 15 miles from Oxford with an adult population of about 11,000. It is situated in the North Wessex Downs and is near a long distance footpath popular with walkers, the Ridgeway. Currently there is no take-up of the CWS around Wantage[6] and no other open access woodlands nearby.

The decision considered here is whether to increase incentive payments for the CWS to encourage take up of the scheme around Wantage. This decision is of course purely hypothetical; if there were to be any increase to CWS payments, they would presumably have to be on a nation-wide level and not just increased in particular areas. However, because of the existence of a detailed contingent valuation (CV) survey of the Wantage area (Bateman al., 1996), this location is suitable for use in a case study. In order to decide whether the payment increase should go ahead, it should be considered what the ecosystem service benefits of the woodland might be (net of any possible environmental costs of the woodland), and whether they are greater than the cost of the increased payment. The distribution of costs and benefits should also be considered, and whether additional payment streams from parties benefiting from the woodland could be sought.

The contingent valuation element of this case study is taken from Bateman and others (1996). Other elements are taken from a comprehensive set of reports to the Forestry Commission on the social and environmental costs and benefits of woodlands in the UK by Willis and others (2003). This overarching report and its several sub-reports are denoted by the superscript [FC].

Appraisal process

The appraisal method suggested here is a cost-benefit analysis (CBA). The appraisal process is as follows:

- Identify the social and environmental benefits and costs of the proposed woodland.

[6] Or at least, at the time of writing of Bateman et al. (1996). Internet searches indicate that there has been no take-up of the scheme around Wantage in the intervening period.

- Of these, identify which may be estimable through benefits transfer from other studies (referred to later as **transferred elements**).
- The remaining will need to be identified through original research (*original elements*). Some of these may be appropriately estimated through techniques such as production function and hedonic pricing. Others may require a stated preference study.
- In both cases, it may be necessary to consider whether some benefits may be small in proportion to the amount of time, effort and cost which it may take to monetise them. It may be sensible to consider whether estimating them will actually sway the result before embarking on doing so.
- In this particular case study, as it is not known in advance what the new level of the payment should be, it is also necessary to conduct a survey of farmers to find out their willingness to accept compensation (WTA) for planting woodlands for community access.
- Compare the calculated costs to benefits and perform a sensitivity analysis.
- Consider the distribution of costs and benefits – ie establish to which parties costs and benefits accrue.

The principal social and ecosystem services of woodlands in Great Britain are described in Willis and others[FC] (2003). These are, also noting whether they will need to be transferred or originally researched:

- recreation (original)
- landscape amenity (original)
- biodiversity provision (probably original although possibly transferred if appropriate)
- carbon sequestration (transferred) and
- absorption of air pollution (transferred)

Only some of these are suitable for valuation by local residents in a stated preference survey. It is appropriate to ask residents for their willingness to pay (WTP) for those services which they can have direct use from, such as recreation and amenity, and to some extent non-use values for biodiversity. Carbon sequestration and prevention of air pollution both relate to indirect use benefits from processes which are not observed, and not easily appreciated by respondents. These ecosystem services are more appropriately valued through the role they play in preventing harm, and can be assessed through hedonic pricing and other methods. In addition, it is more difficult and less appropriate to transfer values which are likely to be specific to the individual site (eg amenity), rather than true of all such sites. All of the ecosystem services generate use values, although biodiversity provision contains both use and non-use elements.

Willis and others. also note that woodlands impose a cost as trees reduce the amount of water available for potable use. This is in contrast to the services that woodlands provide in terms of regulating water supply and increasing water quality, which are not monetised in the report.

The WTA of farmers will incorporate the opportunity costs of planting the woodland (in terms of profits forgone from other crops) and also compensation for any disbenefits the farmer perceives in allowing public access to his land. It is important that the CV survey of farmers does not indicate that the possibility of payments is actually likely, as this may make farmers act strategically and overstate their WTA.

Transferred elements of the appraisal

The figures used in this section have a basis in research, but are rather "low resolution". Were they to be used in a more rigorous CBA, they would need to be amended, ie the transfer value for any one location will be dependent on the size and demographic profile of the local population, and the amount of local air pollution from roads, power stations, etc. They are used here for illustrative purposes.

Trees absorb several pollutants harmful to human health, such as particulates, ozone and sulphur dioxide. Estimated dose-response relationships between these pollutants and both mortality and morbidity (measured by respiratory hospital admissions) have been established by the Department of Health (Department of Health, 1999). Part of the benefit of estimated reductions in levels of pollutants from the woodland is associated with avoided statistical fatality and the costs of hospital treatment. Using this technique, Powe and Willis[FC] (2002) calculate the monetised benefits of the reduction of pollution by woodlands in the Southeast Region of England to be £2.2 million per annum. With a total area of woodland of 226,000 hectares, this represents an approximate value of £9.70 per hectare per annum[7].

The benefits of carbon sequestration can be similarly monetised. For the social cost of carbon, Brainard and others[FC] (2003) use an intermediate value cited by the Intergovernmental Panel on Climate Change of £14.70 per tC. Again, the amount of carbon sequestrated by a typical hectare of forest depends on the tree and soil type. Brainard and others take these factors into account in calculating a present value for indefinite carbon sequestration by woodlands in Southeast England of £730 million. This translates into an annualised figure[8] of £109 per hectare per annum[9].

The results presented by Hanley and others[FC] (2002) on the benefits of woodland biodiversity are less transferable. Valuations of biodiversity are often very context-specific, and are either for particular habitats or for particular species. Valuations for different types of forest habitat are summarised in Willis and others (2003), but are for forest area of 12,000 hectares. Because generally large areas of habitat proportionally contain greater numbers of species than smaller areas, it is not appropriate to re-scale these values for a 40 hectare woodland. For these reasons, biodiversity provision is not used in this CBA, but as it turns out it is not needed in order to determine the result since those benefits that are possible to quantify outweigh the costs (see Table 1). More research would be required for the appraisal if it turned out that a valuation of biodiversity public goods could sway the result of the appraisal.

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7 As with all figures of this type, there are a number of assumptions and limitations surrounding this figure which should be noted. The figure is an upper bound estimate for benefits, assuming that deaths are prevented for one year. The figure is for particulates and sulphur dioxide only, and does not include ozone. Assumptions also had to be made about the ability of different tree types to absorb pollution. The area figure includes all different types of woodlands (conifer, broad-leaved, coppiced, etc.) which would have different effects.

8 Using a discount rate of 3.5% per annum.

9 The UK Government recommends a figure for the social cost of carbon of £70 per tC. Using this figure would give an indefinite-term present value of £3,470 million for woodlands in Southeast England, and an annualised figure of £520 per ha per annum.

According to Willis (2002)[FC], the average externality produced by wooded areas through use of potable water in Oxfordshire is £17.30 per hectare. This was estimated using a hydrological model of the amount of water intercepted by woodland in conjunction with estimates from the literature and from water companies of the long and short run marginal costs of supplying water.

Original elements of the appraisal - CV survey of residents

Bateman and others (1996) provide details of a contingent valuation survey carried out in Wantage to determine willingness to pay for a proposed 100 acre (about 40 hectares) Community Woodland near Wantage with car parking facilities. Respondents were asked whether they were in principle prepared to pay towards the Woodland. Those who answered 'yes' were then asked their household WTP per annum in extra taxes as well as their WTP per visit through a car parking fee. The latter is a somewhat flawed measure, as many people would visit the wood without using their car, a carload contains an undefined number of people, and the measure puts the stress on recreation and not amenity. Therefore, only the former measure is used in this example. Respondents were also asked the usual questions on their expected usage of the woodland and existing usage of other leisure facilities, their attitudes and socio-economic characteristics. Mean WTP for the woodland was found to be £9.94 per household per year, which, aggregated over the number of households in Wantage, gives an annual aggregate WTP of £44,450 or £1,100 per hectare. This total WTP can be taken as a measure of the recreational and amenity benefits, as judged by the population of Wantage, likely to be provided by the Community Woodland. It does not include benefits to users not resident in Wantage.

Original elements of the appraisal - CV survey of farmers

Bateman and others (1996) also interviewed 19 farmers in the Wantage area and asked them whether they would be willing to consider planting a Community Woodland on their land, and if so what the minimum level of compensation per hectare would needed to be. Seven farmers indicated immediately that they would be willing to participate in such a scheme. Interestingly, a further seven initially rejected the idea, but expressed a positive WTA, indicating that despite initial unwillingness, such farmers would consider the idea if, as the study authors put it, "the price was right". Overall mean stated WTA was £617 per hectare per annum, a figure about twice the farmers' mean stated profit of about £309 per hectare, which the farmer would have to forgo if they joined the CWS. This increased value may include the need for compensation for the lack of flexibility of a long-term contract and a dislike of public access. Over a ten-year period, it represents substantially more than the current one-off payment. It should be noted that nineteen is a very small sample, and normally it would be desirable to conduct WTP/A surveys over a much larger sample. However, the requirement in this case of limiting respondents to farmers near Wantage, coupled with the fact that not all potential respondents would have agreed to take part, meant that a small sample was inevitable.

Cost-Benefit and discussion

The quantitative weighing up of ecosystem service costs and benefits is presented in Table 1. Biodiversity provision is not included in the benefits for reasons explained above.

Table 1: Annual per hectare benefits compared to annual per hectare costs of the proposed Community Woodland			
BENEFITS (£ pha pa)		**COSTS (£ pha pa)**	
Recreation	1,100	Payments to farmers	617
Landscape amenity		Water lost to abstraction	17
Biodiversity provision	-		
Carbon sequestration	109		
Absorption of air pollution	10		
TOTAL Benefits	**1,219**	**TOTAL Costs**	**634**

Under the assumption that increasing the payment to £617 per hectare per annum would actually stimulate take-up of the scheme, the table shows that the benefits of increasing the payment to £617 per hectare per annum outweigh the costs substantially. The analysis however would need to be put under some degree of sensitivity testing.

In this scenario, most of the benefits (recreation, landscape and air pollution reduction) accrue to local residents. While the benefits of carbon sequestration accrue to the global population, they represent a small fraction of overall benefits. The bulk of costs are incurred by the donor, with some costs to regional water abstractors.

The willingness to pay for the Woodland was estimated from a status quo of zero woodland near Wantage. It is reasonable to expect that residents will have declining marginal WTP for woodland. Therefore, the benefits might not continue to outweigh the costs of more woodland once a certain amount of woodland has been established.

The current CWS payment annualized over ten years at a 3.5% discount rate is £110 per hectare per annum. This is an order of magnitude smaller than the fairly conservative estimate of the benefits given in Table 1. In a full scale appraisal, both costs and benefits would be aggregated and discounted over time. In some cases, costs and benefits are assumed to be distributed evenly over time, in others a time profile of their distribution can be estimated.

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Annex 3 Benefits transfer procedures

In implementing benefits transfer, the three most common procedures are to:

1. Transfer an average WTP estimate

The simplest form of value transfer would be to ‘borrow’ the estimated average (mean) WTP for some study good and apply it to a policy good context. This approach basically implies that the preferences of the average individual for the study good are an adequate description of the preferences of the average individual in the policy site context. Having sourced a suitable WTP estimate from existing economic valuation studies, the next step in the process would be to aggregate the WTP value over the appropriate population in order to estimate the change in aggregate for the good in question.

2. Transfer an adjusted average WTP estimate

In reality, the policy good and the study good are unlikely to be identical. An alternative approach therefore is to adjust the study good WTP estimate in someway to account for the difference with the policy good. Since income is typically a fundamental determinant of WTP and will in most instances vary between policy site population and study site population, it is common to account for this in the adjustment process. The adjustment factor would then become the ratio of average income at the policy site to the average income at the study site, or Y_{ps}/Y_{ss}. In order to estimate the WTP in the policy site, the WTP at the study site is multiplied with this adjustment factor. A more sophisticated adjustment for income would also use the income elasticity of income (e), ie an estimate of how WTP for the good in question varies with changes in income. This implies another adjustment factor, which is $(Y_{ps}/Y_{ss})^e$. Without making this adjustment, the WTP for the study good would overestimate the WTP for the policy good in the case where income is higher at the study site. Other factors can also be used for adjustment in the same way, provided that we have data about these other factors both at the study and the policy sites.

3. Transfer a WTP function

Where there is the desire to make multiple adjustments to WTP amounts, a function transfer approach may be applied. Rather than transferring unit estimates of WTP, the function transfer approach instead transfers information from the study good context to the policy good context regarding the relationship between WTP and a number of explanatory factors. Specifically, a WTP function (or ‘bid’ function) relates WTP for a change in a non-market good to changes in parameters of interest including the factors relating to (i) the good (eg price and characteristics of the good); (ii) the affected population (eg socio-economic and demographic characteristics and pattern of use of the good); and (iii) the change (eg the quantity and quality of the good available with or without the change of concern). These parameters are factors which economic theory posits as being important in determining the preferences of individuals. The information about these variables at the policy site can then be used to calculate WTP at the policy site. In fact, policy site WTP would be estimated by multiplying the average value of the explanatory variables at the policy site (eg average income, average age of population etc) by the function coefficients estimated for the study good. The coefficients measure the impact of the change in an explanatory variable on WTP. Therefore, to apply the function transfer approach, it is necessary to source a suitable WTP bid function from existing economic valuation studies, and to also have data concerning a number of factors in the policy good context. In practice a single WTP function may be transferred from one study or more sophisticated alternatives may be considered. For example, function transfer may also be facilitated by meta-analysis exercises, which typically take a number of WTP studies in order to derive general relationships between WTP for a particular asset and a number of common explanatory factors. In addition, data concerning the policy site population may be augmented by the use the use of geographical information systems (GIS). This can be particularly useful in accounting for the affect that distance from particular asset has on both use and non-use values.

While the above definition of benefits transfer focuses on WTP alone, the same approaches apply to willingness to accept compensation (WTA) – even though the studies using WTA measure form a much smaller literature. Benefits or value transfer is the subject of a rapidly growing literature, which is not surprising considering that successful employment of the technique could avoid the significantly larger time and cost input associated with undertaking original valuation work. The literature also focuses on the validity of benefits transfer as a technique. Various requirements for valid transfer have been identified, which are often difficult to meet in practice. From Bateman and others (2002) these are:

- the studies included in the analysis must themselves be sound;
- the studies should contain WTP bid functions, ie regressions showing how WTP varies with explanatory variables such as income;
- the study and policy goods, services or sites must be similar in terms of population and site characteristics, or differences in these characteristics must be adjusted for;
- the change in the provision of the good being valued at the two sites should be similar, and WTP measures cannot be changed into WTA measures and vice versa; and
- property rights should be the same across the sites.

The difficulty of arriving at valid estimates using benefits transfer limits its use in certain policy-making contexts. Benefits transfer would be most defensible where the requirement is one of demonstrating the existence, direction and magnitude of ecosystem service benefits. The most limiting factor here is, of course, the availability of existing studies for particular services. In many instances, there will be little choice, but to undertake new work. However, as is discussed in the next section, many ecosystem service benefits can be estimated without the use of stated or revealed preference techniques and at lower cost.

ENGLISH NATURE

Research Information Note

English Nature Research Reports, No. 701

England's Ecosystem Services
A preliminary assessment of three habitat types:
broad-leaved woodland, the inter-tidal zone and fresh-water wetlands

Report Authors: EFTEC, Just Ecology & R. Kerry Turner Date: 2006
Keywords: ecosystem, Economics, ecosystem services

Introduction

This report represents an attempt to join up the science and economics of ecosystem services. It aims to help provide a first attempt at a detailed catalogue of ecosystem services in selected habitats in England, to act as a reference for future evaluation work. The rationale for the research was that we need to understand the science of ecosystem services before we can evaluate their importance to society.

Scientists, economists and policy makers will be interested in Section 2 of this report. It represents an initial assessment of potential ecosystem services for three habitat types in England: broadleaved woodlands, wetlands and inter-tidal zones. It summarises the ecological literature, from a human welfare perspective, distilling this into an assessment of potential ecosystem services which provide societal benefits. This assumes appropriate habitat management and sustainable harvesting. The idea is to use this as a resource for evaluation in more specific assessments. Section 3 is aimed more at the economist audience.

What was done

The report consists of a literature review and analysis to describe the ecological processes which may provide ecosystem services for 3 habitat types in England: broadleaved woodland, terrestrialised freshwater wetlands and inter-tidal habitats. This is followed by an analysis of potential economic valuation approaches, together with some example evidence. The categories of ecosystem service are organised to be consistent with those in the recently published Millenium Ecosystem Assessment.

Results and conclusions

This preliminary analysis identifies numerous services potentially provided by these habitats, of which the following are suggested as especially relevant in England and worthy of particular attention in future evaluation studies:

- carbon budget management
- water quality
- flood risk management.

continued ....

However, it is clear that the actual provision of ecosystem services is complex and will vary from site to site.

In some areas of England it is possible to find healthy functioning ecosystems providing significant services which merit protection. In other areas, the habitats will be modified to such an extent that while rare species remain and need to be conserved, it is difficult to detect significant provision of additional ecosystem services. In the latter cases it may be a question of considering the additional services that might be provided if the landscape were to be restored.

English Nature's viewpoint

English Nature welcomes this contribution to the emerging literature on ecosystem services, which are typically difficult to observe, and thus risk being unaccounted for in economic valuation studies. We see this as a preliminary assessment of ecosystem services which may be evident in the selected habitats. It is not intended to be comprehensive. However, we hope it will be useful as a resource and starting point for researchers considering the socio-economic benefits of habitat protection, and wanting to consider these ecosystem services as part of the evaluation. We recognise that the ecosystem services identified here are one component, but not the totality, of society's desire for habitat protection and its willingness to pay for it.

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Middle left: Co_2 experiment at Roudsea Wood and Mosses NNR, Lancashire.
Peter Wakely/English Nature 21,792
Bottom left: Radio tracking a hare on Pawlett Hams, Somerset.
Paul Glendell/English Nature 23,020
Main: Identifying moths caught in a moth trap at Ham Wall NNR, Somerset.
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