An Assessment of Ecosystem Services and Biodiversity in Europe

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ABSTRACT

Ecosystem services are the benefits humankind derives from the workings of the natural world. These include most obviously the supply of food, fuels and materials, but also more basic processes such as the formation of soils and the control and purification of water, and intangible ones such as amenity, recreation and aesthetics. Taken together, they are crucial to survival and the social and economic development of human societies. Though many are hidden, their workings are now a matter of clear scientific record. However, the integrity of the systems that deliver these benefits cannot be taken for granted, and the process of monitoring them and of ensuring that human activity does not place them at risk is an essential part of environmental governance, not solely at a global scale but also regionally and nationally.

In this chapter, we assess the importance of ecosystem services in a European context, highlighting those that have particular importance for Europe, and we set out what is known about the contribution biodiversity makes to each of them. We then consider pressures on European ecosystem services and the measures that might be taken to manage them.

One of the key insights from this work is that all ecosystems deliver a broad range of services, and that managing an ecosystem primarily to

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deliver one service will reduce its ability to provide others. A prominent current example of this is the use of land to produce biofuels. There is an urgent need to develop tools for the effective valuation of ecosystem services, to achieve sustainable management of the landscape to deliver multiple services.

1 Introduction

1.1 Biodiversity and Ecosystem Services: Why this Topic Matters Now

The past 50 years have seen an unprecedented human impact on ecosystems and on their biodiversity.[1] Current rates of species extinction substantially exceed background extinction rates: International Union for Conservation of Nature (IUCN) estimates that 12% of bird species, 23% of mammals, 32% of amphibians and 25% of conifers are threatened with extinction.[2] Human use of natural resources has grown substantially in this period: roughly half of useable terrestrial land is now devoted to grazing livestock or growing crops. That expansion has been at the expense of natural habitat, so that between a quarter and a half of all primary production is now diverted to human consumption.[3] Other major threats to biodiversity include the introduction of non-indigenous species, pollution, climate change and over-harvesting. In marine ecosystems, over-exploitation of stocks has been the most severe cause of ecosystem degradation and local extinction.[4]

These changes have considerable implications for human society. Living organisms, interacting with their environment in the complex relationships that characterise ecosystems, deliver important, and in some cases crucial and unsubstitutable, benefits to humankind. Most obviously, organisms provide goods in the form of food, fuel and materials for building, but they also deliver other, less apparent services. For example, insects, especially bees, play an important role in the pollination of plants, including staple food crops, and micro-organisms recycle or render harmless the waste produced by human society. Both the bees and the microbes operate within and rely on ecosystems for their survival.

These natural services are of enormous value to human society. Many of the services are irreplaceable: for example, we have no way of providing food for the human population except through the use of natural systems involving soil, soil organisms and crop plants, nor of providing drinking water, except through the operation of the water cycle, which depends critically on the activities of organisms. The maintenance of ecosystems, therefore, must be an essential part of the survival strategy for human societies.

Despite these benefits, investment in conservation does not match the scale of the benefits received from ecosystem services. It was noted by David Pearce that 'actual expenditures on international ecosystem conservation appear to be remarkably small and bear no relationship to the willingness to pay figures obtained in the various stated preference studies'.[5] Pearce concluded 'despite all the rhetoric, the world does not care too much about biodiversity conservation'. This disconnection may arise in part because the links between biodiversity and ecosystem function (and consequently to ecosystem services) remain new areas of research: this chapter assesses the evidence for these links, focussing on ecosystem services that are of major concern for Europe.

The power of economic analysis in policy-making is such that argument about policy is typically constructed in a major part through the language of costs and benefits. There is an urgent need to address the chronic under-investment in conservation of biodiversity and to ensure that future decisions do not lead to an unacceptable loss. This means that it is essential that the value of biodiversity in promoting the delivery of essential and valuable services is expressed strongly (in both economic and other terms) in those areas of decision-making where economic analysis is itself strongest.

1.2 The Current Assessment

The principal focus of assessment of ecosystem services to date has been at a global level. The Millennium Ecosystem Assessment (MA) continues to be a major influence on the development of a global regime for the protection of biodiversity through the Convention on Biological Diversity (CBD). At a national scale, UK National Ecosystem Assessment (NEA), which commenced in mid-2009 and will report in 2011, is expected to have a significant impact on the UK's environmental management strategy. There is also an urgent need to advance the development of regional measures for protecting biodiversity and ensuring the continual flow of ecosystem services. The assessment on which this chapter is based was commissioned by the Council of the European Academies Science Advisory Council (EASAC), an independent association of the science academies of the European Member States, as a contribution to the scientific debate on the future of European biodiversity and measures to protect it.[6]

The assessment consists of four stages:

1. Prioritisation of ecosystem services within a European context using the MA framework;
2. Assessment of the relative significance of biodiversity for each of these services;
3. An evaluation of the role of biodiversity, based on current knowledge; and
4. Identification of specifically European concerns about the future of each ecosystem service.

The initial assessment was made by an expert Working Group. Following extensive review by a wide range of experts, comments and contributions from reviewers were assimilated and the output was subject to a review within the EASAC Member Academies. We believe, therefore, that this assessment is an accurate reflection of the range of views within Europe's scientific communities on ecosystem services and biodiversity in Europe.

2 Biodiversity and Ecosystem Services

2.1 Ecosystem Services

An ecosystem is the interacting system of living and non-living elements in a defined area.[7] Ecosystems can exist at any spatial scale, although in most uses they are large-scale entities, such as a lake or a forest. The importance of the ecosystem is that it is the level in the ecological hierarchy (see Figure 1) at which key processes such as carbon, water and nutrient cycling and productivity are determined and can be measured: these are the processes that determine how the world functions and that underlie all the services identified by the MA.

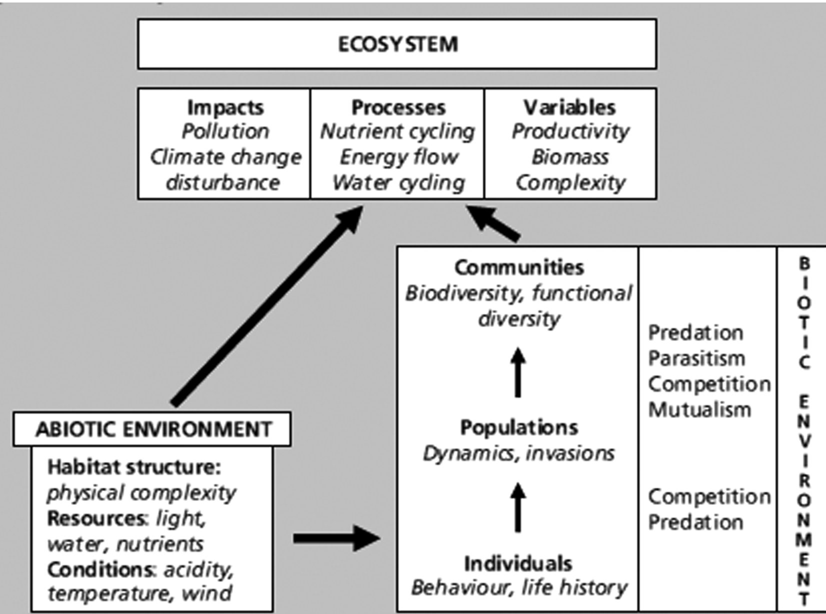
The MA classification of ecosystem services contains four categories – supporting, regulating, provisioning and cultural – which explicitly address the benefits to human societies. The delivery of these services, however, represents the normal operation of the ecosystem, and reflects the natural processes that occur within every ecosystem. The services, therefore, which are a human construct, depend on these underlying processes, such as:

- Fixation of nitrogen gas from the air by bacteria into forms that are useable by plants, which underlies the nitrogen cycle;
- Decomposition of organic matter by microbes, which is the basis of all nutrient cycles, including importantly the carbon cycle; and
- Interactions between organisms, such as competition, predation and parasitism, which control the size of their populations, and underlie services such as pest control.

Because the processes depend on organisms and the organisms are linked by their interactions, the services themselves are also linked. For example, productivity can only be maintained if the cycling of nutrients continues, and all provisioning services depend intimately on the supporting services of production and water and nutrient cycling. Consequently all ecosystems deliver multiple services, although the number of species and the relative scale of the various services will vary greatly among ecosystems.

2.2 Relationships between Biodiversity and Ecosystem Services

Ecosystems vary greatly in biodiversity. Generally, productive natural ecosystems have the highest biodiversity but many highly productive ecosystems, and especially those under human management, have low biodiversity, showing that many other factors are at work. Among those factors are: rates of evolution, which are the underlying driver of biodiversity; rates of dispersal, both natural and assisted by humans, which are especially important when



The diagram represents the components of the ecosystem, which comprises the abiotic factors of the environment and the biological communities that live there. Communities are made up of populations of organisms whose individuals interact with each other and with those in other populations by competing for resources and preying on or parasitising others. It is the individuals that respond to the abiotic factors of the habitat. Processes in ecosystems, which underlie ecosystem services, are the result of the interaction of the organisms and the abiotic environment.

The ecosystem is one stage in a hierarchy of systems recognised by the science of ecology, from the population (the individuals of a single species in a defined area), through the community (the set of populations in that area), to the ecosystem, which brings in the abiotic elements. Although ecologists recognise landscape units such as forests and lakes as ecosystems, they also accept that ecosystems are not self-contained: they have porous boundaries and both organisms and materials move between systems, often with important ecological consequences. Above the ecosystem in this hierarchy, ecologists recognise biomes and the biosphere; both of these are at much larger scale, continental or global.

Figure 1 The Ecological Hierarchy. (Reproduced with permission of EASAC, taken from the original report on ecosystem services prepared by Alastair Fitter and the EASAC working group.)

ecosystems are isolated from others by natural barriers; and the interactions between species, such as predation, competition and parasitism, which control the sizes of their populations and often their persistence in a community.

In ecosystems with many species, species can be grouped into sets that have similar ecological roles, called functional groups, for example, legumes which form a symbiosis with nitrogen-fixing bacteria in their roots and gain access to the pool of atmospheric nitrogen for their nutrition. Similarly, spiders that catch prey in webs and those that do so by hunting represent distinct functional groups of predators and play distinct roles in an ecosystem. Even where, in a biodiverse ecosystem, there are many species within a functional group, some will be rare and others common. Some species play especially important roles in the ecosystem, although these keystone species may not necessarily be common species. Losing an entire functional group from an ecosystem or the keystone species from within that group is likely to have more severe consequences for its functioning than losing one species from a large group, and such a loss is most likely in a species-poor system.[8] Experimental evidence shows that both number of species and number of functional groups can play an important role in controlling ecosystem processes.[9]

Ecosystems can change drastically when sets of key species are lost,[10,11] or when new species invade.[12] One of the great unsolved problems in ecology is to determine how important biological richness is for the operation of processes such as production and nutrient cycling. When there are more species in an ecosystem, and especially more types of species with distinct functional attributes, ecosystem processes, and the services they support, such as biomass production, pollination and seed dispersal are promoted,[13] but the evidence is less clear as to what happens to an ecosystem as it progressively loses species. Because processes in ecosystems with very low biodiversity are in many cases slower or less active, it follows that loss of species will eventually cause degradation of processes. Although the shape of the relationship is not entirely clear (do services decline progressively or suddenly as biodiversity is lost?) there is evidence that it is highly non-linear. A slight decreasing trend in ecosystem functions as species diversity declines may be followed beyond a certain threshold with a collapse of function.[14]

There are numerous well-documented examples that demonstrate that biodiversity plays a large role in the case of many services. Within the context of the Millennium Ecosystem Assessment framework, such examples would include:

- *Supporting services*: in a meta-analysis of 446 studies of the impact of biodiversity on primary production, 319 of which involved primary producer manipulations or measurements, there was 'clear evidence that biodiversity has positive effects on most ecosystem services', and specifically that there was a clear effect of biodiversity on productivity.[15]
- *Regulating services*: in an experimental study of pollination in pumpkins it was the diversity of pollinator species, and not their abundance, that determined seed set.[16]

- *Provisioning services*: where grassland is used for biofuel or other energy crop production, the lower financial return makes intensive production systems involving heavy use of pesticides and fertilisers uneconomic. Under these less intensive production systems, mixed swards of grasses are more productive than pure swards.[17]
- *Cultural services*: evidence from the 2001 foot and mouth disease epidemic in the UK demonstrated that the economic value of biodiversity-related tourism greatly exceeds that of agriculture in the uplands of the UK.

2.3 Land Use and Multiple Services

Land use has a major impact on both ecosystem services and biodiversity, especially when altered by human activity to deliver some particular service, such as food production in agro-ecosystems. However, all ecosystems deliver multiple services, and management to maximise one particular service risks reducing others. For example, forests regulate water flow and quality and store nutrients in soil, among many other functions; clear-felling a forest to obtain the ecosystem service of timber products results in the temporary failure of the system to retain nutrients, as shown by the classic Hubbard Brook experiments in New England, USA.[18] Similarly, arable land managed to maximise yield of food crops stores less carbon in the soil, with negative effects on the service of climate regulation.[19]

Human impact on ecosystems is most extreme in intensive agriculture and in urban landscapes. Urban ecosystems typically contribute minimal levels of provisioning services. Urban landscapes are characteristically heterogeneous, including in relation to biodiversity.[20] Street trees and urban vegetation may generate services of high value for human well-being related to environmental quality such as air cleaning, noise reduction and recreation,[21] or to human health[22] (asthma rates among children aged four and five in New York City were directly proportional to the density of trees). Because of the density of human population, many urban ecosystem services are generated on a very small scale, by patches of vegetation and even individual trees.

Land (and where appropriate water) management always, even if only implicitly, aims to achieve benefits of one or more ecosystem services, but because these services are not independent of one another, there are trade-offs between the services.

- *Temporal trade-offs*: there may be benefits now with costs incurred later (or more rarely *vice versa*). Land used for food production may store progressively declining stocks of organic matter, with long-term consequences both for nutrient cycling, and hence future fertility, and carbon sequestration.
- *Spatial trade-offs*: the benefit may be experienced at the site of management, but the cost incurred elsewhere. When moorland is burned to maximise growth of young heather shoots and the number of grouse, and hence income from grouse shooting, the loss of dissolved organic matter to

water is increased. This appears as colour in drinking water and has to be removed at great expense by water companies.[23]

- *Beneficiary trade-offs*: the manager may gain benefit, but others lose, leading to actual or potential conflict. Most management systems that maximise production by high inputs of fertilisers lead to reduced biodiversity, so that those who appreciate land for its conservation value lose. Equally, land managed for biodiversity conservation, such as nature reserves, has little production value.
- *Service trade-offs*: these occur almost invariably when management is principally for one service, and are in practice similar to beneficiary trade-offs.

These trade-offs are real and well documented. To control their impact, it will be essential to take into account the spatial and temporal scale at which ecosystem services are delivered. For example:

- Pollination, which operates at a local scale and can be managed by ensuring that there are areas of land managed that maintain populations of pollinators in a mosaic of land-use types;
- Hydrological services function at a landscape scale, such as a watershed, and require co-operation among land managers at that scale; and
- Carbon sequestration in organic matter in soil operates at a regional and global scale and necessitates policy decisions by governments and international bodies to ensure that appropriate incentives are in place to ensure necessary behaviour by local land managers.

Hence the importance of assessments at a range of geographical scales, including, as in the work reported here, regional (European in this case) level.

3 European Biodiversity and Ecosystem Services

The full assessment of ecosystem services made in the course of this study by the EASAC Working Group and the panel of experts is given in the Working Group Report.[24] The following is a digest focussing on land-based services; similar issues are raised by consideration of marine services.

A Supporting Services

Supporting services are the basic services that make the delivery of all other services possible.

A1 Primary Production

Primary production is fundamental to all other ecosystem services and is generally high in Europe, where soils are young and fertile and the climate is generally benign. Low productivity is associated with very cold regions (Arctic and alpine), very dry regions (some parts of the Mediterranean region) and seriously polluted or degraded environments. In policy terms, primary production is considered highly important for Europe, and it appears to be strongly dependent on biodiversity.

A large body of evidence relates diversity to primary production, including theoretical, controlled-environment and small and large-scale field studies. However, the relationship is complex. Although the highest productivity is typically achieved in intensively managed systems of very low diversity requiring large inputs of resource, sustained high production without high levels of input is associated with high levels of biodiversity.

In Europe, there is a possibility of serious decline in primary productivity due to increasingly dry conditions in southern Europe, but of increases in the north due to extended growing season. Environmental pressure, including change of land use, climate change and pollution all reduce quantity and quality of biodiversity with consequent loss of primary productivity.[25]

A2 Nutrient Cycling

Nutrient cycling is also considered a highly important ecosystem service for Europe. It is a key process in both terrestrial and aquatic systems and is essential for maintenance of soil fertility. Nutrients are cycled by organisms, which take them up as they grow and release them back into the environment as they decompose. Biodiversity is critical to these cycles.

The capacity of ecosystems to sequester nutrients depends, besides natural factors, on management interventions. In intensively farmed landscapes, nitrate and phosphate may be lost to watercourses, causing both damage to water quality and economic losses on farms. Atmospheric deposition of nitrogen, sulfur and sometimes metals to soils also disrupts nutrient cycling – through effects including acidification, denitrification and inhibition of fixation. In many aquatic systems in Europe, sewage, industrial and agricultural effluent disrupt nutrient cycling.

The widespread use of sewage sludge as an agricultural fertiliser, though an effective way of recycling nutrients removed from soils by agriculture, has resulted in contamination of soils by heavy metals, including zinc, copper and cadmium, which inhibit nitrogen-fixing bacteria. Changes in biodiversity of natural ecosystems brought about by land-use change, climate change or pollution alter the ability of ecosystems to retain nutrient stores, resulting in release of nutrients to other ecosystems with potentially damaging consequences.

A3 Water Cycling

The water cycle is an important process in the overall management of water, storing water, controlling flows and distributing it to all parts of the ecosystem. Humans have made changes in water cycles through urbanization, drainage, dams, structural changes to rivers and other surface waters.[26] Floods and droughts become more intense due to changes in landscapes and feedbacks from precipitation recycling, which include forest cutting, intensive agriculture, urbanization, large-scale reclamations and uncontrolled withdrawals from subsurface stores.[27] Impermeable areas increasingly preclude sustainable aquifer recharge. Impacts are likely to be amplified through climate change.[28]

Both vegetation and soil organisms have profound impacts on water movements and the extent of biodiversity is likely to be important. Changes in species composition can affect the balance between water used by plants ('green water') and water flowing through rivers and other channels ('blue water'), and native flora may be more efficient at retaining water than exotic species. However, land use and landscape structure are likely to be more significant than biodiversity *per se*.

In Europe as a whole, there is concern that soil moisture and green water availability are decreasing as a result of human activity[29] and in Southern Europe these problems apply to both blue and green water. Urban areas with sealed surfaces provide new challenges and increased runoff, flood events and nonpoint pollutant loads[30]are predicted to increase in several European areas due to climate change.[31]

A4 Soil Formation

Soil formation is fundamental to soil fertility, especially where processes leading to soil destruction or degradation (erosion or pollution) are active. It is a continuous process in all terrestrial ecosystems, but particularly important and active in early stages after land surface is exposed (*e.g.* following glaciation). It is highly dependent on the nature of parent materials, biological processes, topography and climate.

Soil biodiversity is a major factor in soil formation. Loss of soil biota, including bacteria, fungi and invertebrates, reduces soil formation rate, with damaging consequences. Key plant types include legumes and deep-rooted species. There is little empirical evidence, however, on the general role of biodiversity in soil formation, but composition of biological communities has been shown to be important, so a range of functional types appears to be needed.

There are particular concerns in Europe about soils that are subject to intense erosion by wind or water. Although soils in Northern European ecosystems in the early stages (10 000 to 20 000 years) of post-glacial recovery are often resilient to intensive agricultural use,[32] much of the Mediterranean region has old soils with lower resilience that have suffered severe damage and are badly eroded.[33] In alpine areas, high rates of erosion may be countered by equally high rates of soil development.

B Regulating Services

Regulating services are the benefits obtained from the regulation of ecosystem processes.

B1 Climate Regulation

Climate regulation refers to the role of ecosystems in managing the levels of climate forcing or greenhouse gases (GHGs) in the atmosphere. Current climate change is largely driven by increase in the concentration of trace gases in the atmosphere, principally as a result of changes in land use and rapidly rising combustion of fossil fuels. The major GHG, carbon dioxide (CO_2), is absorbed directly by water and indirectly (*via* photosynthesis) by vegetation, leading to storage in biomass and in soils as organic matter. Fluxes of other GHGs (*e.g.* methane, CH_4; nitrous oxide, N_2O) are also regulated by soil microbes. Marine systems play a key role in climate regulation through physical absorption of CO_2 and through photosynthetic carbon-fixation.

Europe contains extensive areas of peat that contain large quantities of carbon. Boreal forests are also significant stores of carbon. In all, Europe's terrestrial ecosystems are estimated to represent a net carbon sink of between 135 and 205 gigatonnes per year, which is about 7 to 12% of the 1995 anthropogenic carbon emissions.[34] The interplay between biodiversity and climate regulation is poorly understood. When major change occurs in ecosystems, the time lags in the feedbacks on ecosystem processes that result are important and unresolved. The global carbon cycle is strongly buffered because much anthropogenic CO_2 is absorbed by the oceans and terrestrial ecosystems.[35] However, the rate of emission increasingly exceeds this absorption capacity, which itself is being reduced still further by anthropogenic damage to ecosystem function.

Losses of carbon (C) from soils, from peat in particular, could easily outweigh any savings made due to reductions in fossil fuel use: it has been estimated that UK soils may have lost 0.6% of C each year over last 25 years.[36] Intensive biofuel production may also lead to reduced C retention in soils, since the goal will be to remove as much biomass as possible. There is also some evidence that aerosols produced by boreal forests may affect albedo, thereby cooling the climate.[37]

There is a fundamental requirement to ensure that policies take into account multiple impacts; for example, the consequences of changes in land use to increase biomass production for sustainable C storage in soils and emissions of greenhouse gases (N_2O, CH_4).

B2 Disease and Pest Regulation

The abundance of pests and diseases is regulated in ecosystems through the actions of predators and parasites, as well as by the defence mechanisms of their prey. The services of regulation are expected to be more in demand in the future, as climate change brings new pests and increases the susceptibility of species to parasites and predators.

The role of biodiversity in disease regulation may be important. There is evidence that the spread of pathogens is less rapid in more biodiverse ecosystems. There is also a consensus that a diverse soil community will help prevent losses of crops due to soil-borne pests and diseases.[38] Higher trophic levels in soil communities can play a role in suppressing plant parasites and affecting nutrient dynamics by modifying abundance of intermediate consumers.[39] In many managed systems, the control of plant pests can be provided by generalist and specialist predators and parasitoids.[40,41]

There is a need for the development of European applications of biological control, exploiting the properties of pest regulation in biodiverse ecosystems.

B3 + C2 Water Regulation and Purification (in this assessment these ecosystem services were combined)

The water regulation and purification service refers to the maintenance of water quality, including the management of impurities and organic waste, and the direct supply of clean water for human and animal consumption. Soil state and vegetation both act as key regulators of water flow and storage. Although vegetation is a major determinant of water flows and quality, and microorganisms play an important role in the quality of groundwater, the relationship of water regulation and purification to biodiversity is poorly understood.

In lowland Europe, several factors impinge on water regulation and purification, including use of floodplains, river engineering and increasing urbanisation, leading to higher levels of run-off and contamination of water. Increasing land-use intensity and the replacement of biodiverse natural and semi-natural ecosystems by intensively managed lands and urban areas have resulted in increased run-off rates, especially in mountainous regions. Increasingly, freshwater supplies are a problem in the Mediterranean region and in such densely populated areas as southeast England.

A more coherent approach to the managed recharge of groundwater, with controls on groundwater extraction rates to protect surface ecosystems, would be a valuable enhancement to the Water Framework Directive. Trans-boundary approaches to catchment management are needed that offer a balance between engineered and ecosystem-based approaches to water regulation.

B4 Protection from Hazards

This regulating service reduces the impacts of natural forces on human settlements and the managed environment. It is highly valued in Europe. Many hazards arising in Europe from human interaction with the natural environment are sensitive to environmental change. These include flash floods due to extreme rainfall events on heavily managed ecosystems that cannot retain rainwater; landslides and avalanches on deforested slopes; storm surges, exacerbated by sea-level rise and the increasing use of hard coastal margins; air pollution due to intensive use of fossil fuels combined with extreme summer temperatures; and fires caused by prolonged drought, with or without human intervention.

Ecosystem integrity is important in protection from these hazards, but less so to geological hazards, such as volcanic eruptions and earthquakes, which are localised to a few vulnerable areas. In alpine regions, vegetation diversity is related to the risk of avalanches.[42] Soil biodiversity may play a role in flood and erosion control through affecting surface roughness and porosity,[43] and increasing tree diversity is believed to enhance protection against rockfall.[44] Increased urbanisation and more intensive use of land for production may reduce the ability of ecosystems to mitigate extreme events.

Environmental Quality Regulation

Environmental quality regulation is a new category, not in the MA. In addition to services like water purification mentioned above, ecosystems contribute to several environmental regulation services of importance for human well-being and health. Examples include the role of vegetation and green areas in urban landscapes for air cleaning, where parks may reduce air pollution by up to 85% and significantly contribute to the reduction of noise. For cities, particularly in southern Europe around the Mediterranean, vegetation and green areas may play a very important role in mitigating the urban heat island effect, a considerable health issue in view of projected climate change. Urban development in Europe, just as elsewhere in the world, faces considerable challenges where efforts to reach some environmental goals, for example, increased transport and energy efficiency through increased infilling of open space with urban infrastructure, is not done through sacrificing all other environmental qualities linked to those spaces.

B5 Pollination

The pollination service provided by ecosystems is the use of natural pollinators for crops. The role of pollinators, such as bees, in maintaining crop production is well documented and of high importance, in Europe as elsewhere in the world. There is strong evidence that loss of pollinators reduces crop yield and that the availability of a diverse pool of pollinators tends to lead to greater yields.

Habitat destruction and deterioration, with increased use of pesticides, has decreased abundance and diversity of many insect pollinators, leading to crop loss with severe economic consequences, and to reduced fecundity of plants, including rare and endangered wild species. Reduction of landscape diversity and increase of land-use intensity may lead to a reduction of pollination service in agricultural landscapes.[45,46] The loss of natural and semi-natural habitat can reduce crop production through reduced pollination services provided by native insects, including bees.[47] There is increasing evidence that the diversity of pollinators, not just abundance, may influence the quality of pollination service.[48] Maintenance of biodiverse landscapes, as well as protecting pollinators by reducing the level of use of agrochemicals (including pesticides), is an important means for sustaining pollinator service in Europe.

The concern at a European level is that change in land use, in particular urbanisation and intensive agriculture, has decreased pollination services through the loss of pollinator species. However, we do not fully understand the causes behind recent declines in pollinators.

C Provisioning Services

Provisioning services are the benefits obtained from the supply of food and other resources from ecosystems.

C1 Provision of Food

The delivery and maintenance of the food chain on which human societies depend is clearly of fundamental importance. It is estimated that well over 6000 species of plants are known to have been cultivated at some time or another,[49] but about 30 crop species provide 95% of the world's food energy.[50]

Intensive agriculture, as currently practised in Europe, is centred around crop monoculture, with minimisation of associated species. These systems offer high yields of single products, but depend on high rates of use of fertilisers and pesticides, raising questions about sustainability, both economically and environmentally. Introducing a broader range of species into agriculture might contribute significantly to improved health and nutrition, livelihoods, household food security and ecological sustainability.[51]

Maintenance of high productivity over time in monocultures almost invariably requires heavy inputs of chemicals, energy and capital, and these are unlikely to be sustainable in the face of disturbance, disease, soil erosion, overuse of natural capital (for example, water) and trade-offs with other ecosystem services.[52] Diversity may become increasingly important as a management goal, from economic and ecological perspectives, for providing a broader array of ecosystem services.

C3 Energy resources

The supply of plants for fuels represents an important provisioning service on a global scale. In Europe, traditional dependence on fuel from plants has diminished in line with the uptake of fossil fuels. However, energy from plants is expected to become more important in Europe in the future as pressures build to increase the proportion of renewable energy.

Biodiversity of the crop will probably play a small direct role in most biofuel production systems, although all land-based biofuel production will rely on the supporting and regulating services for which biodiversity is important. At present, the increase of biofuels is being achieved partly by the cultivation of biomass crops, which are burned as fuels in conventional power stations, and partly by diversion of materials otherwise useable as food for people. The expectation is that these 'first generation' fuels will be displaced – at least for ethanol production – by a second generation of non-food materials.

All of these biofuel production systems, however, present serious sustainability issues. There are already established damaging impacts on food production, availability and prices worldwide. In addition, full analyses of the carbon fluxes show that the carbon mitigation benefits are much smaller than anticipated because of losses of carbon from newly cultivated soils; destruction of vegetation when new land is brought under the plough; losses of other greenhouse gases such as nitrous oxide from nitrogen-fertilised biofuel production systems; and transport and manufacturing emissions.

Land-based biofuel production systems also have the potential to be especially damaging to conservation of biodiversity, because their introduction on a large scale will inevitably lead both to more intensive land use and to the conversion of currently uncultivated land to production. However, with the correct regulation and institutions, currently degraded land could simultaneously generate biofuels and a suite of other services as well. A full audit of the implications of increased biomass and bioenergy production is urgently needed.

C4 Provision of Fibres

The provision of fibre has historically been a highly important ecosystem service to Europe but most textiles consumed in the EU are now produced and manufactured abroad. However, the pulp and paper industry is significant in Europe and is the dominant user of plant fibres in Europe. Most raw pulp is produced from highly managed monocultures of fast-growing pine and eucalypts, grown at high densities with limited scope for biodiversity. Such large-scale monocultures are vulnerable to runaway pathogen attack.[53] Biodiverse cropping systems may prove of value for ensuring robust future productivity. Wool production is generally a low-intensity activity on semi-managed pasture lands with the potential to support considerable biodiversity.

C5 Biochemical Resources

Ecosystems provide biochemicals – materials derived from nature as feedstocks in transformation to medicines – but also other chemicals of high value such as metabolites, pharmaceuticals, nutraceuticals, crop protection chemicals, cosmetics and other natural products for industrial use. A report from the US Environmental Protection Agency[54] concludes that economically competitive products (compared with oil-derived products) are within reach, such as for celluloses, proteins, polylactides, plant oil-based plastics and polyhydroxyalkanoates. The high-value products may make use of biomass economically viable, which could become a significant land-use issue. Biodiversity is the fundamental resource for bioprospecting but it is rarely possible to predict which species or ecosystem will become an important source.[55] Harvesting for biochemicals, however, might itself have a negative impact on biodiversity if over-harvesting removes a high proportion of the species.

C6 Genetic Resources

Genetic resource provision, for example, provision of genes and genetic material for animal and plant breeding and for biotechnology, is a function of the current level of biodiversity. EU extinction rates remain low; however, there may be problems in poorly studied systems (for example, soils, marine environments). Genebanks are better developed in EU than elsewhere but have limited capacity to conserve the range of genetic diversity within populations. There are now numerous initiatives to collect, conserve, study and manage genetic resources *in situ* (for example, growing crops) and *ex situ* (for example, seed and DNA banks) worldwide, including most EU countries. New techniques, using molecular markers, are providing new precision in characterising biodiversity.[56]

D Cultural Services

Although the MA recognises many services under this heading, we have considered them in two main groups:

1. Spiritual, religious, aesthetic, inspirational and sense of place; and
2. Recreational, ecotourism, cultural heritage and educational.

All the services within these groups have a large element of non-use value, especially those in the first group to which economic value is hard to apply. Those in the second group are more amenable to traditional valuation approaches. Biodiversity plays an important role in fostering a sense of place in all European societies and thus may have considerable intrinsic cultural value.

Evidence for the importance of these services to citizens of the EU can be found in the scale of membership of conservation-oriented organisations. In the UK, for example, the Royal Society for the Protection of Birds has a membership of over one million and an annual income of over £50 million and the National Trust is even larger: 3.6 million members and an annual turnover of over £400 million. Cultural services based on biodiversity are most strongly associated with less intensively managed areas, where semi-natural biotopes dominate. These large areas may provide both tranquil environments and a sense of wilderness. Low-input agricultural systems are also likely to support cultural services, with many local traditions based on the management of land and its associated biological resources. Policy (including agricultural and forestry policies) needs to be aimed at developing sustainable land-use practices across the EU, to deliver cultural, provisioning and regulatory services effectively and with minimal cost. Maintenance of diverse ecosystems for cultural reasons can allow provision of a wide range of other services without economic intervention.

In Europe, cultural services are of critical importance because of the high value many of Europe's people place on the existence and opportunity to enjoy landscapes and open spaces with their flora and fauna. Although the intrinsic biodiversity of natural space in Europe varies greatly, there is evidence that people value 'pristine' environments and regard the impoverishment of landscape, flora and fauna as negative factors, impacting heavily on their enjoyment of nature. The economic value of ecosystems for tourism and recreation often exceeds their value for provisioning services.

The results of the assessment are summarised in Table 1; a number of ecosystems services have high importance for Europe and of these, biodiversity is important in a significant number of cases.

4 Managing Ecosystem Services in Europe

4.1 How Ecosystems Respond to Change

All ecosystems experience environmental change and disturbance, but they also have the ability to maintain themselves in the face of change. The successive appearance of distinct communities of plants and animals on a site, ecological succession, has been much studied and an important distinction between primary and secondary succession has emerged. Primary succession occurs on bare or recently uncovered surfaces such as muds, glacial moraines and river gravels. Secondary succession is the replacement of an existing community after removal of all or part of the vegetation. The major difference between the two processes is that soil has to be formed in primary succession, a process that may

Table 1 Expert opinion on the role of biodiversity in maintaining current ecosystem services in Europe.

	Increasing role of biodiversity	
Increasing importance of ecosystem service	A3: Water cycling A4: Soil formation B1: Climate regulation B3/C2:Water regulation and provision B4: Protection from hazard C1 Food provision Environmental quality	A1: Primary production A2: Nutrient cycling B5 Pollination D2: Cultural services: recreation
	C3: Energy provision C4 Fibre production D1: Cultural services: spiritual	B2: Disease regulation C5 Biochemicals provision C6: Genetic resources

take thousands of years. Secondary succession, for example, the return of woodland to abandoned agricultural fields, depends on the ability of species to survive or disperse back into the disturbed area. If the disturbance is on a very large scale, recovery of the ecosystem can be slow.[57]

The concept of succession implies that communities recover in predictable ways after disturbance. However, species previously found on a site may fail to re-colonise. If the disturbance is on a very large scale, in space or time, the species may be extinct in the area and unable to disperse back in; for long-lived species, the local environment may have changed so much that they are no longer able to reproduce or grow from seed, either due to physical changes (*e.g.* climate change) or biotic changes (*e.g.* invasive species or a parasite). If the change is sufficiently severe, the community may shift to a new stable state, as happened in the well-documented example of the Newfoundland cod fishery, where the serious disturbance of gross and sustained over-fishing drove the population below a level from which it has been able to recover.[58]

Sustaining desirable states of an ecosystem in the face of multiple or repeated disturbance therefore requires persistence of functional groups of species.[59] Consequently, high levels of biodiversity in an ecosystem can be viewed as an insurance against major disturbance and the likelihood that the community will fail to recover to its original state, simply by increasing the chance that key species will survive or be present. The insurance metaphor can help us understand how to sustain ecosystem capacity to cope with and adapt to change, even in more complex ecosystems that have numerous possible stable states and in human-dominated environments.[60–62] In biodiverse ecosystems, species within functional groups will show a variety of responses to environmental change, and this diversity of response may be critical to ecosystem resilience. However, high species diversity does not necessarily entail high ecosystem resilience or *vice versa*, and species-rich areas may also be highly vulnerable to environmental change.

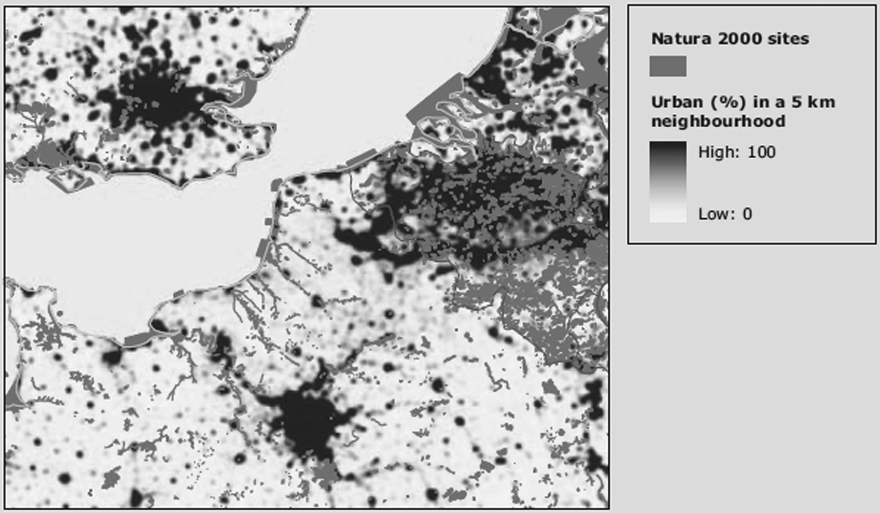
One large challenge for ecology is to predict the likely changes in ecosystems after disturbance or environmental change. Modelling tools allow improved regional estimates, and are an increasingly reliable source for estimates of ecosystem response to environmental change. As a significant example of an estimate of European ecosystem response, climate change combined with the effects of increased atmospheric CO_2 concentrations on vegetation growth were shown to produce changes in the cycling of carbon in terrestrial ecosystems.[63] Impacts were predicted to vary across Europe, showing that regional-scale studies are needed.

4.2 Threats to Biodiversity, and Consequences for Ecosystem Services in the European Union

The landscapes of Europe have altered substantially in the past 60 years, under the twin pressures of the intensification of agriculture and urbanisation. Intensive agriculture threatens delivery of many ecosystem services, especially in the European lowlands (for example, the Netherlands, parts of southern England and northern France) and in large-scale irrigation systems (for example, in Greece). The amount of carbon stored as soil organic matter has declined in most intensive arable soils and this trend is likely to continue;[64] improved management practices that take carbon sequestration as a goal could double the amount stored, with demonstrable impacts on carbon emission targets.[65] Many other examples have been documented, including threats to pollinators leading to a decline in the service of pollination;[66] increased pest problems due to the more rapid spread of pathogens through ecosystems with low biodiversity; and the impact of atmospheric nitrogen deposition on semi-natural ecosystems resulting in declines in biodiversity and poorer water quality.[67] The evidence for the effects of nitrogen deposition is clear: the long-running (more than 150 years) Park Grass experiment at Rothamsted Research in Hertfordshire, UK, shows that a species-rich grassland can be converted to a monoculture of a single grass by sustained addition of high levels of ammonium nitrogen.[68] Similarly, the almost complete loss of heathland from the Netherlands has been ascribed to atmospheric nitrogen deposition.[69]

The direct outcome of these pressures on biodiversity shows in indicators based on birds, butterflies and plants that suggest a decline of species populations in nearly all habitats in Europe: largest in farmlands, where species populations declined by an average of 23% between 1970 and 2000.[70] Large declines in agricultural landscapes of populations of pollinating insects, such as bees and butterflies, and birds, which disperse seeds and control pests, may have consequences not only on agricultural production but also on maintaining species diversity in natural and semi-natural habitats across Europe.

Urban environments have many distinctive features, the most prominent of which is their extreme heterogeneity: there are patches where both biodiversity and ecosystem service delivery is minimal, for example, where land surfaces are covered with concrete or tarmac, and others where biodiversity may be very



Source: EEA (based on Corine land cover 2000 and Natura 2000 data).

Figure 2 Central Belgium is composed principally of highly urbanised areas and areas of high conservation value (Natura 2000 areas). (Reproduced with kind permission of European Environment Agency.)

high, as in some gardens and parks. A consequence of this heterogeneity is the fragmentation of habitats, which favours species that are effective dispersers but militates against others. This pronounced selection leads to distinctive communities, often dominated by alien species, which by definition are good at dispersing or being dispersed. In some regions, such as central Belgium, the effect of urbanisation has been to produce a dichotomy between highly urbanised and protected areas (Figure 2).

4.3 Methods of Valuing Biodiversity and Ecosystem Services

Many threats to ecosystem services arise because of the way in which different uses of land are valued. The immediate value taken into account in decisions is typically expressed in terms of the market price of the land to a developer or the value of a crop it will produce. These approaches ignore the value of the ecosystem services provided by the land, which will be placed in jeopardy by the proposed development. The valuation of ecosystem services offers the potential to place a value on the services forfeited by the development to balance the value of the development itself in assessments of costs and benefits of alternatives. Approaches of this kind have been used widely in project evaluation both of alternative land use and for conservation investments.

The EU has taken an active role in advancing valuations through the recent TEEB (The Economics of Ecosystem Services and Biodiversity) initiative.[71] This highlights the importance of valuation of ecosystem services and the biodiversity that underpins them, and gives powerful global examples. The scoping study concludes that there are major threats to ecosystem services from the current high rate of loss of biodiversity, but that there is an emerging range of policy instruments, based on valuing ecosystem services, that provides options for managing them in future.

At the most basic level, the services provided by an ecosystem at risk can form a powerful part of the narrative in project assessment. Simply by setting down the nature of the services and their potential scale, it is possible to alter the terms of assessment so that the 'development gain' is not the only factor for consideration.

4.3.1 Quantitative Methods

In recent years, there has been considerable progress in attaching monetary value to ecosystem services and, in certain cases, to the biodiversity underpinning them. Ecosystems have value in terms of their use, for example, for the production of food or management of flood risk. However, they also have a set of non-use values associated, for example, with the cultural and aesthetic significance they have. In many cases it has proved possible to capture both main kinds of value through a range of instruments including:

- *Revealed preference methods* based on evidence of current values as shown, (for example, in the market price of products, the impact of services on productivity or the costs associated with recreational use of landscape);
- *Cost-based methods* based on costs of replacement or damage avoided; and
- *Stated preference methods* that assess the amount people say they would be prepared to pay for ecosystem services.

Each method has strengths and weaknesses but stated preference methods, especially in the form of contingent valuation, have been most widely used in dealing with the real case of multiple services from an ecosystem. This bias reflects both an ability to handle multiple services better than the more objective methods that tend to focus on single attributes (for example, food production or flood defence) and the poor availability of the economic data that those methods require.

There is also much current interest in the development of markets for ecosystem services, as exemplified by carbon trading schemes. A new tool, payment for ecosystem services (PES)[72] defines a payment for an ecosystem service as a voluntary transaction where a well-defined ecosystem service is bought by at least one buyer from at least one supplier, but only if the supplier secures the provision of the service. The transaction should be voluntary and the payment should be conditional on the service being delivered. Paying for an ecosystem service is not necessarily the same as trading nature on a market: markets may play a role, but because many ecosystem services are public goods, we cannot rely on markets alone. Actions by governments and intergovernmental organisations are also needed.

There are numerous challenges to the implementation of PES.[73] However, we lack international institutions to broker deals between suppliers of ecosystem services and the rest of the world, though some non-governmental organisations play that role for specific projects and the Global Environmental Facility (GEF), funded by all countries, is designed to deal with global conservation issues.

4.3.2 Qualitative Methods: Multi-Criteria Analysis

Generally, economic valuation of biodiversity offers ways to compare tangible benefits and costs associated with ecosystems,[74] but ignores the information about non-economic criteria (for example, cultural values) that defines biodiversity values. However, decision-making processes require knowledge of all influencing factors.[75] Multi-criteria analysis (MCA) is a structured approach for ranking alternative options that allow the attainment of defined objectives or the implementation of policy goals. A wide range of qualitative impact categories and criteria are measured according to quantitative analysis, namely scoring, ranking and weighting. The outcomes of both monetary and non-monetary objectives are compared and ranked, so that MCA facilitates the decision-making process while offering a reasonable strategy selection in terms of critical criteria.

The basis of all valuation methods, however, is an assessment of the nature and scale of the ecosystem services themselves and, in cases where the viability of the ecosystem is placed at risk, the nature and scale of the consequent impacts on the provision of ecosystem services. Where the ecosystem services are dependent on biodiversity, loss of biodiversity can be valued in terms of ecosystem services foregone or reduced, provided that there is a robust description of the relationship between biodiversity and ecosystem services. The quality of the underlying science is therefore of great significance in all kinds of valuations.

4.3.3 Putting Valuation into Practice

Methods for valuing ecosystem services and biodiversity are becoming accepted and embedded in a wide range of policy instruments.

The UK Department for Environment, Food and Rural Affairs (Defra) appraisal of options for a Flood and Coastal Erosion Risk Management (FCERM) scheme includes specific estimates of the economic value of changes in ecosystem services under a range of options, using the 'impact pathway approach'. This involves a series of steps so that a policy change; the consequent impacts on ecosystems; changes in ecosystem services; impacts on human welfare; and economic value of changes in ecosystem services are considered in turn.[76]

Key stakeholders in FCERM are broadly supportive of moves towards greater inclusion of economic value estimates in appraisals, despite the remaining uncertainty about the absolute value of the ecosystem services, resulting from uncertainty about both the physical changes in ecosystem services and the appropriate monetary values to apply to these. The authors suggest that practical appraisals 'need to compare the relative magnitude of changes in the provision of ecosystem services across different options' and conclude that this can be possible even with 'limited availability and precision of scientific and economic information. In most cases it should be possible to present a robust assessment, with suitable sensitivity analysis, highlighting the key uncertainties and exploring their implications'.[77]

The prime current example of PES, carbon trading, is developing rapidly. In Europe, the EU Emissions Trading Scheme (EU ETS) is in a second phase of development and now accounts for about 65% of global carbon trading. Current allowance prices for carbon within the EU ETS show some volatility but are currently (October 2009) around €15 (per tonne CO_2 equivalent). Volumes traded average about 8.5 million tonnes per month.

The results of valuation are increasingly recognised and accepted in policy debates and in individual decisions, on environmental impacts of projects of economic development, for example. Current knowledge of ecosystem services and the processes behind them gives a strong basis for valuation. However, it is clear that more is needed to strengthen the underpinning science.

4.4 Prioritising Ecosystem Services in Land Management: Weighing up Alternative Land Uses

There have been numerous attempts to find optimal habitat management strategies for particular broad ecosystem types, aiming to maintain biodiversity. In natural ecosystems such as forests, minimal intervention is usually the best habitat management strategy, although different types of sustainable forestry may work as well.[78] In natural aquatic ecosystems, the management of nutrient status of ecosystems is of primary importance,[79] whereas regulation of hydrology is an important issue when managing wetland ecosystems. Optimal habitat management in agricultural ecosystems requires the regulation of land-use intensity.[80] There has been much attention on semi-natural grasslands: optimal grazing and mowing regimes, techniques of cutting shrubs and burning, *etc*. have been discussed.[81] However, in all these cases the linkage to delivery of ecosystem services has been weak.

At the same time, there is accumulating evidence of the impact of land-use type and intensity on ecosystem services. For instance, the significance of European semi-natural grasslands as a source of clean and sustainably produced fodder has been recently recognised.[82] Those grasslands are extremely rich in species, but also rich in genetic variability within species and may thus provide genetic resources, which might contribute to the development of new breeds of agricultural plants, medical plants, *etc*. They also provide different regulatory services like pollination,[83] or hazard prevention,[84] or multiple cultural services. The availability of those services is primarily dependent on the continuation of the extensive land use in agricultural landscapes.

Although agri-environmental schemes encourage farmers to restore species-rich grasslands on arable land or on culturally improved pastures, the land-use types that maximise ecosystem services are not targeted in the current policies of the EU. The Common Agricultural Policy aims to increase agricultural production, without valuing ecosystem services. Similar policies apply to land use in forest or wetland ecosystems. Current policies also lack a landscape perspective and fail to take into account the linkages between landscape units or the delivery of multiple services from ecosystems. The opportunity for maintaining both ecosystem services and biodiversity outside conservation areas lies in promoting diversity of land use at the landscape and farm rather than field scale.[85] To achieve that goal, however, would require an economic and policy climate that favours diversification in land uses and diversity among land users.

Current strategies of habitat management and land use in Europe, focusing on economic benefit on the one hand and on the conservation of habitats and species of special interest on the other, now need to be broadened in order to cover a wider range of societal needs. There is therefore an urgent need for policies that prioritise the delivery of ecosystem services from land and that favour appropriate land use, encouraging habitat management and aiming to preserve or improve multiple ecosystem services. Proper ecosystem management strategies have to offer principles for land use in order to minimise the possible conflict between management goals that target different services. Besides traditionally accepted cultural services and more utilitarian services like production of food, fibre and fuel, supporting and regulatory services deserve much more attention than they have received until now.[86]

5 Conclusions

This assessment shows that the services provided to humanity by ecosystems in Europe are many, varied, of immense value and frequently not open to substitution by any artificial process. Although in some cases, biodiversity appears to play a relatively small role in maintaining ecosystem services, there is clear evidence that in others the biodiversity plays a fundamental role in the delivery of the service.

We have highlighted four of these services as being both of key importance to our survival as a society and particularly susceptible to the biological richness of the ecosystems that deliver them: primary production, nutrient cycling, pollination and a set of cultural services centred around ecotourism and recreation. Other services for which the evidence suggests that biodiversity is important appear to play a smaller role in sustaining modern European societies, at least at present.

Focussing on these services, however, may obscure a more fundamental point: that all ecosystems deliver a broad range of services, for some of which biodiversity is crucial and some of which are of particular economic or social value. Two key points arise from understanding that all ecosystems deliver multiple services:

1. Managing an ecosystem primarily to deliver one service will almost certainly reduce its ability to provide others: a forest managed exclusively for timber production will have minimal amenity and ecotouristic value, will store little carbon and will be ineffective at retaining nutrients;
2. Many of the multiple services that arise from a single ecosystem are either undervalued or completely unvalued: in the case of the forest, society currently places no value on nutrient cycling, only rarely values water cycling and regulation, and is only beginning to find ways to value carbon storage effectively.

Generally speaking, we undervalue all ecosystem services that do not provide goods that can be handled through conventional market mechanisms. Some value is placed on amenity, because of the increasing recognition that the economy of many rural areas in agriculturally marginal zones is heavily dependent on tourism, but usually the potential beneficiaries are not the managers of the land, leading to a beneficiary trade-off. No effective values are placed on most of the basic supporting services (soil formation, water and nutrient cycling) and primary production is generally only valued insofar as it creates marketable goods. Regulating services are almost always undervalued, perhaps most notably in the case of pollination, despite the fact that in this case it is possible to understand the value that it provides in relation to marketable goods such as food.

There is an urgent need therefore to provide incentives to managers of land and water to ensure the maintenance of the broad range of services from the ecosystems that they manage. Because of the difficulty of using traditional economic instruments to achieve this goal, an alternative regulatory framework is needed, which may require the development of a set of binding legal requirements, as in the case of the Water Framework Directive.

The research that has been assessed in this chapter demonstrates that both the quality and quantity of biodiversity are important for maintaining the health of ecosystems and their ability to deliver services to society. The importance of biodiversity varies greatly among services, being particularly strong for primary production, nutrient cycling and pollination, for example, but much less so for protection from natural hazards. The way in which biodiversity ensures the processes that underly ecosystem services is only partly understood, and there is an urgent need for research to determine how great a loss of biodiversity can be experienced before service delivery declines.

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