Part 7

Ecosystem Services and climate change

Introduction

The natural environment, its landscapes, habitats and biodiversity provide ecosystem services to people - benefits to society that are often under-noticed and undervalued. Four broad categories of ecosystem services are now widely recognised: supporting, provisioning, regulating, and cultural. These are provided through a mix of biological, ecological, physical and chemical agents and processes.

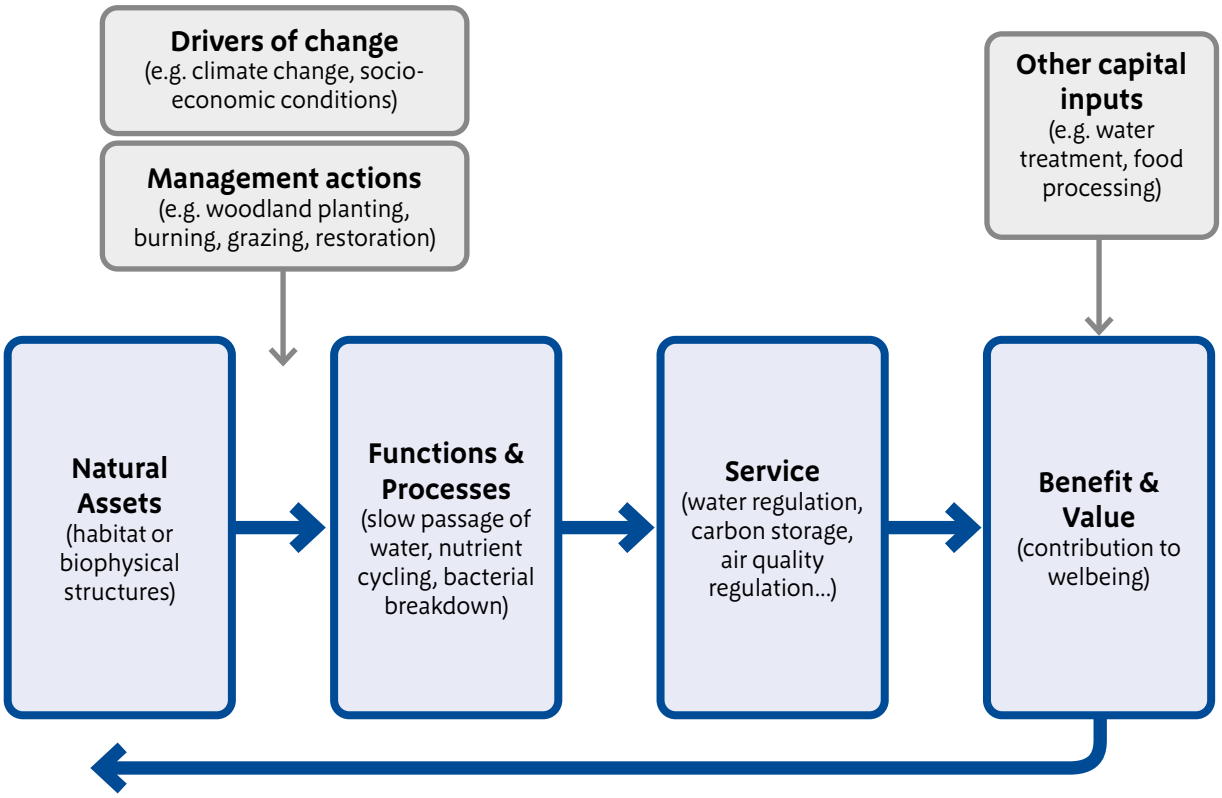
As climate change affects the natural environment, this will impact on the ecosystem services the environment provides. Maintaining these services to people and society can be a powerful lever to secure interest in, and resources for, adaptation of the natural world.

This section provides a brief analysis of the potential impact of climate change on the provision of ecosystem services and potential adaptation responses to this. This analysis is drawn principally from the **United Kingdom National Ecosystem Assessment** (UK NEA 2011), which provides an overview of the state of UK ecosystems, the services they provide, and the key drivers of change, including climate change.

An ecosystem is 'a dynamic complex of plant animal and micro-organism communities and their non-living environment interacting as a functional unit' (Millennium Ecosystem Assessment MA 2005). The UK NEA uses the Broad Habitat types from the Countryside Survey as the basis for its classification of ecosystems. Ecosystems, or habitats, and the ecosystem processes that occur through the interactions of their biotic and abiotic components, provide the basic infrastructure of life. These underpin the supporting services: the capture of energy from the sun (primary production), the formation of soil, and the cycling of water and nutrients. These are required for the production of all the other provisioning, regulating and cultural ecosystem services. Factors such as climate change, which result in changes to ecological processes and the supporting services, affect all the other services which they support. The relationship between habitats, soils and underlying landforms (natural assets), ecosystem processes and the resulting benefits to people (ecosystem services) is commonly illustrated as the ecosystem services cascade (see below).

This section does not provide a detailed analysis of the impact of climate change on individual ecosystem services. Instead, it draws out the links between habitats, ecological processes and ecosystem service provision, and considers how climate change is likely to impact on the processes of primary production, soil formation and nutrient and water cycling (the supporting services).

Recognising that many adaptation responses for biodiversity will also address these important life support services, it signposts those habitats that are important for delivery of particular services. It does not provide detail on the impact on provisioning, regulating or cultural services. However, through the summary of the impacts of climate change on the supporting services, it aims to aid consideration of the resulting impacts on the other ecosystem services.



The ecosystem services cascade (modified from Haines Young and Potschin 2010)

Habitats and the provision of ecosystem services

As shown in the ecosystem services cascade, the continued provision of ecosystem services is dependent on a series of ecosystem functions that are defined by the nature and quality of habitats. The table below identifies which habitats are particularly important for the provision of particular ecosystem services and identifies the relevant habitat sheets. The assessment of the relative importance of Broad Habitats for delivering ecosystem services is taken from the UK (NEA) Synthesis Report. The UK NEA Technical Report, Broad Habitat chapters, provides more detail on the provision of ecosystem services by habitats. Some ecosystem services are not just habitat specific, but are also strongly location specific depending on where the service is 'produced' relative to the people who benefit. This makes it difficult to develop generic rules about habitat-ecosystem service relationships that can be applied in all circumstances. The table below should therefore be interpreted in the context of local knowledge.

Service Group	Ecosystem Service	Broad habitats considered to be of high or medium to high importance in the provision of each ecosystem service (excluding marine and urban habitats)	Relevant habitat sheets
Provisioning	Crops	Enclosed farmland	Traditional orchards
	Livestock/ aquaculture	Enclosed farmland	Hedgerows and walls
	Fish	Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
		Coastal margins	Coastal saltmarsh Coastal floodplain grazing marsh
	Trees, standing vegetation, peat (for timber, construction, fuel etc.)	Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog
		Enclosed farmland	Hedgerows Traditional orchards
		Freshwaters – open waters, wetlands and floodplains	Lowland fen Reedbed
	Water supply	Mountains, Moorlands and Heaths	Upland heath Lowland heath Blanket bog Upland flushes, fens and swamps
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
Cultural	Wild Species Diversity Environmental settings: landscapes/ seascapes and local places	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Lowland dry grassland Upland acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal vegetated shingle habitat Coastal floodplain grazing marsh
		Enclosed farmland	Arable field margins Hedgerows Traditional orchards

Service Group	Ecosystem Service	Broad habitats considered to be of high or medium to high importance in the provision of each ecosystem service (excluding marine and urban habitats)	Relevant habitat sheets
Regulating	Climate (includes greenhouse gas regulation and local micro-climate effects e.g. cooling from urban trees)	Mountains, Moorlands and Heaths	Upland heath Lowland heath Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh
	Hazard (e.g. regulation of soil erosion, flood risk, landslides, river and coastal erosion)	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows
		Woodlands	Broadleaved mixed and yew woodlands Wood pasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed Lowland raised bog
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh
	Disease and pests	Enclosed farmland	Arable field margins Hedgerows Traditional orchards
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed
	Pollination	Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows Traditional orchards
	Noise	Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh

Service Group	Ecosystem Service	Broad habitats considered to be of high or medium to high importance in the provision of each ecosystem service (excluding marine and urban habitats)	Relevant habitat sheets
Regulating	Water Quality	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland and limestone pavement Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed Lowland raised bog
		Coastal Margins	Coastal saltmarsh Coastal sand dunes Coastal floodplain grazing marsh
	Soil Quality	Mountains, Moorlands and Heaths	Upland heath Lowland heath Montane habitats Blanket bog Upland flushes, fens and swamps
		Semi-natural grasslands	Acid grassland Calcareous grassland Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows and walls Traditional orchards
		Woodlands	Broadleaved mixed and yew woodlands Woodpasture and parkland
		Freshwaters – open waters, wetlands and floodplains	Rivers and streams Standing water Lowland fen Reedbed Lowland raised bog
	Air Quality	Semi-natural grasslands	Lowland dry acid grassland Upland acid grassland Calcareous grassland and limestone pavement Lowland meadow Upland hay meadow Purple moor grass and rush pasture
		Enclosed farmland	Arable field margins Hedgerows Traditional orchards
		Woodlands	Broadleaved mixed and yew woodlands Wood pasture and parkland

Adapted from UK NEA Synthesis Report Figure 5 and Technical Report Table 2.1.

Potential climate change impacts on supporting services

The impact of climate change on ecosystem services is principally through changes to biogeochemical and physical processes within ecosystems, as well as through impacts on biodiversity which may provide ecosystem services (e.g. materials, pollination, physical structures, tourism). These changes affect the supporting services, resulting in impacts on the other provisioning, regulating and cultural services they underpin. This section provides a brief analysis of how climate change impacts on the supporting services of primary production, soil formation, nutrient cycling and water cycling, and the potential effects of these changes on other ecosystem services. This structure is intended to guide readers through an analysis of the likely impacts on ecosystem services and help link to adaptation responses described elsewhere in this manual.

There is much uncertainty about how climate change will impact on the supporting services, particularly on nutrient cycling and primary productivity. The impacts on supporting services are also interconnected; for example, changes in nutrient and water availability affects rates of primary production, which in turn affects nutrient and water cycles. The impacts are highly complex and responses to one aspect of climate change (e.g. drought) may be countered by responses to another (e.g. elevated carbon dioxide) or management responses (e.g. irrigation). As an example, primary production is expected to increase with higher temperatures and increasing levels of atmospheric CO_2. However, water availability and soil nutrient supplies may limit this.

The focus on these four supporting services does not address the impact of climate change on disease and pests, with an increase in the prevalence of non-native species, pests and pathogens predicted. It also does not adequately consider changes in biodiversity in terms of the diversity of different levels within food chains and the impact of this on broader services. The impact of climate change on cultural services is particularly uncertain. We do not know the relationship between current habitat condition and cultural services, let alone how climate change will impact on this relationship. We have addressed some of these impacts in this second edition of this manual, including recreation and access. We intend to address other aspects such as the historic environment and landscape character in future editions of this manual.

The table below is based on the supporting services chapter of the UK NEA (UK NEA Chapter 13 Supporting Services) and its evidence base.

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Increased frequency of storms and intense rainfall events	Altered coastal and freshwater dynamics and morphology. Increased erosion. Tree and other plant damage.	**The water cycle** Increase in the frequency and intensity of peak flows and tidal surges. Changes in sediment dynamics - increased sediment loads, changes in geomorphology.	**Provisioning** Crops/livestock/aquaculture (e.g. soil erosion, flood damage). Trees, standing vegetation and peat (e.g. wind throw of trees). **Cultural** Wild species diversity (e.g. loss of coastal and freshwater habitat, loss of species sensitive to high nutrient levels). Environmental settings (e.g. changes in landscapes with erosion, deposition and flood damage). Recreation (e.g. footpath erosion and closures). **Regulating** Climate (e.g. erosion and dissoluton of stored carbon in soils). Hazard (e.g. landslides, increased flood risk). Water quality (e.g. increased nutrient and sediment loads).
		Nutrient cycling Increased leaching of nutrients and increased nutrient run-off. Increased flux of carbon (both dissolved and particulate). Changes in soil microbial activity with water logging.	
		Soil formation Loss of soils due to erosion. Loss of organic matter due to leaching.	
		Primary production Loss of and damage to standing timber, crops and vegetation.	
Sea Level Rise	Increased erosion. Saline intrusion. Anthropogenic intervention, such as hard sea defences.	**The water cycle** Changes in the extent of tidal influence. Changes in the location of the boundary between freshwater and sea water.	**Provisioning** Crops (e.g. agricultural land loss due to erosion). Livestock/aquaculture (eg risk to livestock of increased coastal flooding). Trees, standing vegetation and peat (e.g. affected by salination of soils). Water supply (e.g. saline intrusion of groundwater). **Cultural** Wild species diversity (e.g. loss of coastal and freshwater habitat). Environmental settings and recreation (e.g. loss of beaches and dunes). Historic environment (eg erosion of coastal archaeological sites). **Regulating** Climate (e.g. changes in stored carbon in soils). Hazard (eg increased flooding, landslips). Water quality (e.g. saline intrusion). Soil quality (e.g. salination of soils).
		Nutrient cycling Changes in location of the interface between freshwater and sea water, affecting the habitats present, geomorphological processes, and nutrient cycling.	
		Soil formation Brackish water encroachment on low lying land and soil salinisation (Orford and Pethick 2006). Disturbance of coastal landforms, habitats and soils, with change in rates of erosion, sediment transport and accretion, steepening, and landslide activity on susceptible coasts. Coastal squeeze of habitats not able to move further landward due to hard defences.	
		Primary Production Brackish water encroachment on lowland coastal areas affecting primary productivity. Changes in the location of the boundary between freshwater and sea water, and associated changes in species distribution and nutrient supply. Loss of soil due to erosion.	

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Increased annual average temperatures Hotter summers	Increased evapo-transpiration. Increased rate of biogeochemical processes. Longer growing season. Fewer winter frosts. Changes in crop and timber species. Increased risk of wildfires. Increase in the prevalence of invasive non-native species, pests and pathogens.	**Water cycle** Decreases in soil moisture. Changes in river flow regimes, contributing to low flows. Changes in sediment erosion, transport and accretion. Changes in evapotranspiration with changes in crop species. **Nutrient cycling** Changes in the abundance and activity of soil organisms/microbes. Increased rates of soil weathering. Increased rate of decomposition of soil organic matter. Changes in plant growth and the composition of vegetation communities, affecting the activity of soil organisms/microbes. Increases in ammonia emissions and methane fluxes, with increased soil temperature. Changes in denitrification and increased rates of nitrate loss from rivers and lakes (Whitehead *et al* 2009). Increased phytoplankton growth in freshwater, with associated algal blooms. Extended periods of temperature stratification in lakes and associated anoxia (lack of oxygen) at depth. **Soil formation** Changes in the abundance and activity of soil organisms/microbes. Increased rates of soil weathering. Increased rate of decomposition of soil organic matter and loss of soil carbon (Dorrepaal *et al* 2009). Reduction in the frequency of freeze/thaw cycles, which are important for montane soil formation. Changes in the composition of vegetation communities. Increased soil erosion by water, wind and human activity. **Primary production** Shifts in species distributions in terrestrial and freshwater habitats. Changes in the timing of seasonal events, migrations and food web interactions (Visser and Both 2005, Memmott *et al* 2007). Changes in soil microbial activity and nutrient cycling affecting plant nutrient supply and primary productivity (Bardgett *et al* 2008). Increased soil weathering and changes in the availability of nutrients. Increased phytoplankton growth in freshwater (with associated impacts on algal blooms and eutrophication). Changes in rates of plant growth.	**Provisioning** Crops (e.g. changes in crop selection). Livestock/aquaculture, fish (e.g. affected by low flows). Trees (e.g. changes in forestry productivity). Water supply (e.g. loss to evapotranspiration). **Cultural services** Wild species diversity (e.g. montane species no longer within climatic limits). Environmental settings, recreation (e.g. algal blooms affecting water-based activities). Historic environment (e.g. affected by changes in plant growth on archaeological sites). **Regulating** Climate (e.g. loss of stored carbon with wild fires). Hazard (e.g. changes in soil erosion with changes in soil formation). Disease and pests (e.g. increase in prevalence of pests and diseases, such as Lyme disease with increased tick survival in warmer winters). Pollination (e.g. bumblebee declines with climatic niche shifts (Williams *et al* 2007) changes in timing of flowering and the emergence of pollinators). Water quality (e.g. deterioration with increased concentrations of nutrients). Soil quality (e.g. with changes in soil formation). Air quality (e.g. increases in ammonia emissions).

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Drier summers	Increased frequency and duration of drought. Possible increases in visitor numbers in drier summers. Changes in the selection of crop species. Increased abstraction for irrigation. Increased competition for water resources. Increased risk of wildfires.	**Water cycle** Increased evapo-transpiration. Decreases in soil moisture. Low flows in rivers and reduced water levels in still waters, with loss of habitat complexity. Changes in sediment dynamics, sediment loads, and geomorphological processes. Changes in evapotranspiration with changes in selection of crop species. **Nutrient cycling** Changes in the abundance and activity of soil organisms/microbes. Changes in rates of soil weathering. Increased rate of oxidation and decomposition of soil organic matter, and loss of soil carbon. Changes in the composition of vegetation communities. Increased phytoplankton growth in freshwater, with associated algal blooms. Extended periods of stratification in lakes and associated anoxia (lack of oxygen) at depth due to reduced through-flow. Decreases in rate of leaching of nutrients. Potential for enhanced nutrient loss following drought periods, when plants have failed to make use of nutrients and fertiliser. **Soil formation** Changes in the abundance and activity of soil organisms/microbes. Increased rates of soil weathering. Increased rate of decomposition of soil organic matter and loss of soil carbon. Repeated summer droughts can have the cumulative effect of increasing soil carbon dioxide flux (Sowerby *et al* 2008 upland heathland). Oxidation of previously anaerobic peat soils, increased microbial activity and carbon loss (Freeman *et al* 2004). Changes in the composition of vegetation communities. **Primary production** Shifts in species distributions in terrestrial and freshwater habitats. Changes in soil microbial activity and plant nutrient supply. Changes in soil weathering, and plant nutrient supply. Increased phytoplankton growth in freshwater (with associated impacts on algal blooms and eutrophication). Changes in rates of plant growth. Desiccation/loss of vegetation.	**Provisioning** Crops/livestock (e.g. reduced crop yield). Aquaculture, fish (e.g. with low flows and deterioration in water quality). Trees, standing vegetation, peat, (e.g. reduced timber yield). Water supply (with low flows). **Cultural** Wild species diversity (e.g. affecting species intolerant of drought). Environmental settings (e.g. draw down on reservoirs). Recreation (e.g. water-based). **Regulating** Climate (e.g. loss of soil carbon). Water quality (e.g. increase in pollutant concentration). Soil quality (e.g. desiccation). Air quality (e.g. decreased removal of air pollutants by plants, as stomata are closed with low soil moisture levels).

Cause	Consequence	Potential impacts on supporting services	Provisioning, Regulatory and Cultural services affected
Wetter winters	Altered coastal and freshwater dynamics and morphology. Increased erosion. Increased risk of soil compaction and trampling/ mechanical damage.	**The water cycle** Increase in the frequency and intensity of peak river flows. Increased sediment loads in rivers and changes in river form. **Nutrient cycling** Increased leaching of nutrients and increased nutrient run-off. Loss of organic matter and soil carbon due to leaching. Changes in soil microbial activity with water-logging. Water-logging of soils, resulting in increases in anaerobic conditions and changes to oxidation/ reduction processes. Soil compaction and loss of soil structure. **Soil formation** Loss of soils due to erosion. Loss of organic matter and soil carbon due to leaching. Waterlogging of soils resulting in increases in anaerobic conditions and changes to oxidation/ reduction processes. Soil compaction and loss of soil structure. **Primary production** Loss and damage of standing timber, crops and vegetation.	**Provisioning** Crops (e.g. changes in crop productivity). Livestock (e.g. loss of grazing land due to water-logging). Aquaculture, fish (e.g. affected by increased sediment loads in rivers). Water supply (e.g. increases in water availability in winter). **Cultural** Wild species diversity (e.g. affecting species intolerant of water logging). Environmental settings (e.g. flood damage). **Regulating** Climate (e.g. with changes in soil organic matter and stored carbon). Hazard (e.g. increase in frequency of landslips). Disease and pests (e.g. increased risk of combined sewer overflow pollution). Water quality (e.g. with increased soil erosion). Soil quality (e.g. with increased surface run-off and leaching).
Increased CO2	Increased CO_2 fertilisation.	**The water cycle** Changes in evapo-transpiration as a result of changes in plant growth and vegetation community composition. **Nutrient Cycling and Soil Formation** Increased flux of carbon to plant roots and soil organisms/microbes (Bardgett *et al* 2008). Changes in plant growth and the composition of vegetation communities can affect the activity of soil organisms/microbes (Bardgett et *al* 2008). Changes in rates of soil carbon sequestration. **Primary production** Increased plant photosynthesis and growth. Changes in the composition, diversity and primary productivity of vegetation communities. Changes in the energy flows, structure and function of food webs.	**Provisioning** Crops, livestock, aquaculture, fish, trees, standing vegetation, peat, (e.g. affected by changes in plant growth). Water supply (e.g. potentially affected by changes in evapo-transpiration). **Cultural** Wild species diversity (affected by changes in composition of plant communities). **Regulating** Climate (with changes in rates of soil carbon sequestration). Soil quality (with changes in nutrient cycling and soil formation). Air quality (e.g. reduced uptake of ozone through plant stomata due to increased atmospheric CO2).

Ecosystem Services - Adaptation responses

The concept of ecosystem services is an important component of the 'ecosystem approach', a framework for sustainable management of land and sea. A key element of the ecosystem approach is the management of ecosystems to ensure the delivery of multiple services and benefits. Adaptation to climate change is integral to the ecosystem approach as defined by the twelve ecosystem approach principles in The Convention on Biological Diversity (CBD Ecosystem Approach principle).

Those principles that are most relevant to climate change adaptation are:

Principle 5:

Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach

Ecosystem functioning and resilience depends on a dynamic relationship within species, among species and between species and their abiotic environment, as well as the physical and chemical interactions within the environment. The conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity than simply protection of species.

Principle 8:

Recognising the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term

Ecosystem processes are characterised by varying temporal scales and lag-effects. This inherently conflicts with the tendency of humans to favour short-term gains and immediate benefits over future ones.

Principle 9:

Management must recognise the change is inevitable

Ecosystems change, including species composition and population abundance. Hence, management should adapt to the changes. Apart from their inherent dynamics of change, ecosystems are beset by a complex of uncertainties and potential "surprises" in the human, biological and environmental realms. Traditional disturbance regimes may be important for ecosystem structure and functioning, and may need to be maintained or restored. The ecosystem approach must utilise adaptive management in order to anticipate and cater for such changes and events and should be cautious in making any decision that may foreclose options, but, at the same time, consider mitigating actions to cope with long-term changes such as climate change.

The delivery of multiple ecosystem services and benefits from a place is integral to the ecosystem approach. This delivery of multiple benefits is dependent on healthy, functioning, connected ecosystems, of a sufficient scale to enable the provision of the full range of ecosystem services, and that are able to adapt to the impacts of climate change. It is not possible to provide specific adaptation responses for multiple ecosystem services, as these will be locally specific. However, the habitat sheets suggest adaptation responses for priority habitats of importance in the provision of ecosystem services.

Further information

UK National Ecosystem Assessment

UK Climate Change Risk Assessment Evidence Report 2012

Key evidence documents

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