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Synthesis Report C13: Maintaining biodiversity and ecosystem services while feeding the world

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Contents

About this report

This Report has been commissioned as part of the UK Government's Foresight Project on Global Food and Farming Futures and forms one of a set of 13 'Synthesis Reports' synthesising the evidence base of over 80 independent reviews commissioned by the Project. For the Final Project Report and a map of all the Foresight Project publications please see the project CD or website at www.bis.gsi.gov.uk/foresight

C13. Maintaining biodiversity and ecosystem services while feeding the world

C13.1 Introduction

Food production takes up more land and has a greater impact on the sea and freshwater bodies than any other facet of human activity. It thus inevitably has a major impact on the earth's biodiversity as well as on how natural and manipulated ecosystems function and the benefits they provide for humanity[1]. As global population density has risen, the pressure on natural environments has steadily increased. The current rate of species extinctions is estimated to be between 100 and 1,000 times greater than background levels (if mankind were absent)[2]. Further increases in demand for land and other resources risk a reduction in biodiversity of the same order of magnitude as the cataclysmic extinction events at the end of the Palaeozoic and Mesozoic geological eras.

The likelihood that the density of the human population, and consequent demand for food, will reach a plateau this century[3] offers the prospect of an end to the continual increase in pressures on ecosystems and biodiversity. If irreversible losses to biodiversity and ecosystem functioning can be prevented over the next 50 years as population numbers stabilise, and if global climate change can be arrested, then there is a significant chance that a substantial proportion of global biodiversity can be preserved indefinitely. As has been stressed elsewhere in this Report, this is a unique time in history and urgent decisions that need to be taken now will have a disproportionate impact on future generations.

Until recently, policies for conservation and food security were largely developed in isolation. Increasingly, they are being explored together. Many of the world's biodiversity hotspots are in low-income countries[4] that suffer chronic food insecurity and have high rates of population growth. Food security is therefore a prerequisite for successful conservation and successful development that provides incomes and access to food to facilitate the protection of biodiversity. At the same time, the extent to which the production of food relies on natural capital is becoming more apparent: uncosted services, such as the provision of pure water, are provided by different ecosystems – by agricultural land itself as well as more natural habitats[5]. Different practices in food production affect the degree to which farmland and aquatic habitats provide these services, and influence those provided by non-food-producing ecosystems. Protecting biodiversity and ecosystems, and ensuring food security, thus occupy broadly overlapping areas of policy.

C13.2 Biodiversity and ecosystem services

Biodiversity is a fairly recent contraction of 'biological diversity' and is a term used to denote the variety of life on earth[6]. It encompasses all levels of variation, from the genetic diversity within a species to the variety of species within a community or ecosystem and the diversity of ecosystems themselves. Within the literature on food production, the term biodiversity is sometimes used in a more specialist sense to describe the genetic diversity within a crop or livestock species that needs to be preserved by mankind (an aspect of biodiversity that is treated elsewhere in this report, see Project Report C6)[7]. Currently, the most important international forum for policy relating to biodiversity is the Convention on Biological Diversity (CBD)[8].

1 Tilman et al. (2001); Foley et al. (2005)
2 Lawton and May (1995)
3 DR1 (Annex E refers)
4 Myers et al. (2000)
5 Daily (1997); MEA (2005)
6 Wilson (1988)
7 http://www.bioversityinternational.org/
8 The tenth meeting of the conference of the parties took place in Nagoya in October 2010. See http://www.cbd.int/

The plants, animals and micro-organisms at a particular locality linked by different biophysical processes constitute an ecosystem. Ecosystems might be highly influenced by a variety of factors, such as human (for example urban ecosystems and 'agro-ecosystems') or environmental (rainforests, coral reefs), or indeed, anywhere in between. Ecosystems provide a range of benefits to mankind that are termed ecosystem services[9]. Although concepts related to ecosystem services have a long history in applied ecology, the Millennium Ecosystem Assessment (MA)[10] has played a leading role in raising these ideas to their current prominence.

The MA also introduced a categorisation of the main types of ecosystem service. Ecosystems can provide direct goods such as food, fibre or timbers, termed *provisioning services*. They can also help enable the provision of direct goods, for example by providing pollinators, natural enemies of pests, pure water and a conducive local climate – these are termed *regulating services*. Both these categories can rely on more fundamental processes such as those producing fertile soils, recycling water or nutrients, which are called *supporting services*. Finally, ecosystems can provide less tangible public goods, such as landscapes that people cherish and the preservation of biodiversity that in most value systems is considered beneficial – these are called *cultural services.*

A primary goal of using ecosystem services is to accord monetary and non-monetary value to different components of the environment to help policy-makers prevent the erosion of natural capital. This is most easily done by a more economic development of the concept of ecosystem services, and summarised in Figure C13.1[11]. Here, to avoid double counting of ecosystem services, a distinction is made between primary and intermediate ecological functions and *final ecosystem services* that directly influence goods that benefit mankind[12]. The value of these goods can in theory be wholly or partly monetised, and partitioned into that owing to natural capital (the value of the ecosystem services) and that owing to human forms of capital. This conceptualisation acknowledges the limitations of the economic analysis of ecosystem services, and the fact that decision-makers will also need to consider possible non-monetary benefits provided by ecosystems.

There are huge complexities in assessing the value of ecosystem services. Some provisioning services have calculable market values (though care must be taken to avoid the distorting effects of taxes and subsidies) while the benefits of others can be estimated using economic models of production output. Sometimes the benefits of not allowing an ecosystem service to decay can be calculated, or the costs that people are willing to pay to avoid a negative outcome can be measured. For other ecosystem services, particularly cultural services, indirect measures, such as the willingness of people to pay to visit or live in certain habitats or surveys of relative preferences, have been employed. A current programme, The Economics of Ecosystems and Biodiversity (TEEB), aims to provide new tools to assist policy-makers in this area of modern economics[13].

9 Fisher et al. (2008)

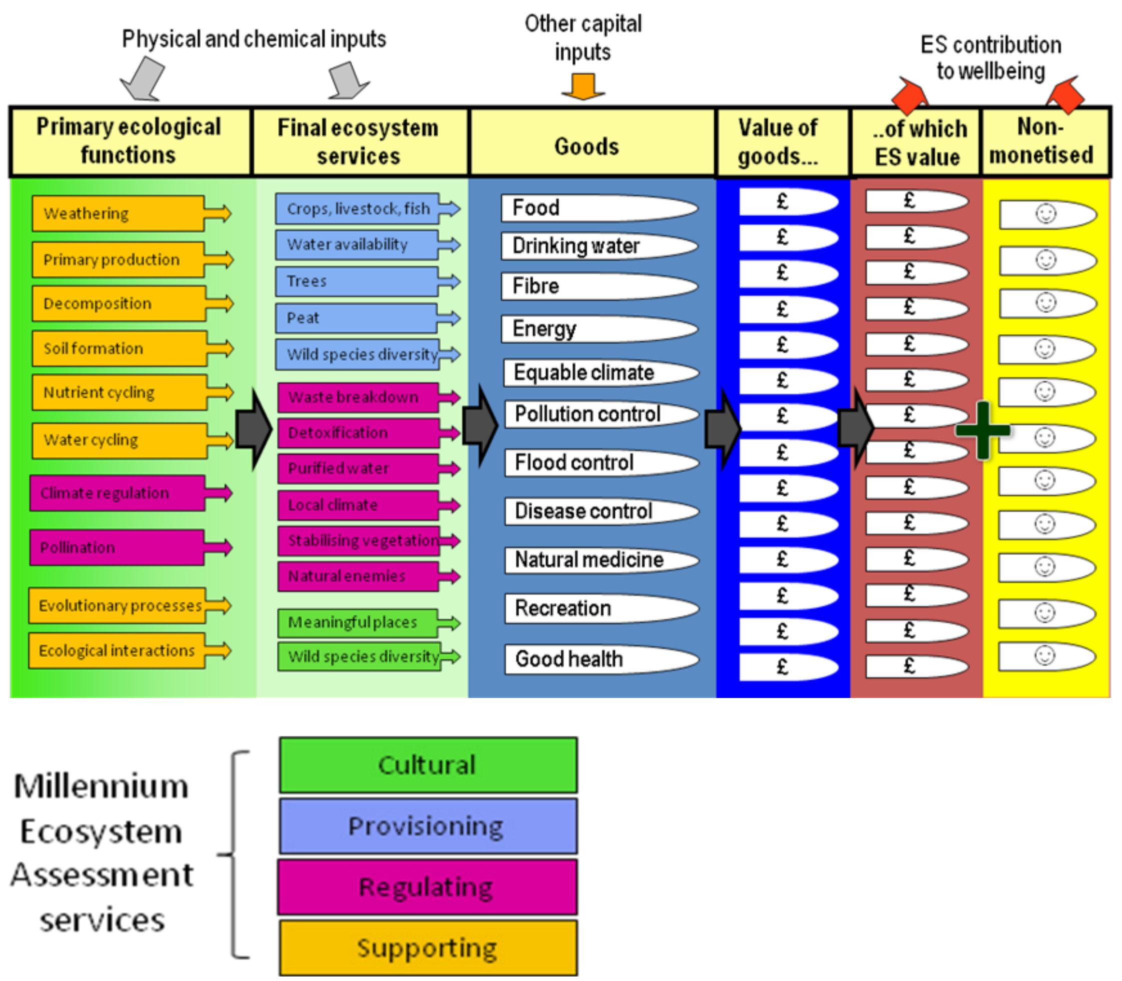
10 MEA (2005)

11 SR39 (Annex E refers)

12 Heal et al. (2005); Fisher et al. (2008)

13 SR39 (Annex E refers); see http://www.teebweb.org/

Figure C13.1: From ecosystem processes and final services to economic goods – the conceptual framework for the UK National Ecosystem Assessment (NEA). This figure illustrates the distinction between those primary processes that underpin (but are to some extent distinct from) the final ecosystem services that contribute directly to the production of goods. Primary processes are to some extent determined by exogenous inputs (e.g. sunlight). In an analogous manner, final ecosystem services are supplemented by other inputs (e.g. man-made capital) in the production of goods. Because of this the entire value of such goods cannot be attributed to final ecosystem services but instead have to be disaggregated from these and other inputs before deriving estimates of the net contribution to that value obtained from natural systems. Note also that Figure 13.1 allows for the probability that not all of the wellbeing effects of the ecosystem can be captured in monetised values. More ephemeral impacts, such as some of those included within the Millennium Ecosystem Assessment cultural services (e.g. spiritual, inspirational, citizenship etc.), may be beyond the capabilities of existing valuation methods, yet may still be important contributors to wellbeing. Accordingly, the NEA explicitly supplements the disaggregated impact of ecosystem services upon valued goods with non-monetary measures of wellbeing.



Source: SR39 (Annex E refers), adapted from Fisher et al. (2008) and Mace et al. (2009).

C13.3 Sustainable intensification, ecosystem services and biodiversity

One of the main conclusions of the Foresight Final Report is that to be able to address global food security, all available options for policy, including those aimed at increasing production, must be sustainable. But what does sustainable intensification mean from the point of view of biodiversity and ecosystem services?

The long-term aim of the CBD is to reduce the loss of biodiversity to what would be background levels in the absence of mankind. In this context a sustainable food system would not increase the risk of further loss of biodiversity. This could be done by fostering biodiversity on farmland or in the water bodies used for capture fisheries, or by making efficiencies so that land can be spared from food production (and other human activities) and set aside for conservation. A corollary of this approach is that planning for sustainable biodiversity has to be made at regional, national and international levels and must involve the whole landscape.

Underlying the rationale for using ecosystem services is the belief that many of the benefits provided by biodiversity in non-food-producing ecosystems as well as within agro-ecosystems are unappreciated[14]. One reason for this belief is that the food producer does not have to pay for these goods. Another is that they are sometimes not even understood. Similarly, any harm to biodiversity is not measured and the costs are not borne by the producers. Environmentalists, by costing ecosystem services and 'disservices', hope to provide a means of more accurately judging the overall benefits of alternative strategies. Of course, even if successful, this approach would only identify which options would optimise possible benefits to society. A further question is how to incentivise individual actors with different interests to implement these assessments.

A successful application of the ecosystem services approach will often show unexpected benefits of preserving biodiversity. It has been estimated that natural pest control services save US$13.6 billion per year in agricultural crops in the USA[15] while the economic impact of the loss of insect pollination on world food production has been estimated at US$153 billion[16]. However, there have been fewer economic studies to assess whether leaving areas uncultivated to provide pollinators and natural enemies is actually optimal for the individual farmer. The results are likely to be context specific, even when the full ecosystem costs of alternatives (for example managed pollinators and chemical pest control) are included.

C13.4 Some major trade-offs

In this section some of the major trade-offs confronting decision-makers in food security and biodiversity are explored.

Yield versus ecosystem services

Increasing yield often comes at the expense of different ecosystem services[17]. For example, maximising productivity in arable fields may involve the elimination of all non-crop species and hence a reduction in biodiversity. It may also involve an increase in the application of nitrogen fertiliser and a reduction in the ability of the agro-ecosystem to provide pure water (an ecosystem service) and increase nitrogen run-off and pollution (an ecosystem disservice). There is an extensive literature exploring the relationship between yields in organic systems and the often positive benefits of this form of agriculture to biodiversity[18].

Trade-offs between different ecosystem services

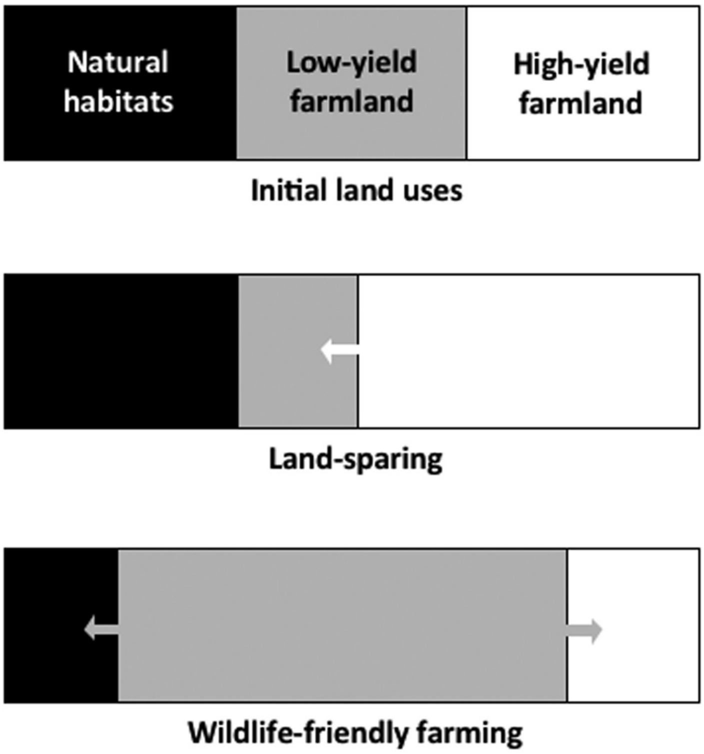
Different ecosystem services are favoured by different management strategies. For example, positive ecosystem services such as pollination and pest control provided by non-farmed habitats can best be maximised by a landscape configuration consisting of a mosaic of farmed and 'natural habitat' patches. But such a landscape would be far from optimal to conserve species that require large contiguous areas of habitat[19]. A goal of modern land-use planning is the development of multifunctional landscapes[20], and its implementation will require the identification and understanding of multiple trade-offs amongst ecosystem services and other land-use objectives[21].

14 DR7A (Annex E refers)
15 Losey and Vaughan (2006)
16 Gallai et al. (2009)
17 Donald (2004); Green et al. (2005a,b)
18 Lampkin (2010)
19 SR36 (Annex E refers)
20 Foresight (2010)
21 Rodríguez et al. (2006)

Land sharing versus wildlife-friendly agriculture

A major debate in the literature on conservation concerns the relative advantages of changing agricultural practice to increase on-farm biodiversity at the expense of yield, and maximising food production to allow land to be set aside for biodiversity protection (Figure C13.2). A useful way to explore this trade-off is to consider the relationship between a measure of biodiversity and the yield of food obtained from the land[22]. Complications arise if intensifying production in farmed areas produces negative externalities such as pollutants that reduce the value of land set aside for biodiversity[23].

Figure C13.2: Illustration of how land-sparing or wildlife-friendly farming strategies could be used to meet an increase in food demand. This example starts from a region with equal areas of natural habitats, extensive and intensive land uses (top). Land-sparing (centre) involves increasing yields in the production landscape while protecting natural habitats. Wildlife-friendly farming (bottom) involves expanding the area of extensive farmland at the expense of natural habitats.



Source: SR36 (Annex E refers).

Marine reserves and no-capture zones

Modern fishing can have a major effect on marine ecosystems, greatly damaging biodiversity. Marine protected areas (MPAs), where a range of activities are controlled and fishing is banned or restricted, can be a valuable means of protecting biodiversity, and some 0.7% of the world's oceans are now designated as MPAs[24]. However, there is not a simple trade-off between the size of marine reserves, their consequent benefits for biodiversity and the degree to which harvests are reduced. MPAs can allow disturbed habitats to recover and reduce the harmful effects of by-catch and discards on non-target species: in general, biodiversity is higher within MPAs than outside, although this has not always been demonstrated[25]. MPAs can bring economic benefits through tourism and sport fishing, but the stakeholders who benefit may not be the local fishing communities whose activities are restricted[26]. There may also be 'spillover' effects where MPAs benefit biodiversity outside the reserve and even

22 Green et al. (2005a)
23 Daly et al. (2007)
24 World Database on Marine Protected Areas (http://www.wdpa-marine.org)
25 FAO (2007)
26 Balmford et al. (2004)

increase stock recruitment, although a better evidence base is needed to understand these effects. The value of MPAs varies with their size and the type of ecosystem protected and the effectiveness of controls on external fishing pressures. However, on balance, if well designed and effectively supported, it is likely that MPAs will have an increasingly valuable role in sustaining aquatic biodiversity.

Biodiversity and the needs of the poor

Some of the most threatened and diverse habitats on earth exist in very low-income countries, and interventions to make farming more wildlife friendly or to set land aside as reserves may affect the livelihoods of the very poorest people. Some have argued that there is seldom a trade-off and that low-input, labour-intensive agriculture in low-income countries is both pro-poor and pro-biodiversity[27]. Undoubtedly this will sometimes be the case, but as explored further in Project Report C11, in other circumstances the needs of low-income societies will be better met by adopting more intensive forms of agriculture, while setting land aside as reserves may produce better biodiversity outcomes[28]. Whatever strategy is adopted, it is important to recognise and quantify these trade-offs as there are strong ethical arguments that the costs of protecting biodiversity should not be borne by those least able to pay them.

C13.5 Better understanding of the trade-offs

The false agriculture–wild interface

Although one of the trade-offs discussed above is between preserving biodiversity in farmland and setting aside land for protected areas, it is important to realise that there is not a sharp dichotomy between the two. Virtually all ecosystems have been shaped by human action, some by deliberate management to increase certain valued resources, and lately much more by the side-effects of pollution, waste and over-consumption. Many non-agricultural habitats are inhabited by indigenous people who obtain a large proportion of their food from these ecosystems. Moreover, farmers, hunters, gatherers, fishers and foragers do not simply take resources from a compliant environment. In many cases they manage and amend resources in much the same way as is standard practice on farmland[29]. Foragers maintain resources by sowing seeds of wild plant species, irrigation of grass swards, burning to stimulate plant growth, selective culling of game animals and fish, replanting of portions of roots, tree-planting, and selective extraction of honeycombs so sites are not deserted by bees. All these activities have equivalents in conventional agriculture, and are variously designed to increase the productivity and stable supply of useful plants and animals[30].

The provision of food to poor communities by natural habitats is an ecosystem service that has been consistently underestimated and needs to be better incorporated into biodiversity policies. In addition, non-cultivated plants and animals that persist in mosaic agro-ecosystems may provide important supplementary food, which bears on debates about the intensification of agricultural production in poor countries. Today, wild plants and animals remain vital for many agricultural communities. The average number of wild food species used by agricultural and forager communities in 22 countries of Asia and Africa (36 studies) is 90–100 species per location, while estimates of the total number of species used per country can be as high as 300–800 (e.g. India, Ethiopia, Kenya)[31,32].

In trying to understand the advantages of different food production systems for biodiversity and ecosystem services, it is important to establish common baselines[33]. Thus:

- Alternative agricultural practices should be compared appropriately (for example with equivalent best-practice conventional agriculture).
- Many agricultural systems are rotations and the effects of different practices on ecosystem services and biodiversity must be considered over the entire time span of the rotation.

27 Perfecto et al. (2009)
28 SR36 (Annex E refers)
29 Kelly (1995); Bird Rose (1996); Lee and Daly (1999); Brookfield and Padoch (2007); Berkes (2009); Heckenberger (2009)
30 DR21 (Annex E refers)
31 See C1 (Annex E refers)
32 DR21 (Annex E refers)
33 SR36 (Annex E refers)

- In highly modified landscapes there may be little biodiversity remaining with relatively restricted ecosystem services. When exploring different policies, more radical policies such as recreating natural habitats should be considered.
- Some modified landscapes may currently contain more biodiversity than they can support sustainably because it takes time for extinctions to occur. For example, long-lived trees may persist but in the absence of their pollinators or fruit dispersers they may not be able to reproduce. Extinction debt is the term used to describe these species that are doomed to disappear.

Does increased production lead to less pressure on biodiversity?

Although in principle increasing production on land already converted to agriculture can allow land to be spared to protect biodiversity, whether or not this occurs depends on complex socio-economic factors, particularly pressures to use the land for other reasons including the production of non-food products such as biofuels. Evidence suggests that at local scales, innovations that increase the productivity of tropical agriculture can either increase or decrease the rate of conversion of natural habitats, while at larger scales (at the level of nation states), there is a weak tendency for increases in yields to be associated with reduced expansion of agricultural land and lower rates of loss of natural forests[34,35]. There are no reports of increases in crop yield resulting in perfect land sparing in practice, i.e., where a given proportional increase in yield results in a corresponding decrease in the area of land converted from natural habitat to agriculture. Unless combined with other incentives, yield increases seem more likely to slow rather than reverse habitat conversion[36].

Trade-offs can cross national boundaries

Decisions about food, ecosystem services and biodiversity have several international dimensions:

- The value of protected areas often increases with their size, and hence reserves that cross national boundaries can be particular important.
- Ecosystem services and 'disservices' originating in one country can have consequences in another. The emissions of greenhouse gases obviously has a global reach while the effects of water extraction for agriculture and the release of pollutants into water bodies can have consequences for countries downstream[37].
- Successful protection of biodiversity may need decisions made in multiple countries. For example, the protection of long-distance migrant birds requires that environments such as wetlands and woodlands are not converted to agriculture in both the breeding and wintering grounds, and at stopping points along the migration routes[38].

C13.6 Land-sparing

A negative externality of low-yield agriculture is that more land is required for production to meet demand. There are several reasons why providing enough food from cultivated land to allow land-sparing or prevent further conversion is critical for the protection of biodiversity.

Some biodiversity cannot persist in agro-ecosystems

As described above, as land is converted to food production, its value for biodiversity typically declines along the dimension of production practices, leading to higher yields. However, for some ecosystems a significant proportion of biodiversity is lost almost immediately, even when modifications to land use are relatively minor or spatially restricted. A survey of recent reviews of the proportion of species in natural habitats that were also observed on farmland designated as wildlife friendly[39] found overall, 54% of species from the natural habitats were observed on the farmland. However, such data from a meta-

34 SR36 (Annex E refers)

35 Barbier and Burgess (1997); Angelsen and Kaimowitz (2001); Ewers et al. (2009)

36 Rudel et al. (2009)

37 Project Report R3 (Annex E refers)

38 See, for example, http://www.ramsar.org/; http://www.bto.org/research/migrationresearch.htm

39 SR36 (Annex E refers)

analysis should not be interpreted uncritically and it is likely that some of the species observed on farmland are subject to extinction debt (see above), or were present in populations that would be unviable without migrants from protected areas. But the fact that approximately half of all species seem to require natural habitats shows a limit to the effectiveness of on-farm schemes for protecting biodiversity.

The importance of rainforests

As discussed in Project Report C12, much land that might be brought into agriculture is currently covered by tropical rainforest. Pressure from expanding agriculture has been a major factor leading to recent tropical deforestation, especially in South America (conversion to soybean and cattle ranching) and South East Asia (conversion to oil palm plantations). The conversion of tropical forests to agriculture releases large amounts of greenhouse gases (GHG), and this is one of the most serious contributions of the food system to global warming[40]. Indeed, a recent study has estimated that by reducing the area of land that would have had to be converted to agriculture to meet food demand, the Green Revolution made a very positive net contribution to GHG emissions, despite its contribution to increased emissions from fertiliser production and other sources[41]. In addition to its effects on GHG, tropical deforestation may have direct and damaging effects on local climate[42].

In addition to their role in mitigating climate change, tropical rainforests harbour more biodiversity than any other habitat. Much of this biodiversity can only exist in rainforests, and is lost immediately once the land is converted to other uses[43]. Moreover, a sizeable fraction requires large tracts of intact rainforest and is significantly affected by 'edge effects' including that caused by the construction of roads[44].

The importance of tropical forests to climate change was underlined at the United Nations Climate Change Conference (COP 15) in Copenhagen in 2009 where agreements were reached on a set of market and fiscal incentives known as REDD (Reducing Emissions from Deforestation and Forest Degradation) to help low-income countries protect their forests. REDD+ (a commitment at COP 15 Copenhagen and reinforced at COP16 Cancun) goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks and helps to enhance biodiversity and improve other ecosystem services such as watershed control. To achieve these multiple benefits, REDD+ will require the full engagement and respect for the rights of Indigenous Peoples and other forest-dependent communities, and will need to establish monitoring protocols to ensure the fair distribution of benefits and avoid the creation of perverse incentives. A new initiative that calls for agriculture to be part of the solution to climate change was announced at the COP16 climate negotiations in Cancun, Mexico, and proposes key actions to be taken to link agriculture-related investments and policies with the transition to 'climate-smart' growth. An increased focus on aligning REDD+ with agriculture and food security in low-income countries will be essential for its success[45].

Some agro-ecosystems have great importance for biodiversity

In some parts of the world, the most important remaining biodiversity exists in artificial agro-ecosystems. Examples of this include the richness of the South European Mediterranean flora that exists in a landscape farmed for thousands of years, the biodiversity richness of mixed oak and pasture landscape in Spain, and areas of steppe and semi-steppe in Europe and South America where cattle substitute for large extinct herbivores.

To make rational decisions about such habitats it is important to know the rate at which biodiversity is lost as they are subject to more intensive management practice. If this trade-off is steep then the best

40 Stern (2006)
41 Burney et al. (2010)
42 DR2 (Annex E refers); IPCC (2007)
43 SR36 (Annex E refers)
44 Ewers and Didham (2008)
45 The Roadmap for Action: Agriculture, Food Security and Climate Change is the result of discussions among 70 ministers of agriculture and other agricultural leaders at the Global Conference on Agriculture, Food Security and Climate Change, hosted by the Government of the Netherlands, November 1-5, 2010.

strategy might be to preserve some land in its original state and allow other land to be developed intensively. This is the same trade-off between land sparing and wildlife-friendly farming that has been discussed elsewhere in this report. But a difference here is that another option may be to try to increase biodiversity beyond what currently exists by reconstructing lost ecosystems. This is sometimes called 'rewilding' and in its most radical forms might involve the replacement of cattle by a wild vertebrate herbivore together with its top predator[46]. It has been argued that environmental decisions made by society are influenced by the options available in recent history, and the baseline of what is considered natural constantly shifts towards more artificial environments as humanity's footprint expands. Rewilding and similar suggestions are a means of countering this shifting baseline.

Restored land

In Project Report C2, it has been argued that bringing land back into agriculture is an important way of increasing food production, and examples of successful major land restoration projects have been described[47]. Some secondary forests can have carbon storage and biodiversity values that approach primary forests, and degraded land, especially in areas where little biodiversity may remain, can be a major reservoir of rare species of plants and animals. The consequences of restoration for environmental externalities should be assessed and measured in the same way as for land conversion[48].

C13.7 Improving biodiversity and ecosystem services on farmed land

Throughout this Report the trade-off between yields and the amount of biodiversity and other ecosystem services that agro-ecosystems can support or provide has been acknowledged. But this trade-off is not fixed and there are some examples where both yields and ecosystem services can be increased together or where the shape of the trade-off can be modified such that without damaging yields, negative externalities affecting biodiversity can be reduced.

Reduce externalities

There is a very large literature on wildlife-friendly farming and the numerous ways that biodiversity can be encouraged on productive land[49]. Many high-income countries have schemes that reward or incentivise food producers for practices that encourage wildlife, although there have also been debates about the effectiveness of some interventions[50].

The requirements for water to maintain minimal environmental flows in rivers is the single most important competing demand for water for agriculture[51]. Minimal environmental flows are required to maintain different river and lake ecosystem services, including the preservation of freshwater biodiversity. Indeed, many environmentalists argue that estimates of minimal environmental flows are systematically too low to protect biodiversity. Interventions that increase water efficiency in agriculture will decrease pressure on water extraction and, depending on how water is managed, may benefit biodiversity. Similarly, interventions that reduce the volume of agricultural inputs such as fertilisers, herbicides and pesticides may reduce pollution and benefit biodiversity both on farmland and in other habitats.

Landscape manipulation

Interventions at the landscape level can offer different ways of mitigating the effects of agriculture and food production on biodiversity and other ecosystem services. For example, in a highly modified landscape areas of natural habitat with high biodiversity value may be restricted to isolated patches. These may each contain populations of animals that alone could not persist because of the probability of extinction (small populations are at elevated risk of extinction through purely random processes, and also through genetic inbreeding). Corridors linking habitats can help mitigate these effects by allowing

46 Donlan et al. (2005)
47 Annex E refers
48 SR36 (Annex E refers)
49 Scherr and McNeely (2007)
50 Kleijn and Sutherland (2003)
51 DR12 (Annex E refers)

genetic exchange between otherwise isolated populations, and by allowing recolonisation after local extinction. It has also been argued that wildlife-friendly farming can provide a benign environment to allow migration between habitat patches[52], though such arguments should be examined within the wider context of trading off yield for protected areas[53].

It has also been argued that habitat heterogeneity per se is a positive feature and this is an argument in favour of an agricultural landscape consisting of a mosaic of different habitats[54]. There have, however, been cautions against this approach, pointing out that the benefits of habitat heterogeneity are highly species- and system-specific[55]. In many cases, biodiversity outcomes are likely to be optimised if large intact blocks of land are set aside.

In Project Reports C5 and C11 the value of better infrastructure and the development of food markets in low-income countries was stressed as an important strategy for development, and a way of tackling hunger amongst poor people. Different options for infrastructure may vary in their impact on biodiversity. An example is the development of roads, something that will often be essential to raise rural incomes. Roads built through protected areas can have disproportionate effects on biodiversity, both through edge effects (for example the impact of a disturbance can penetrate deep into a forest) and through enabling illegal settlement and timber extraction[56]. Similarly, the construction of ports can affect mangrove, coral reef and other coastal and marine ecosystems. Effects on biodiversity should be considered in decision-making processes on the selection of different options for infrastructure.

C13.8 Major knowledge gaps

Knowledge gaps: ecosystem services

There is a need for a better and more systematic understanding of the ecosystem services provided by different habitats. The Millennium Ecosystem Assessment[57] (2005) provided a necessarily coarse overview at a global scale and a first-generation methodology for more detailed smaller-scale assessments. The UK's National Ecosystem Assessment[58] will provide information about the ecosystem services provided by different habitats in the UK, as well as the marginal costs and benefits of ecosystem manipulations. More assessments of this type are required, especially in low-income countries, to provide a stronger evidence base for policy makers.

Knowledge gaps: ecological and environmental sciences

Fundamental ecological research is required to help protect species, communities and ecosystems and the key questions identified for the ecological sciences of particular relevance to the food system include[59]:

- How will reform of the Common Agricultural Policy affect biodiversity at the landscape scale?
- What are the environmental consequences of farming patterns ranging between the extremes of widespread extensification versus complete segregation of agricultural production and conservation areas?
- How do farming systems such as conventional, integrated farm management and organic compare in terms of their effects on biodiversity and other environmental impacts?
- How do current agricultural practices affect the conservation value and extent of non-agricultural habitats such as woodland edges, hedgerows and ponds, and how can detrimental impacts be mitigated?

52 Vandermeer and Perfecto (2007)
53 SR36 (Annex E refers)
54 Fischer et al. (2008)
55 SR36 (Annex E refers)
56 Dobson et al. (2010) is an example of a recent controversy about roads.
57 MEA (2005)
58 http://uknea.unep-wcmc.org/
59 Sutherland (2006)

- What are the impacts of agricultural activities and practices (e.g. fertilisers, pesticides and physical disturbance) on soil biodiversity and soil functions?
- What are the ecological consequences of changes in upland grazing regimes for biodiversity and soil ecology?
- What is the impact of the harvest of forage fish for the production of aquaculture foodstuffs on biodiversity?
- What are the ecological impacts of faecal matter, pesticides and undigested food flows from aquaculture?
- How important are caged fishes as reservoirs of parasites and pathogens that have detrimental effects on wild populations?
- What are the direct (catch) and indirect (food supplementation by discards, prey depletion) impacts of commercial fishing on cetaceans and seabirds?
- How large should MPAs be, and where should they be located to protect biodiversity and enhance surrounding fisheries?

The relation between biodiversity and ecosystem function and services, and the determinants of ecosystem resilience, are poorly known[60]. Arguments from the perspective of precautionary safe minimum standards suggest that biodiversity loss should be kept to ten times less than background rates to avoid putting ecosystem resilience at risk[61]. However, the theoretical underpinning for this is weak, and 'safe' levels of biodiversity loss may depend on both the system and the ecosystem service under consideration.

Knowledge gaps: environmental economics

Probably the most serious problems facing the effective and robust valuation of ecosystem services are gaps in the understanding of science relating those services to human wellbeing (the generation of economic 'goods') and the lack of data regarding the values of these goods[62]. Addressing this will require novel interdisciplinary partnerships between natural and social scientists. Specific issues that need research include:

- The incorporation of spatial effects such as differences in the recreational value of ecosystems located at different distances from population centres.
- Better ways to take account of the consequences of current actions for the future, for example the incorporation of sensible discount rates and time-dependent preferences (how biodiversity will be valued by future generations compared with the present generation).
- How to deal with irreversible processes (such as extinction) and determine the appropriate investment in methods to assure ecological resilience.

C13.9 Policy implications

Knowledge gaps

There are substantial knowledge gaps in the areas of biodiversity, ecosystem services and environmental economics explored in this Report. Much of this knowledge is a public good and hence is not funded by the private sector. Government and third-sector funders should facilitate novel interdisciplinary approaches, in particular linking natural and social scientists.

60 Díaz et al. (2007)
61 Rockstrom et al. (2009)
62 SR39 (Annex E refers); Farley (2008)

Preserving substantial biodiversity requires dedicated reserves

There is a trade-off between investments in maintaining biodiversity on land used for food production and using it to set aside land in reserves where the primary aim is conservation. A large fraction of biodiversity, especially in the tropics, can only be protected in dedicated reserves.

Investment in protecting on-farm biodiversity

Substantial and important components of biodiversity can be maintained on land used for food production. There is a growing understanding about which interventions have the greatest benefits, and policy makers should encourage the systematic analysis of this evidence base and its use in decision-making.

All land has value and provides ecosystem services

It is increasingly recognised that agriculture contributes to the provision of a wide range of 'public goods' associated with managed landscapes and habitats, public access to the countryside and the regulation of water and atmospheric gases. It is important that policy makers in this sector recognise both the monetised and non-monetised ecosystem services produced by land not used of production.

Different timescales of agricultural and food production policy

The protection of biodiversity is a long-term process and robust institutions are required to ensure that the benefits of both protected areas and wildlife-friendly farming are maintained over time. Consistency of policy is particularly important for on-farm biodiversity as agricultural systems are affected by rapidly changing social, economic and environmental factors.

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