Chapter 19:
Status and Changes in the UK Ecosystems and their Services to Society: Scotland

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Key Findings*

Scotland has a distinctive biodiversity with about 90,000 species: about 50,400 on land and 39,200 in the seas around Scotland[1]. Scotland's biodiversity has unique assemblages of species found in many habitats, including Atlantic and montane floras, and fungal communities reflecting combinations of boreal, Arctic-alpine, oceanic and Lusitanian elements. Similar distinctive patterns are found in bryophytes, lichens and birds[1]. There have been significant changes to Scotland's biodiversity and ecosystems over the last 70 years, with examples of species with ranges that are expanding into Scotland as well as others that are contracting in range[1]. The delivery of provisioning services has increased considerably, especially from agricultural systems. This development has had significant impacts and consequences for biodiversity in Scotland, with declining capacities of all ecosystems to support sustained use. Habitats and ecosystems have declined in both area and condition[2]. Biodiversity has shown both declines and increases, although the general trend has been one of decline[2].

[1] well established
[2] established but incomplete evidence

The ecosystems and landscapes of Scotland provide significant ecosystem goods and services and considerable economic benefit to the nation[1]. Provisioning services have a particularly high economic value[2]. Values for other services have not always been assessed and in many cases are unknown[2]. The role of agriculture and forestry in shaping landscapes and ecosystems in Scotland is important because they affect a large proportion (92%) of Scotland's land area. Continued loss of habitat, changes in nutrient storage and cycling, climate change and the impacts of climate change on biological function within habitats have significant consequences for human well-being. Supporting, regulating and provisioning services depend on the continued physical, chemical and biological operation of Scotland's land and marine ecosystems. One of the dominant drivers of change in these ecosystems is resource management.

[1] well established
[2] established but incomplete evidence

The areal extent of many of Scotland's habitats has declined since the 1940s[1]. Mountain, Moorland and Heathland habitats currently occupy about 46% of Scotland; the area of mire and Bog habitats has declined from about 2.3 million hectares (ha) in the 1940s to about 1.8 million ha in the 1980s. Grasslands occupy about 25%, but Semi-natural Grasslands, of highest biodiversity and conservation value and of international significance, are less than 1% of the total area of grassland in Scotland. Enclosed Farmland occupies about 11% of Scotland. The area has declined from over 1.3 million ha in the 1940s–1960s to 950,000 ha in the 2000s. Yields per unit area have increased for barley, wheat, oats and potatoes; the total production of barley increased by a factor 10 and wheat by a factor of 7 between the 1940s and 2000s[1]. The area of permanent grassland increased from about 450,000 ha in the 1940s to over 900,000 by the 2000s[1]. Woodlands currently occupy about 17% of Scotland. Planting rates for new woodlands are currently less than 5000 ha per year[1]. Freshwater systems occupy about 2.5% of Scotland by area and Scotland has about 70% of the UK's freshwater by area and 90% by volume[1]. There are changes in the hydrological regimes of Scottish rivers, reflecting changes in rainfall patterns since the 1960s. River flow is becoming much more seasonal, with increasing discharge in winter months[1]. Urban areas occupy about 2.5% of the land area and are home to over 80% of the population. The extent of Urban areas is increasing in Scotland[1]. The length of Scotland's coastline is over 11,800 km, and about 13% of the total land area of Scotland consists of islands. Coastal Margin habitats are under threat from habitat destruction and rising sea levels[1]. The seas around Scotland are potentially among the most biologically productive seas on the planet, but many Marine habitats are of bad and deteriorating status, damage being caused by climate change, human activities including fishing practices, pollution and infrastructure development[1].

[1] well established

* Each Key Finding has been assigned a level of scientific certainty, based on a 4-box model and complemented, where possible, with a likelihood scale. Superscript numbers indicate the uncertainty term assigned to each finding. Full details of each term and how they were assigned are presented in Appendix 19.1.

Supporting services function effectively in Scotland's ecosystems[2]. Scotland has abundant peat and organic-rich soils; Scotland's peatland soils are estimated to store 1,620 megatonnes (Mt) of carbon. Nutrient cycling in Scotland's ecosystems has been altered by pollution, including nitrogen deposition, and by fertilisation in arable systems. The extensive uplands of Scotland receive considerable rainfall and large loads of pollutants through atmospheric deposition. Nutrient inputs are damaging for many native species of high conservation importance and also damage soils[1]. Scotland has abundant water, lochs storing almost 35 billion cubic metres (m^3), and soils storing up to 42 billion m^3 [1]. The quality of the water environment is generally good[1]. Primary production in land and marine ecosystems displays strong seasonal patterns and supports a very broad range of land- and marine-based activities[1].

[1] *well established*
[2] *established but with incomplete evidence*

Regulating services contribute significantly to Scotland's economy[2]. Climate regulation occurs through carbon sequestration in peat soils, woodlands and grasslands on land, and in marine systems[1]. The marine ecosystem also exerts a significant climate regulating effect on Scotland's land areas[1]. Flood and other hazard regulation contributes to social and economic well-being in Scotland[2]; changes in the flow regimes of rivers associated with changing climate patterns are of concern for flood regulation and control. Disease and pest regulation is effective in Scotland[1], although much of this is based on pesticide use rather than ecosystem-based regulation. New diseases and pests are increasingly likely to become established in Scotland, possibly as a result of climate change or movement of infected plants or animals[1]. These diseases may pose significant threats to Scotland's ecosystems, species and habitats. Pollination contributes significantly to biodiversity conservation and through contributions to Scottish agriculture, adds significant economic value to provisioning services[1]. Scotland's ecosystems have a significant capacity for noise, soil, air and water quality regulation[1].

[1] *well established*
[2] *established but with incomplete evidence*

Provisioning services from Scotland's ecosystems contribute significant quantities and varieties of raw materials, as well as economic value to Scotland[2]. Food production from agriculture is highly developed in Scotland and has an impact over about 75% of the land area[2]. Livestock represents the dominant agricultural product in Scotland at over 47% of the value of agricultural production, with livestock products contributing a further 16%. Milk and milk products contribute 14%, beef production contributes about 28%, lamb meat about 10%, pork about 3.5% and poultry almost 5% of the value of agricultural output. Fish production from marine systems is important and has historically supported the economy of coastal and island communities in Scotland. The catch of wet fish has, however, declined, mainly through long-term overfishing. Demersal fish currently constitute about 60% by weight and 40% by value of fish caught and landed by Scottish boats in Scotland. Pelagic fish constitute about 20% of the value of marine fish caught. The shellfish fishery has grown since the 1960s and currently contributes 39% of the total value of fish caught. Aquaculture is growing rapidly, mainly for salmon, trout and shellfish. Salmon and migratory trout in estuary and freshwater areas are important, although numbers caught have declined since the 1950s; catch and release schemes are used to conserve declining stocks. Game from the hunting of birds and mammals is important, especially in upland ecosystems, and field sports provide significant income to sporting estates. The size of game bags for both birds and mammals has declined since the mid-1970s. Timber and a wider variety of timber products are obtained from Scotland's forest ecosystems. Softwood makes up more than 99% of the wood harvest; about 44% of Great Britain's (GB) softwood production is managed by sawmills in Scotland. Softwood is also sold to bioenergy plants. Non-timber forest products are particularly important in Scotland with about 300 species used. Peat is used as fuel for heating, for horticultural compost and in the whisky industry. The area of peat extraction has fallen recently. Ornamental resources are a high value product produced from a relatively small area of land. Scotland has remarkable capacity for generation of renewable energy from land- and marine-based wind power, and from wave and tidal sources.

[2] *established but with incomplete evidence*

Scotland benefits from diverse and extensive cultural services from ecosystems[1]. Local places and landscapes and seascapes are valued highly by Scotland's population and visitors. The landscapes and seascapes of Scotland are distinctive and contribute to Scotland's brand, nationally and internationally. Habitats and landscapes provide opportunities for recreation and tourism and are well used by the Scottish population and by visitors. Nature-based tourism in Scotland is estimated to provide about £1.4 billion in income, with about 39,000 full-time equivalent jobs. Scotland's landscapes are also of high aesthetic and inspirational value.

[1] *well established*

The Scottish government is actively developing Acts and policies that encourage the enhancement of Scotland's environment while using the many ecosystem services to promote the health and well-being of Scotland's population. Many Acts and policies require the development of an integrated approach to the many pressures and demands placed on Scotland's ecosystems from environmental change and human activity.

19.1 Introduction

19.1.1 Scope and Purpose

The geographical diversity of environmental conditions and history of human impacts in Scotland have produced a rich and varied suite of ecosystems, providing landscapes with distinctive regional character and offering a wide range of ecosystem services that support economic and social development and well-being. The purpose of this chapter is to give an overview and analysis of the status, condition and trends of ecosystems, ecosystem services and drivers of change in Scotland. The chapter identifies Scotland's characteristic ecosystems through a series of broad habitat types, and recognises some of their differences from other parts of the UK (and in some cases, possibly also Europe). The chapter also briefly examines consequences of change, sustainable management to enhance biodiversity, ecosystem services, human well-being, and also knowledge gaps. Although not a policy analysis the chapter aims to give clear messages that can help policy makers to identify where priorities might lie. This is especially important where the UK narrative elsewhere in the UK National Ecosystem Assessment (UK NEA) may not address important aspects of the environment and its services to society in Scotland.

Ecosystem assessment invites a *whole systems* view of the interdependence of natural (physical, chemical and biological) and socio-economic (human) resources. The holistic character of this systems view is important. First, it allows interactions between people and the environment to be structured and understood in ways that mirror the rich complexity of human relations with the 'natural' environment. Second, it recognises the complexity and interdependencies that are encapsulated in biodiversity, geodiversity and ecosystem functioning (Woodward 2009), these being important aspects of the way in which environments support human uses. Third, a whole systems understanding is also important for developing an evidence base to inform policy and management (Aspinall *et al.* 2010)

The concept of ecosystem health is closely aligned with that of ecosystems and ecosystem services and relates to biodiversity and ecosystem function. Healthy ecosystems:

- are able to deliver the ecosystem services that support all forms of life including human, and
- do not suffer loss of productivity or carrying capacity to sustain society and biodiversity.

For an ecosystem to be considered in good health it must demonstrate resilience (Rapport 2007). Resilience is the capacity of an ecosystem to respond to disturbances without loss of structure and functional capability (Bennett & Balvanera 2007; Petchey & Gaston 2009). A healthy ecosystem can, therefore, recover from and adapt to change. Resilience and functional capacities provide benchmark criteria for monitoring ecosystem health and for assessing the sustainability of human uses of ecosystems; biodiversity is an indicator of ecosystem health.

19.1.2 Ecosystems in Scotland

The ecosystems of Scotland, with their rich environmental and biological features, structures and variability, reflect the geography of environmental conditions (climate, geology, soils, vegetation) and processes in Scotland, as well as long environmental and land use histories.

Scotland is located on the north-west coast of Europe at latitudes between 54.6°N and 60.9°N at the interface of polar, continental and Atlantic airstreams (Manley 1952), with sub-polar and sub-tropical influences, and with exceptionally high geological variety (Gordon *et al.* 2004; Gordon 2008). This allows Scotland to support a diversity of ecosystems and habitats rarely equalled in areas of similar size elsewhere in the world (Watling 1997; Baxter *et al.* 2008). Strong topographic and latitudinal variation, and island and coastal effects, add to the variability of regional and local climates and the diversity of ecosystems within Scotland's land and sea area and in turn influence the distribution and abundance of flora and fauna (McVean & Lockie 1969). These underlying patterns of environmental variability produce clear ecological and land use distinctions between different parts of Scotland. Variability in the natural environment also provides a template on which environmental and human histories have shaped the detailed and particular nature of the different ecosystems found, as well as the contemporary uses of ecosystems to support human needs. The majority of the ecosystems in Scotland are profoundly influenced by centuries of management and use, and by the demands placed on them by people. Knowledge of the history of human impacts on ecosystems is therefore important for understanding their current state as well as their functional capacity, health and resilience.

Although environmental variation in geographic space is often gradual (Mather & Gunson 1995), it can be codified in biogeographic zonations (Carey *et al.* 1994; Carey *et al.* 1995; Matthews *et al.* 1997; Kiemer *et al.* 1998), and in mapping of ecosystems and land cover as exemplified by the Land Cover of Scotland, 1988 (MLURI 1993), the Great Britain (GB) Countryside Survey (Norton *et al.* 2009) and national assessments of Land Capability for Agriculture (Bibby *et al.* 1982) and Forestry (Bibby *et al.* 1988; Pyatt *et al.* 2001). The patterns of environmental variability are also mirrored in the Scottish Government's classification of rural accessibility[1].

The UK NEA documents ecosystems and ecosystem services using definitions of Broad Habitat types from the EU Habitats Directive, UK BAP and GB Countryside Survey. These Broad Habitats are used both to identify and characterise the ecosystems of interest. However, ecosystems reflect more than the dominant habitat, vegetation or land cover type, and where possible, reference is made to other qualities that are relevant to the function and health of ecosystems associated with each of the Broad Habitat types.

1 The Scottish Government uses a 6-fold and an 8-fold classification of Scotland that recognises urban and rural areas. Urban areas include different categories based on population size of towns. Rural areas are separated into accessible rural (within 30 minutes' drive time of the centre of a town with a population of 10,000 or more) and remote rural. Unless otherwise stated, this chapter includes both accessible rural and remote rural within 'rural'.

19.2 Scotland's Land, Seas and People

Scotland's land area is about 7.9 million hectares (ha). About 13% of this is islands, including almost 200 of at least 40 ha (Haswell-Smith 1996). A highly varied geology within a limited area produces a diverse topography, ranging from significant mountain areas to fertile lowlands. With over 30,000 natural lochs, lochans and pools, and more than 100,000 km of rivers, Scotland's freshwaters represent over 90% of the volume and 70% of the surface area of freshwater in the UK, and include 14 of its 15 largest standing waters. Scotland has 88,600 square kilometres (km^2) of seabed within the 12 nautical mile (nm) limit, and a total surrounding sea area of about 470,000 km^2 to the 200 nm international limit. Around Scotland's coast the same varied geology supports spectacular marine diversity, from voes, sea lochs, lagoons, large estuaries and firths, and thousands of kilometres of rocky coasts, sandy beaches and island shores. Sea lochs such as Loch Alsh and Kyle Rhea have strong tidal streams and contain soft corals, sea firs, sea mats, sponges, anemones, and beds of mussels and brittlestars (Scottish Biodiversity Forum 2003). There are 139 saline coastal lagoons in Scotland, internationally important priority habitats due to their rarity and species (Scottish Biodiversity Forum 2003). The vast majority of the deep seabed in UK waters is found off the north and west coasts of Scotland.

Land throughout rural Scotland is used to produce food, energy and timber, to supply and store water, and to provide for recreation, sport, tourism, and conservation of biodiversity, among other uses. Renewable energy production is emerging as an important land use and ecosystem service, especially in the hills and uplands where there is already well-developed hydropower and also considerable wind energy potential that has long been recognised (Golding 1961), and in coastal areas where there is potential for wind, wave and tidal energy (Brown & Hunter 1961). Coastal systems and floodplains provide coastal defences and flood mitigation using natural environmental system processes. The soils of Scotland, most particularly but not exclusively the organic peat soils in the uplands, are recognised as important stores of carbon and, where active peat-forming vegetation is present, for their capacity to sequester carbon. More generally, the role and central importance of soils in support of ecosystem services is now acknowledged, with attention being paid to soil conservation and management (Sutherland *et al.* 2006; Ritz *et al.* 2009) to ensure healthy soil functions (Puri & Gordon 1998) as a basis for maintenance of supporting, regulating and provisioning ecosystem services. It is important to recognise soil health as an essential element of ecosystem health (Janvier *et al.* 2007; Kibblewhite *et al.* 2008; van Eekeren *et al.* 2009), providing major ecosystem functions including carbon transformations, nutrient cycles, maintenance of soil structure, regulation of pests and diseases, and regulation of water flows and quality. These functions are supported by the combined actions of biological and environmental processes, including by interaction of soil organisms in the abiotic soil environment. Establishing connections between soil health and broader aspects of biodiversity, including that of microorganisms, is critical for sustainable use of natural resources as soils are a major determinant of the capacity of land to support agriculture and other uses, and hence of many cultural landscapes across Scotland. International and UK work on the function and importance of soil biodiversity has been led by projects taking place in the UK's Natural Environment Research Council (NERC) funded Soil Biodiversity Research Programme (Fitter *et al.* 2005; Usher *et al.* 2006). The field location for this programme was a grassland site at Sourhope in the Cheviot Hills in southern Scotland, already the most studied site in the 10-year MICRONET programme funded by the Scottish Executive (Ritz *et al.* 2004). The Soil Biodiversity Programme investigated the diversity and function of soil microbes (Griffiths *et al.* 2006), soil mycorrhizal fungi (Krsek & Welllington 2006), soil protozoa (Esteban *et al.* 2006) and meso- and macro-fauna (Cole *et al.* 2006), as well as dynamics of carbon cycling (Leake *et al.* 2006), the importance of soil biodiversity to soil structure (Davidson & Grieve 2006) and impacts of management with fertilisers (Murray *et al.* 2006). The work clearly demonstrates the importance of soil microbial populations to ecosystem function (Irvine *et al.* 2006).

There is a strong agricultural influence on landscapes and ecosystems throughout Scotland. Agricultural uses extend to about 75% of the land area (Rural and Environment Research and Analysis Directorate 2009c), arable production taking place on about 11.2% of the land (predominantly in the east) with additional non-enclosed systems, especially improved and upland grasslands, and heaths and moors being used as rangeland pastures for grazing. The interdependence of arable (cereal) production and livestock grazing is marked. About 50% of cereals grown in Scotland are used for animal feed (DTZ 2007). Livestock in some areas are moved from grazing land and into arable areas during winter when the upland grazing areas cannot support large numbers of animals and the weather is cold. The static picture provided by snapshot surveys of land cover and habitat data, and by the June Agricultural Census, hides this well recognised and long-standing interdependence and dynamic of Scotland's agricultural systems.

Grazing animals are not only important for agriculture, but are also an important tool in the management of upland systems for biodiversity conservation, landscape character and sport shooting. Recent declines in sheep and cattle numbers have been identified, after reaching their highest recorded levels (cattle: 1974; sheep: 1990/1) in the late 20th Century (RSE 2008; SAC 2008). Relationships between grazing intensities and biodiversity are well studied (SNH 2000; Albon *et al.* 2007; Pearce-Higgins *et al.* 2008) and it is increasingly recognised that low intensity agricultural systems, especially those based on cattle grazing and limited arable production to provide feedstocks, are of high importance for biodiversity conservation (Bignal & McCracken 1996; Dennis *et al.* 1997; Evans *et al.* 2006). This is recognised in the emerging conceptualisation, identification and mapping of High Nature Value farming systems across Europe (European Environment Agency 2004), and their strong representation in Scotland.

Land tenure continues to be important for ecosystem change and use. The Land Reform (Scotland) Act (2003) and Scotland's access laws provide exceptional opportunities for recreation and enjoyment and contribute to the social, economic and health values afforded by Scotland's diverse environments and landscapes.

The marine areas of Scotland have been subject to human use for over 10,000 years and it is unlikely that there are any pristine ecosystems left on the Scottish continental shelf (Hughes & Nickell 2009). A wide range of regulating, provisioning and cultural services are provided by Scotland's coastal and marine ecosystems. Fishing is an important activity, long contributing to the viability and sustainability of coastal and island communities around Scotland. However, marine fishing, notably trawling and dredging, have damaged and altered ecosystems in coastal seas around Scotland (Hall-Spencer & Moore 2000a; Gordon 2001) and led to declines in species targeted by fisheries (Greenstreet *et al.* 1999b, a) as well as others caught as bycatch (Piet *et al.* 2009). Habitats including maerl bed, oyster bed, file shell, fan shell and tubeworm reef, that form living crusts on the seabed, have been damaged and declined in distribution around Scotland and in extent at sites where they occur (Scott & Moore 1996; University Marine Biological Station Millport 2007; Hughes & Nickell 2009; Moore *et al.* 2009). Marine areas of Scotland are subject to a wide variety of human uses, including not only fishing but also transportation and renewable and fossil fuel-based energy industries. Impacts of climate change are also apparent in marine ecosystems around Scotland, including a rise in sea surface temperature, rises in sea level and increased ocean acidification (UKMMAS 2010). Marine areas in Scotland are now subject to concerted actions for their conservation, including via legislation through the Marine (Scotland) Act and the application of an ecosystem approach (Greenstreet *et al.* 2009).

The human population of Scotland has remained relatively stable for the last 60 years and is currently about 5.2 million (**Figure 19.1**). There has been a change in the age structure of the population over time, with an increasing representation of older age groups (**Figure 19.1**). Differences in age structure are also evident between rural areas and the rest of Scotland, rural areas having a lower percentage of population between 15 and 34 and higher proportion of 40–69 year-olds than elsewhere. The average population density is low by global—and UK—standards, at about 65 persons per square kilometre. There are four cities with populations greater than 100,000, and a further 350 towns and villages with more than 1,000 inhabitants. Many of these towns and villages are located within the central belt or around the coast (**Figure 19.2**). One-third of the total population of Scotland live in Edinburgh and Glasgow. The average population density in rural areas is only about 12 persons per square kilometre. The changing age structure, with low population densities in rural areas, presents particular challenges for use and management of resources, especially for island and coastal communities, and for hill and upland areas (Post & Pedersen 2008). There are social and economic issues associated with depopulation, counter-drift migration and relative deprivation in rural, hill and

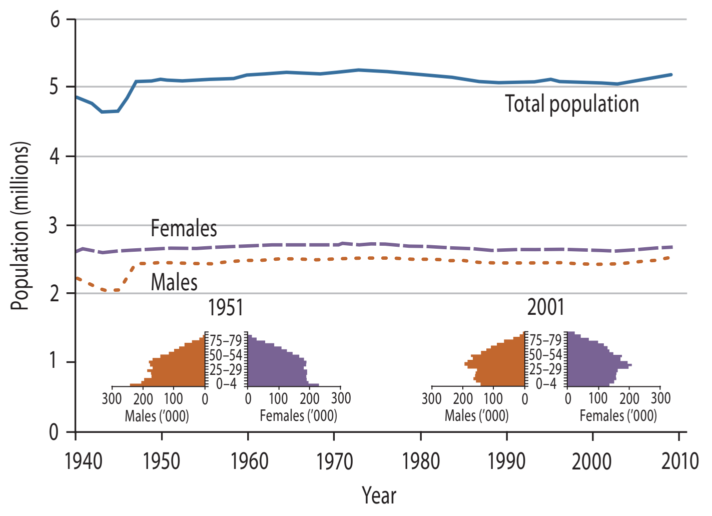


Figure 19.1 Population of Scotland 1940–2009, with population pyramids showing age structure for 1951 and 2001. Source: data from General Register Office for Scotland.

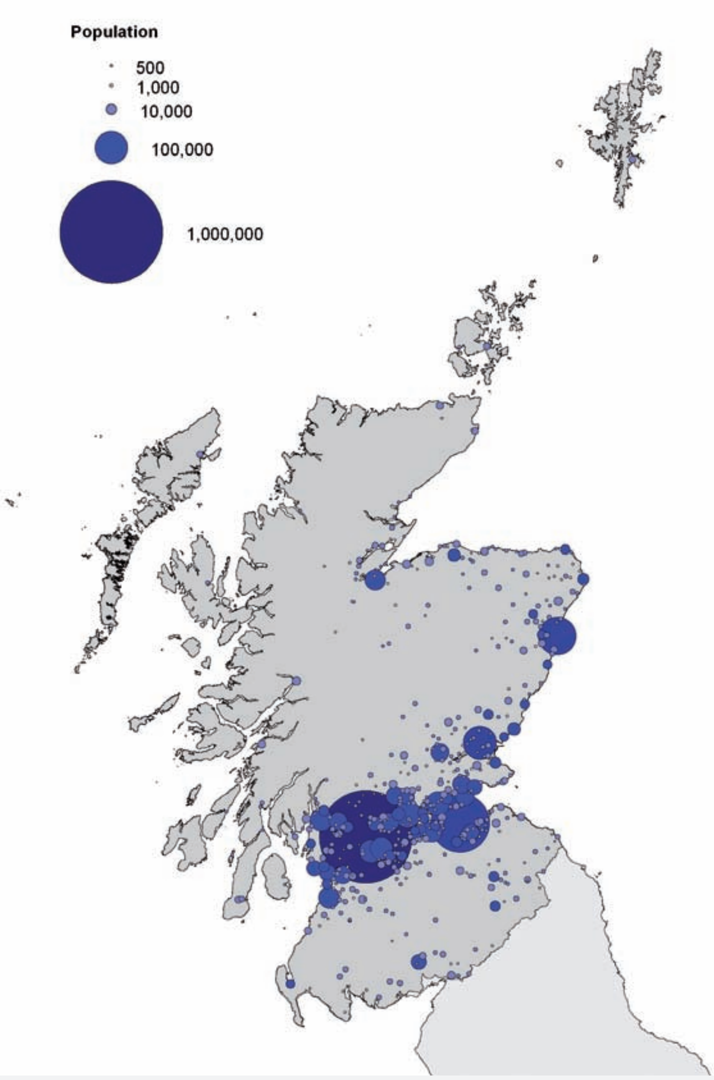


Figure 19.2 Population size of settlements with over 500 people resident in 2008. Source: data from General Register Office for Scotland.

island areas that have an impact on provision of and access to societal services, viability of communities, opportunities for rural development and economic growth, and supply and demand for ecosystem services.

19.3 Biodiversity in Scotland

The diversifying effect of Scotland's varied geological foundations and its position with respect to global atmospheric and oceanic circulations is reflected in its biodiversity resource. The total number of species in Scotland is estimated at about 90,000 (Usher 2002a, b), about 50,400 on land and 39,200 in the seas around Scotland. This total is made up of about 44,100 species of viruses, bacteria and protozoa; 19,184 terrestrial and freshwater invertebrates; 19,069 fungi, algae and bryophytes; 5,527 marine invertebrates; 1,080 vascular plants, 349 marine vertebrates and 310 terrestrial and freshwater vertebrates (Usher 1997, 2002a).

Scotland's biodiversity has been the subject of numerous reviews (Mackey 1995; Usher 1997; Miles *et al.* 1997; Usher 1999, 2002a, b; Mackey 2002; Scottish Biodiversity Forum 2003; Mackey & Mudge 2010). Whilst Scotland's latitude makes it unremarkable in terms of sheer number or global rarity of species, it is remarkable for the unique assemblages of species found in many habitats. For example, nowhere outside Scotland do Atlantic and montane floras co-occur so extensively (Birks 1997). Similarly, the fungal community of Scotland reflects combinations of boreal, Arctic-alpine, oceanic and Lusitanian elements (Watling 1997) and similar patterns are found in taxonomic groups as diverse as bryophytes, lichens and birds (e.g. Thompson *et al.* 1995), with 58% of Europe's bryophyte species found in Scotland (Mackey *et al.* 2001). In the marine environment, a high biodiversity afforded by the coincidence of Lusitanian and boreal/Arctic biogeographic zones in Scotland is further enhanced by the physical and biological heterogeneity created by geological variety, ocean currents and fronts between water masses. This also has its effect in the terrestrial environment, with Scotland supporting the majority of the global populations of Manx shearwaters (*Puffinus puffinus*), northern gannets (*Morus bassanus*), great skuas (*Stercorarius skua*) and grey seals (*Haliochoerus grypus*), and globally important concentrations of a wide range of migratory and wintering wader and wildfowl species (Scottish Biodiversity Forum 2003). In addition, Scotland's rivers, dominated by short catchments and high-energy gravel beds systems, are global strongholds for species such as Atlantic salmon (*Salmo salar*) and freshwater pearl-mussel (*Margaritifera margaritifera*). Lastly, it is in the offshore marine environment that habitats may rank as genuinely highly diverse in global terms. Coldwater coral reefs formed by the hard coral *Lophelia pertusa* may be as rich in biodiversity as some tropical reefs. Similarly, although still poorly studied, deep-sea sediments are likely to be highly species rich and virtually all of the UK resource of these habitats lies off the Western Isles (Matthews *et al.* 1997).

Scotland's topographic diversity also creates biogeographical isolation, whether on its islands, in its lochs or on its montane summits. Endemism and marked genetic and phenotypic distinctiveness within species are therefore marked in Scotland, given its modest land area. The current Scottish Biodiversity List identifies 31 species endemic to Scotland (excluding apomictic plant species), ranging from well-known examples such as the Scottish primrose (*Primula scotica*) and Scottish crossbill (*Loxia scotica*), to a flea (*Ceratophyllus fionnus*) found only from Manx shearwater colonies on Rum, and 11 vascular plants, 10 lichen species, five mosses, and four insects (Mackey & Mudge 2010). Local adaptations within species further add to the genetic component of Scotland's biodiversity (Ennos & Easton 1997). For example, variations amongst island populations of field mice (*Apodemus sylvaticus*) and loch populations of Arctic char (*Salvelinus alpinus*) have been well studied (Hartley *et al.* 1995); recent molecular studies have revealed substantial population genetic structure in water voles (*Arvicola terrestris*) and red grouse (*Lagopus l. scoticus*) between catchments and moors respectively (Piertney *et al.* 1998; Stewart *et al.* 1999); and island forms of several terrestrial bird species, including wren (*Troglodytes troglodytes*), starling (*Sturnus vulgaris*) and song thrush (*Turdus philomelos*), are considered sufficiently distinctive to merit sub-species status (Clugston *et al.* 2001).

Major changes in biodiversity have occurred in Scotland, as elsewhere in the UK, since the 1940s (Rackham 1986; Lovegrove 2007). However, systematic monitoring of biodiversity has only been carried out since the 1960s and 1970s (Marchant *et al.* 1990), when declines in populations became very apparent, for example in birds of prey from the effects of organochlorine pesticides (Ratcliffe 1980) and in native flora from the intensification of agriculture (Perring 1970). Studies of individual species groups, particularly birds, provide evidence of changes since the 19th Century and earlier, e.g. chough (*Pyrrhocorax pyrrhocorax*) (Warnes 1983), crested tit (*Lophophanes cristatus*) (Cook 1982) and others. Recent changes in the distribution of butterflies in Scotland have also been reported (Sutcliffe 2009), four species showing major expansion of their ranges while others have reduced ranges. Usher has reviewed Scotland's coastal biodiversity (Usher 1999) and Scott identified some challenges for development of biodiversity action plans for Scotland's coastline (Scott 1999).

19.3.1 Designated Species and Habitats

In 2004 *Scotland's Biodiversity* (Scottish Executive 2004) was published, a 25-year framework for action to conserve and enhance biodiversity in Scotland. In early 2010 an assessment of biodiversity in Scotland was published (Mackey & Mudge 2010) to coincide with the International Year of Biodiversity.

Overall, Scotland has 65 (38%) of the 169 conservation priority habitat types listed under Annex I of the EU Habitats Directive (Scottish Biodiversity Forum 2003; Scottish Executive 2004), and 82% of the 79 habitats represented in the UK. Over 50% of Scotland's land remains under some form of natural or semi-natural vegetation cover, and Scotland supports examples of 81% of all National Vegetation Classification communities, despite occupying only 35% of the land area of Britain (Miles *et al.* 1997). Amongst the Broad Habitat types to be considered in detail below, Scotland is internationally important for its resource of blanket bog, heather moorland, montane, native woodland and High Nature Value farmland (e.g. machair) habitats. Scotland also holds the UK's largest reedbed, which fringes the lower reaches of the River Tay, the Insh Marshes in the Spey valley, which are the UK's largest continuous area of base-poor fen, and one of Europe's richest surviving concentrations of lowland raised bog (Scottish Biodiversity Forum 2003). Off the coast, some of the finest marine habitats in Europe are in Scottish waters, including estuarine sand and mudflats, coldwater coral reefs, maerl beds, saline lagoons, and deep-sea mud communities (Baxter *et al*. 2008). The Cromarty Firth has the UK's largest known area of dwarf eelgrass (*Zostera noltii*) and the Solway coast contains 10% of the total UK area of saltmarsh (Scottish Biodiversity Forum 2003).

The status of priority species and habitats was reviewed in 2005 and again in 2008 (Mackey & Mudge 2010). Habitats and species that are strongly in decline or particularly vulnerable are identified for targeted action and referred to as biodiversity priority habitats and species. There are 197 UK priority species and 39 priority habitats in Scotland. The summary status of the priority habitats and species is shown in **Figure 19.3**.

Of the 39 priority habitats assessed in 2005 and again in 2008, 17 were stable or increasing, 13 were declining, and the status of nine was unclear or unknown; the overall condition is positive (Mackey & Mudge 2010). Among 41 habitats assessed in 2008, the proportion that were stable or increasing (41%) exceeded those declining (31%; see Mackey & Mudge 2010). Three Priority Habitats of the UK BAP occur only in Scotland (within the UK): serpulid reefs, machair, native pine woods; in 2008, the first two of these were stable and the third increasing. The overall trend for 181 of the 197 priority species in Scotland assessed in 2005 and again in 2008 is negative (Mackey & Mudge 2010). For the 197 priority species assessed in 2008, 74 were stable or increasing, 42 were declining, and the trend was unknown or unclear for a further 77. Three others were lost before or after publication of the BAP and one subsequently was determined not to be a species (Mackey & Mudge 2010; BARS 2011). Among a total of 230 species assessed in 2008, the proportion that were stable or increasing (32%) exceeded those declining or lost (15%; see Mackey & Mudge 2010). The status of priority habitats and species reflects mixed fortunes for BAP species and habitats in Scotland.

Priority habitats and species in Scotland have also been assessed in groups linked to five broad groups of ecosystems (Mackey & Mudge 2010):

Upland: The trend for eight priority habitats associated with Scottish upland ecosystems was positive in 2008. Whereas all the upland priority habitats assessed in 2005 were declining, one had become stable by 2008. The trend for 122 priority species in upland ecosystems was stable and among 13 species assessed in 2008, the proportion that were stable (84%) exceeded those that were declining (8%).

Lowland and farmland: In lowland and farmland ecosystems the trend for 10 priority habitats was stable by 2008. However, of the eight priority habitats assessed in 2008, those declining (63%) exceeded those stable or increasing (39%). The trend for 108 priority species in lowland and farmland ecosystems was divergent, and of 16 priority species assessed in 2008 the proportion that were stable or increasing (32%) was the same as those declining (32%).

Woodland: In woodland ecosystems the trend for seven priority habitats reviewed in 2005 and 2008 was positive and all priority habitats assessed in 2008 were stable or increasing. The trend for 170 priority species in woodland ecosystems is divergent, showing positive and negative elements; of 31 species assessed in 2008, the number stable or increasing (45%) exceeded the number declining or lost (28%).

Freshwater and wetland: In priority habitats associated with freshwater and wetland ecosystems, the trend for nine priority habitats between 2005 and 2008 was stable (no change). Five priority habitats assessed in 2008 showed the proportion that were stable (60%) to be greater than those declining (40%). The overall trend for 75 priority species associated with freshwater and wetland ecosystems was

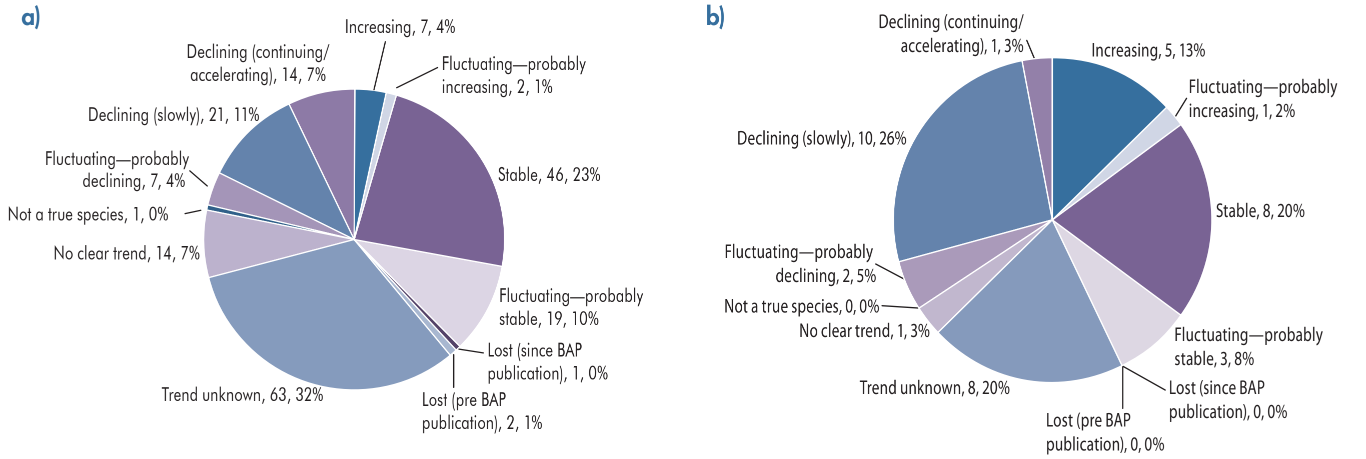


Figure 19.3 Status of Biodiversity Action Plan a) species and b) habitats in Scotland in 2008. Data source: Scottish Government.

stable (no change). The proportion that were stable or increasing (41%) exceeded the number declining (25%) in 2008 for the 32 species assessed.

Coastal and marine: Among 26 priority habitats in coastal and marine ecosystems the trend was divergent. Of 11 habitats assessed in 2008, the proportion that were stable (51%) exceeded the proportion declining (38%). The trend for 136 priority species in coastal and wetland ecosystems is positive; those stable or increasing rose from 59% to 66%. Of 28 species assessed in 2008 the proportion that were stable (41%) exceeded those declining (8%).

Although these five groups do not match directly with the eight Broad Habitats used in the UK NEA, they do provide an indication of the status of priority habitats and species across Scotland.

The known trends in populations for well-recorded groups in Scotland similarly are mixed. **Figure 19.4** shows the change in status of widespread breeding land birds in Scotland between 1994 and 2005. Of 54 species studied, 23 showed a statistically significant increase, 7 a statistically significant decrease, and 24 showed no significant change.

Scotland has internationally important populations of breeding seabirds. About 60% of the global population of great skuas, almost 50% of northern gannets, and more than one-third of Europe's Manx shearwaters breed in colonies around Scotland (Mitchell *et al.* 2004). Three seabird surveys have been carried out in Britain, in 1969–1970, 1985–1987 and 1998–2002. Using these data, between 1969 and 1970 and between 1998 and 2002, nine out of 18 seabird species showed a marked increase in their breeding population (i.e. by at least 10%), and five showed a marked decline (Mitchell *et al.* 2004). **Figure 19.5** shows the percentage changes for 18 species of seabird between the dates of the surveys. Only five of the species increased in both the periods between the three surveys, and only seven increased between 1985 and 1987 and between 1998 and 2002.

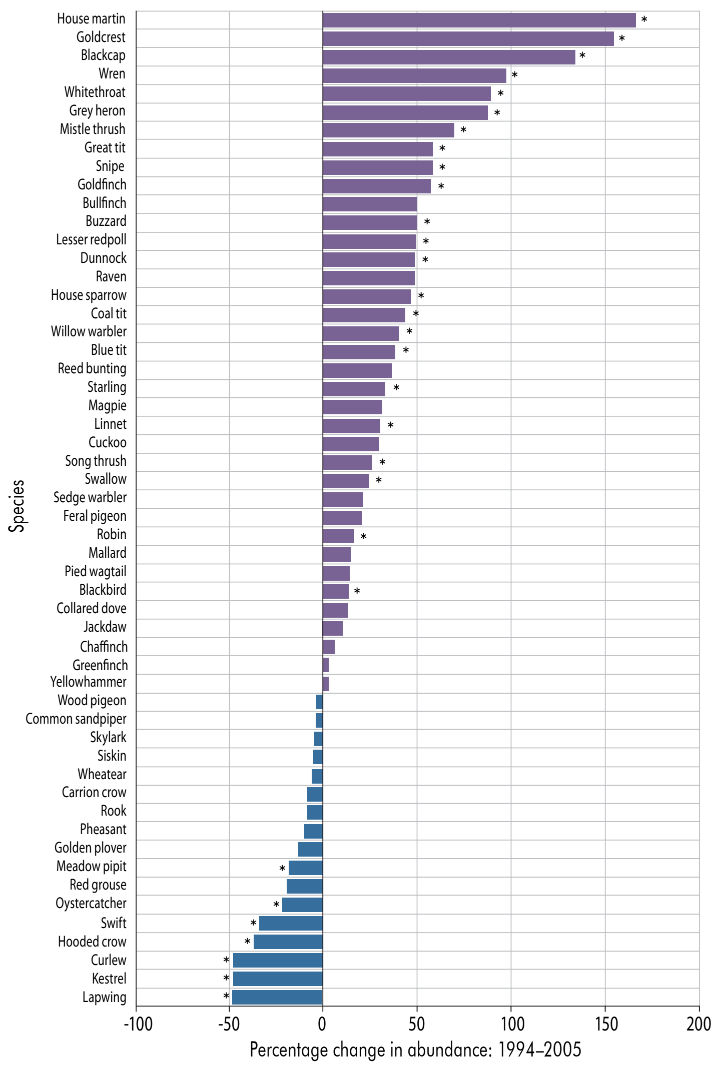


Figure 19.4 Change in the status of widespread breeding land birds in Scotland between 1994 and 2005. Source: data from Raven & Noble (2006). Note: * Identifies species for which population change is statistically significant.

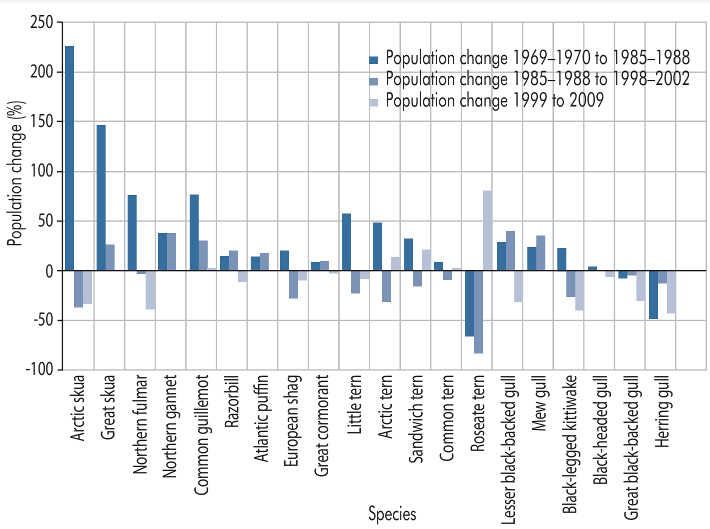


Figure 19.5 Percentage changes in seabird populations between 1969–1970 and 1985–1987 and between 1985–1987 and 1988–2002. Source: data from Mitchell *et al.* 2004.

19.3.2 Designated Areas

The value of the biological, geological and other characteristics of Scotland's ecosystems in the land area is recognised and many areas have been given at least one international, European, national or local designation (**Table 19.1**).

As of 30 November 2008 there were 1,447 Sites of Special Scientific Interest (SSSIs) in Scotland (944 biological, 314 geological, 189 mixed) covering 1,023,000 ha (12.7% of the land area; see **Table 19.1**). Scotland also contributes to the Natura 2000 network as part of the network of protected areas representing the most important wildlife sites in the European Union. Natura 2000 is made up of sites designated as Special Areas for Conservation (SACs) and Special Protection Areas (SPAs). Special Areas of Conservation refer to the European Commission Habitats Directive (Directive 92/43/EEC) and SPAs to the European Commission Birds Directive (Directive 79/409/EEC). There are 239 SACs in Scotland (about 960,000 ha or 9.6% of Scotland's land area) and 153 SPAs (about 1.3 million ha or 13.4% of Scotland's land area, **Table 19.1**). Some of the SACs and SPAs apply to the same area, giving a total of 391 Natura 2000 sites in Scotland. These provide protection for 56 habitats, 79 bird

Table 19.1 Area of Scotland designated under national and international conservation designations. Source: Scottish Natural Heritage, Joint Nature Conservation Council 2011.

Type	Number	Area (ha)	Proportion of Scotland's land area (%)
International Designations			
Biogenetic Reserves	2	2,388	0.03
Biosphere Reserves	3	11,445	0.14
European Geoparks	3	804,329	10.02
Ramsar sites	51	313,181	3.90
(Natural) World Heritage Sites	1	24,201	0.01
European Designations			
European Diploma Areas	2	5,848	0.07
Special Areas of Conservation (SAC)	239	962,690	9.61
Special Protection Areas (SPA)	153	1,296,489	13.42
National Designations			
Areas of Special Protection	8	1,518	0.02
Gardens and designated landscapes	386	75,383	0.94
Marine Conservation Areas (MCA)	29	111,895	
National Nature Reserves (NNR)	63	133,746	1.67
National Parks (NP)	2	639,150	7.97
National Scenic Areas (NSA)	40	1,378,358	12.72
Sites of Special Scientific Interest (SSSI)	1447	1,023,152	12.74
SSSI (biological)	944	568,848	7.24
SSSI (geological)	314	34,569	0.44
SSSI (mixed)	189	422,466	5.38
Local Designations			
Country Parks	36	6,481	0.08
Local Nature Reserves (LNR)	57	10,009	0.12
Long Distance Routes (LDR)	5	-	-
Regional Parks (RP)	4	86,160	1.07
Scheduled Ancient Monuments	7,896	17,330	0.22

species and 18 other animal species. The majority of SPAs and SACs are also underpinned by SSSI legislation as part of the Nature Conservation (Scotland) Act 2004. An economic assessment of the costs and benefits of Natura 2000 sites in Scotland carried out in 2004 showed that the sites had a national welfare benefit seven times greater than the national costs over a 25-year period (Jacobs 2004).

Although SPAs and SACs can apply to land and marine areas, there are no SACs or SPAs that are entirely in marine areas in Scotland; there are 36 SACs in Scotland with a marine component (Joint Nature Conservation Council 2011). There are 29 Marine Conservation Areas with a total area of 1,119 km² (see **Table 19.1**). The Marine (Scotland) Act 2010 and the UK Marine and Coastal Access Act include new powers for Scottish Ministers to designate Marine Protected Areas (MPAs) in the seas around Scotland. Marine Protected Areas offer a range of measures to manage and protect Scotland's seas. Under the Marine (Scotland) Act 2010 MPAs can be designated within Scottish territorial waters (inside 12 nm) for conservation of nationally important marine wildlife, habitats, geology and undersea landforms, as Demonstration/Research MPAs to demonstrate or research sustainable methods of marine management or exploitation, and as Historic MPAs for features of historic/cultural importance such as shipwrecks and submerged landscapes. The UK Marine and Coastal Access Act includes equivalent provisions for Scottish Ministers to designate MPAs for the conservation of nationally important marine wildlife, habitats, geology and undersea landforms in offshore waters (outside 12 nm) adjacent to Scotland.

19.4 Condition, Status and Trends in Broad Habitats

The distribution of the Broad Habitat types of Scotland are shown in **Figure 19.6** and the relative proportions are shown in **Table 19.2** and **Figure 19.7**. There are considerable differences between the islands and mainland Scotland in the proportion of different Broad Habitats (see **Table 19.2** and **Figure 19.7**) together with associated land uses and opportunities for land use.

In addition to ecosystem services associated with the Broad Habitats and associated land cover, the ways in which habitats are arranged relative to one another and distributed within different geographic areas also contributes to both the character of Scotland's landscapes and the regional and local nature of ecosystem goods and services that are realised. For example, **Figure 19.8** shows the proportion of each of the Broad Habitats in some of the major river catchments of Scotland, revealing considerable differences across the country. The composition and relative proportion of different habitats, types of land cover and associated land uses within catchment areas, and especially the proportion of arable agriculture, have been found to have a strong correlation with water chemistry in rivers (Wright *et al.* 1991). An understanding of catchment level characteristics is important for river basin management (Ferrier & Jenkins 2010), including flood regulation. Engineering works, especially in urban areas and for sewage management, are also important for maintenance of water quality.

There are a number of general traits that are shared across all the ecosystems represented by the Broad Habitats in Scotland. All cycle nutrients and water and use energy through a complex series of biogeochemical and physical processes. Microbiological communities and processes are among the most important drivers of biogeochemical cycling and energy flow, yet the microbiology of ecosystems

Table 19.2 Amount and proportion of UK NEA Broad Habitat types in Scotland (Mainland, Islands, All Scotland). Source: data derived from the Land Cover Map 2000 (Fuller *et al.* 2002). Note: the area of Woodland in Scotland in 2009 is 17.2% (Forestry Commission 2009).

UK NEA Broad Habitat	Mainland (ha)	%	Islands (ha)	%	All Scotland (ha)	%
Mountains, Moorlands & Heaths	2,887,910	42.2	717,620	69.4	3,605,540	45.7
Grasslands, including Semi-natural Grasslands	1,610,770	23.5	212,680	20.6	1,823,450	23.1
Enclosed Farmland	883,120	12.9	600	0.1	883,720	11.2
Woodlands	1,107,000	16.2	50,490	4.9	1,157,490	14.7
Freshwaters – Openwaters, Wetlands & Floodplains	132,790	1.9	32,710	3.2	165,500	2.1
Urban	186,020	2.7	5,500	0.5	191,530	2.4
Coastal Margins	19,130	0.3	19,200	1.1	38,330	0.4
Total	**6,826,740**		**1,038,800**		**7,865,560**	

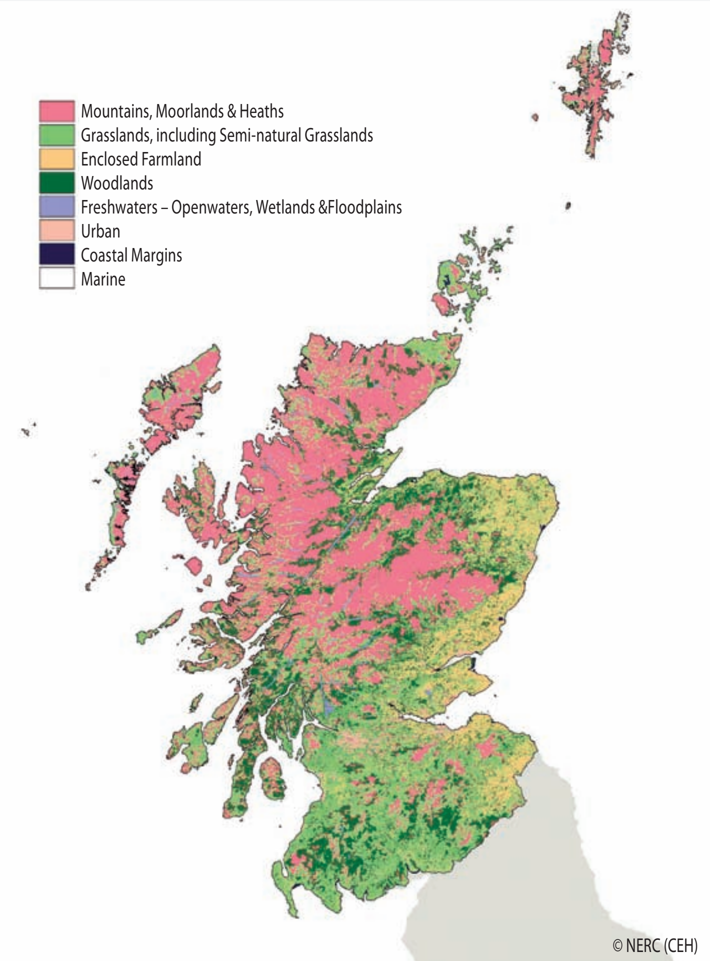


Figure 19.6 Distribution of the UK NEA Broad Habitat types in Scotland. Source: Land Cover Map 2000 (Fuller *et al.* 2002).

and their associated soils and habitats are among the least studied aspects (Grayston *et al.* 2001; Grayston *et al.* 2004; Aalders *et al.* 2009) with the exception from the upland grassland research at Sourhope (Usher *et al.* 2006). Scotland's ecosystems demonstrate not only the application of environmental processes but also the specific and singular variability of place, time and scale that supports the biodiversity and individual character of places and communities. The influence of human systems is also

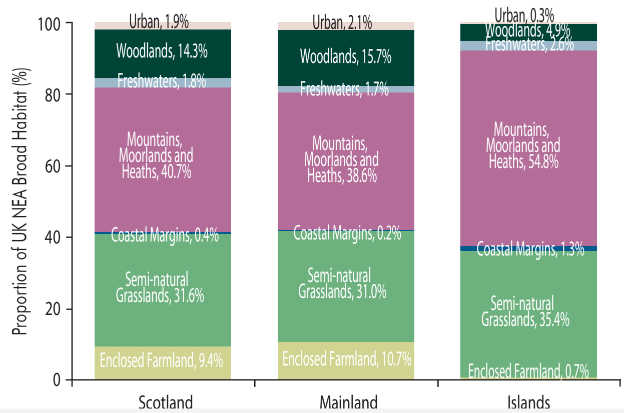


Figure 19.7 Proportion of UK NEA Broad Habitat types in Scotland (All Scotland, Mainland, Islands). Source: data derived from the Land Cover Map 2000 (Fuller *et al.* 2002).

strongly evident in Scotland. Ecosystems are increasingly documented, studied and understood through a systems view that recognises the importance of human social and economic systems (Aspinall *et al.* 2010). Across the set of ecosystems and habitats considered here, management intensity not only provides a gradient of variation but also provides a good predictor of vegetation type and diversity, as well as consequences of land use change scenarios (Wilson *et al.* 2003).

Associations between the Broad Habitats and major soil groups in Scotland are shown in **Figure 19.9**. The sequences of changes in soils associated with Enclosed Farmland, Semi-natural Grasslands, Woodlands, and Moorland vegetation roughly reflect management intensity. Soil has not been mapped for about 50% of the area of urban land (shown as 'urban' or 'built up area' (bua) in soils maps).

19.4.1 Mountains, Moorlands and Heathlands

Mountains, Moorlands and Heathlands are extensive in Scotland (**Figures 19.6** and **19.10**), which contains a significant area of land at high elevation. Some 30.5% of the land area is above 305 m, 5.8% above 609 m, 3.1% above 700 m and 1.3% above 800 m. There are some 540 distinct tops with 284 over 914 m designated as 'Munros',

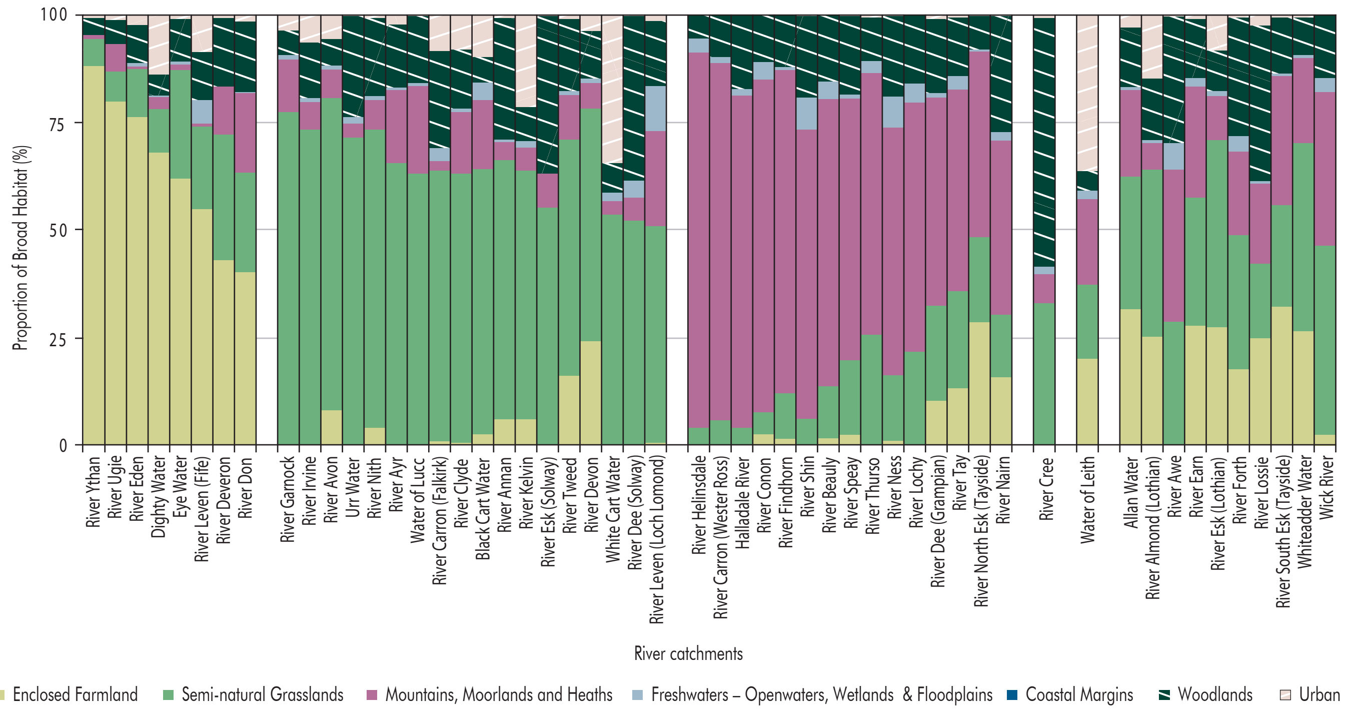


Figure 19.8 Proportion of UK NEA Broad Habitat types in some of the main river catchments in Scotland. Source: derived from the Land Cover Map 2000 (Fuller *et al.* 2002) and spatial data for water catchments in Scotland.

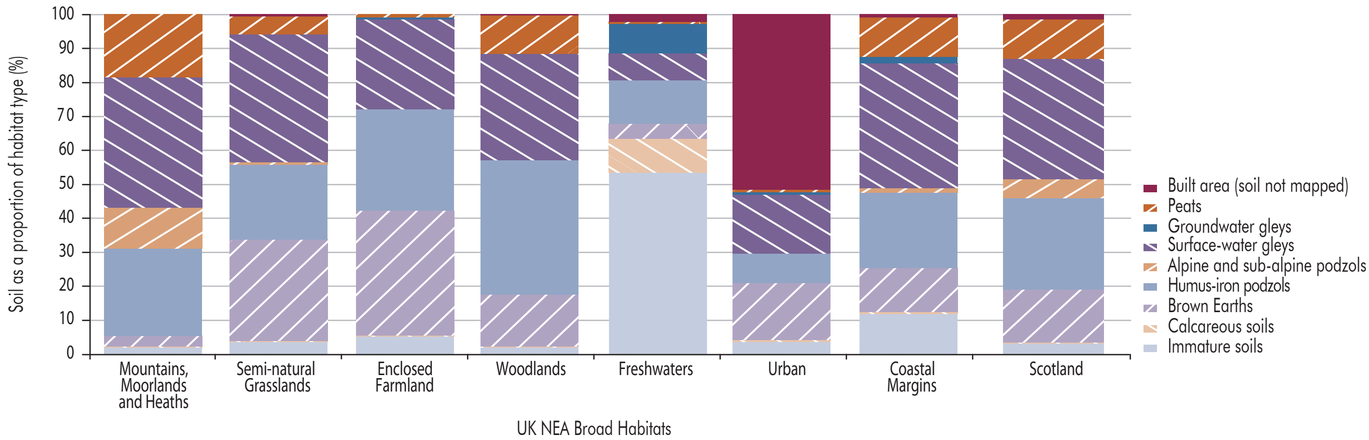


Figure 19.9 Associations between UK NEA Broad Habitat types and major soil groups (based on area of habitats and major soil groups). Source: derived from the Land Cover Map 2000 (Fuller *et al.* 2002) and Major Soil Groups from the 1:250,000 soils map of Scotland (Macaulay Land Use Research Institute).

and over 200 summits between 820 and 914 m designated as 'Corbetts' (Donaldson 1974). The lower elevation limit of the montane area is generally considered to be between 700 and 840 m (McVean & Lockie 1969) and the UK resource of montane habitats is thus heavily concentrated in Scotland.

The vegetation of the high elevation areas is a mix of montane and upland vegetation types including heather moorlands, mires and blanket bog, and poor quality grasslands. Vegetation-environment relationships in upland Scotland show a general pattern that reflects degree of oceanicity and the number of wet days, as well as temperature and other gradients that correlate with geographic location as elevation and latitude (Brown *et al.* 1993; Brown *et al.* 1993). Mountain, Moorland and Heathland habitats cover about 46% of Scotland's land area and are far more extensive than elsewhere in the UK (5% in England, 17% in Northern Ireland and 12% in Wales).

The climatic conditions in Scottish Mountain environments are harsh (Birse & Robertson 1970; Birse & Dry 1970). Winters are extremely cold with significant snowfall. Summers are cool and wet. High wind speeds produce exposed conditions which limit both woody and herbaceous plant growth. Soils are nutrient poor, thin and rocky and, where developed, include a high proportion of humus-iron podzols, alpine and sub-alpine podzols, and surface water gleys, as well as peats (Soil Survey of Scotland

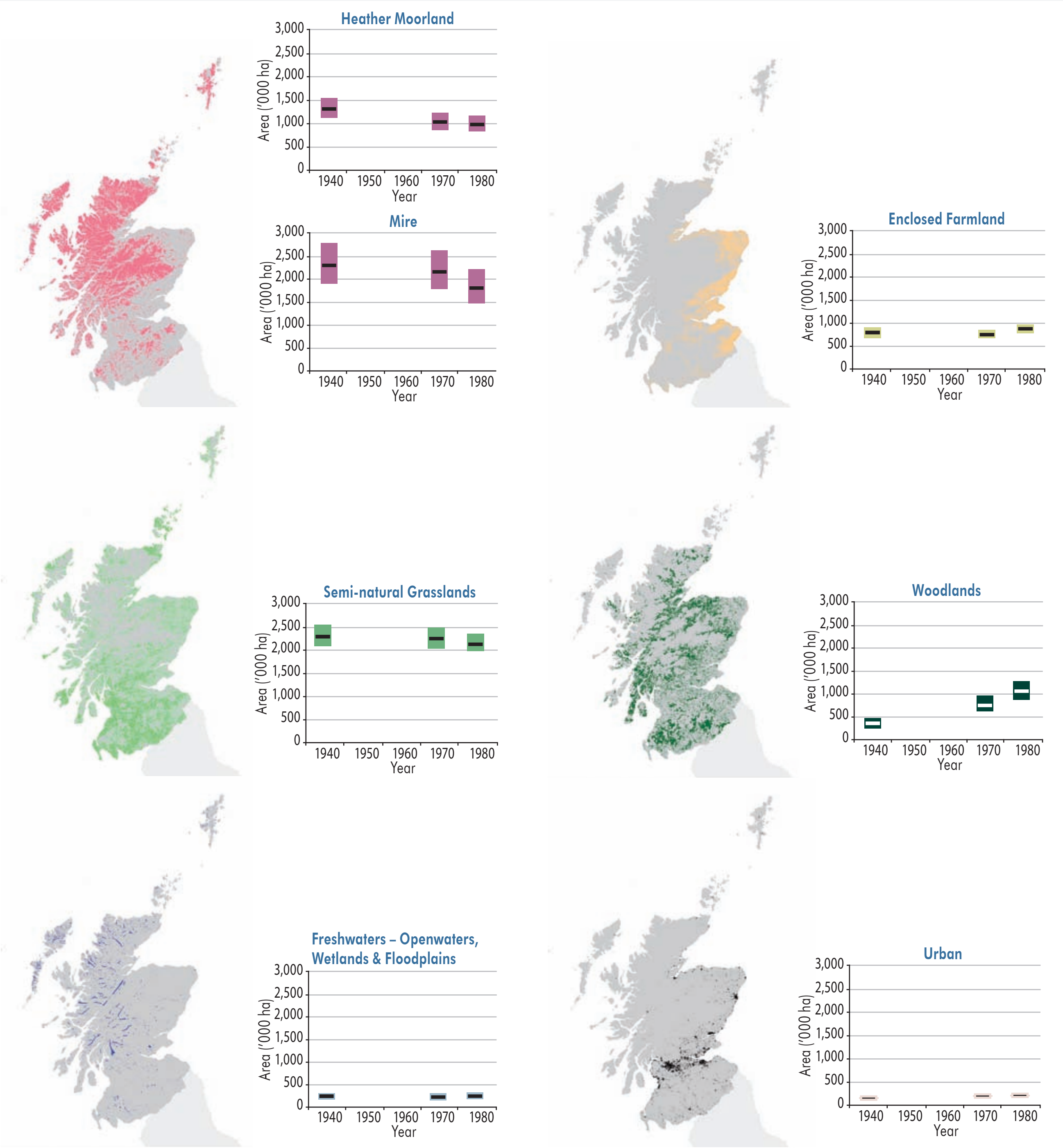


Figure 19.10 Summary of UK NEA Broad Habitats: distribution and change in area between the 1940s and 1980s. The height of the bars on the charts represents the 95% confidence limits around the estimated area of the habitat; the estimated area is shown as a line across the bar. Source: Land Cover of Map 2000 (Fuller *et al.* 2002) and data from the National Countryside Monitoring Scheme (Mackey *et al.* 1998). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

1984). Plant growth is slow in these conditions and primary production is low.

A variety of important Montane habitats are found in Scotland, including *Racomitrium* and lichen heaths, plant communities associated with snow beds, mires, and dwarf shrub heaths (Pearsall 1950; McVean & Lockie 1969). *Nardus* grasslands are also present as a result of overgrazing and atmospheric pollution and may replace *Racomitrium* heath (McVean & Lockie 1969).

The Montane habitats of Scotland have several distinctive features (Mackey 1995):

- They are oceanic and southern outliers of communities representative of Arctic-alpine fellfield and mountain tundra environments (Brown *et al.* 1993).
- They contain representative examples of globally rare or local vegetation.
- Their breeding bird communities include both Arctic and temperate species (Thom 1986; Forrester *et al.* 2007), many of which are rare, of international significance, and protected.
- They contain extremely rich and diverse bryophyte and lichen communities, especially within a European context (Thompson *et al.* 1995, Summers *et al.* 1999).

Moorland vegetation includes a range of semi-natural vegetation types dominated by Dwarf Shrub vegetation, especially *Calluna vulgaris*. Moorlands occupy land physically located between the Montane habitats at high elevations, and the Enclosed Farmland, rough grasslands, Woodlands, and Bogs located at lower elevations in Scotland, although in the far north Moorland vegetation is found at or near sea level. Many Moorland areas were formerly covered by woodland, but grazing, mainly since the late 17th Century to develop sheep pasture, and burning, since the 1840s to encourage grouse for shooting, have removed the trees and created the open, heather- and grass-dominated landscapes familiar today (Gimingham 1972). Controlled burning on shooting estates continues to maintain patchworks of heather habitats suitable for grouse (Tharme *et al.* 2001). Grazing by red deer (*Cervus elaphus*) and by sheep also has an impact on Moorland vegetation (Clarke *et al.* 1995; Hester & Baillie 1998; Hester *et al.* 1999; Cuartas *et al.* 2000; Albon *et al.* 2007).

The GB National Vegetation Classification recognises 19 moorland plant communities (Rodwell 1992). Nine of these (**Table 19.3**) are of international importance in Scotland (Mackey 1995).

Heather moorland is associated with nutrient-poor soils and a variety of heather moorland types are recognised (Pearsall 1950; Gimingham 1972). Mires are associated with organic peat soils actively created by their plant communities under wet and cool climatic conditions (Ellis & Tallis 2000; Bragg 2002). Heather moorlands are a product of active land management over the last 200 years, notably by grazing with sheep and, in many areas, by burning, to create habitat for red grouse on sporting estates (Gimingham 1972). Overgrazing and burning exacerbated by drainage of blanket peats for land improvement to increase areas of grassland for grazing, and the expansion of plantation forestry since the 1920s (through direct government action and fiscal support to the private sector) have reduced the area of heather moorland and mire in Scotland since the 1940s (**Figure 19.11**).

The major pressures on Scotland's montane environments arise from grazing, pollution from atmospheric deposition of nitrogen and sulphur, and from climate change that alters the distribution of climatic conditions required by montane biodiversity. Mountains, Moorland and Heathland habitats are also a location for significant leisure activities, hillwalkers being attracted to the highest mountain areas of Scotland. Environmental impacts of these activities include habitat damage, erosion, and disturbance of breeding animals (Gordon *et al.* 2002).

Montane and Moorland plant communities are at risk from increased nitrogen deposition (Woolgrove & Woodin 1996; Britton *et al.* 2005; Britton & Fisher 2007a,b, 2008), climate change (Trivedi *et al.* 2008), overgrazing, especially by red deer and sheep (Albon *et al.* 2007), and increased recreation activity (Bayfield 1973; Sidaway & Thompson 1991; Sidaway 2001).

Atmospheric deposition of nitrogen and sulphates and grazing by sheep reduce the growth of *Racomitrium* and lead to its degradation and replacement by grass-dominated vegetation (van der Wal *et al.* 2003; Britton *et al.* 2005). These changes have been implicated in changes in distribution of dotterel (*Charadrius morinellus*) in Scotland. Dotterel breed on montane heaths dominated by *Racomitrium*, the close juxtaposition of these heaths with montane bogs providing the preferred feeding conditions for both adults and chicks (Galbraith *et al.* 1993). Recent evidence of decline in late-lying snowpack has implications for snowbed communities in montane environments (Bjork & Molau 2007). Similar declines in snowbed communities can be expected in Scotland with changed snowfall patterns (SNIFFER 2006) and earlier snow melt. Snowbed changes can also be expected to have implications for water quality and quantity, and for fish stocks and fishing, as patterns of flow and water temperatures in rivers have changed (Doughty *et al.* 2002; Soulsby *et al.* 2002).

Climate change has implications for all ecosystems in Scotland, not solely for upland ecosystems. Consequences of climate change have been predicted for many species at European, UK and more local scales (Huntley *et al.* 2007). Moreover, climate envelope models have been shown successfully to identify recent changes in bird populations as a function of observed climate changes (Green *et al.* 2008). In Britain, summer temperature has been found to provide the best overall explanation for bird diversity patterns (Lennon *et al.* 2000). Upland species are particularly at risk, as suitable climatic habitat for species that are already located at high elevation may not occur in Scotland under warming conditions (Huntley *et al.* 2007). Detailed ecological understanding of the mechanism through which climate change affects individual upland species remains scarce, but is growing. For example, protracted spring warming has been implicated in the decline of the capercaillie (*Tetrao urogallus*) in Scotland (Moss *et al.* 2001), increased summer temperatures may underlie declines in the British ring ouzel (*Turdus torquatus*) population (Beale *et al.* 2006). There is also now good evidence that future population trends of golden plover (*Pluvialis apricaria*) populations are likely to depend upon interactions between summer rainfall and temperature, their effect on tipulid populations (a key food source for many upland birds), and impact upon plover reproductive success (Pearce-Higgins & Yalden 2004; Pearce-Higgins *et al.* 2010).

Table 19.3 National Vegetation Classification of Moorland habitat plant communities found in Scotland, and that are of international importance.
Source: SNH (2000).

NVC Classification	Community name
H10	*Calluna vulgaris – Erica cinerea*
H12	*Calluna vulgaris – Vaccinium myrtillus*
H16	*Calluna vulgaris – Arctostaphylos uva-ursi*
H21	*Calluna vulgaris – Vaccinium myrtillus – Sphagnum capillifolium*
M15	*Scirpus cespitosus – Erica tetralix*
M16	*Erica tetralix – Sphagnum compactum*
M17	*Scirpus cespitosus – Eriophorum vaginatum*
M18	*Erica tetralix – Sphagnum papillosum*
M19	*Calluna vulgaris – Eriophorum vaginatum*

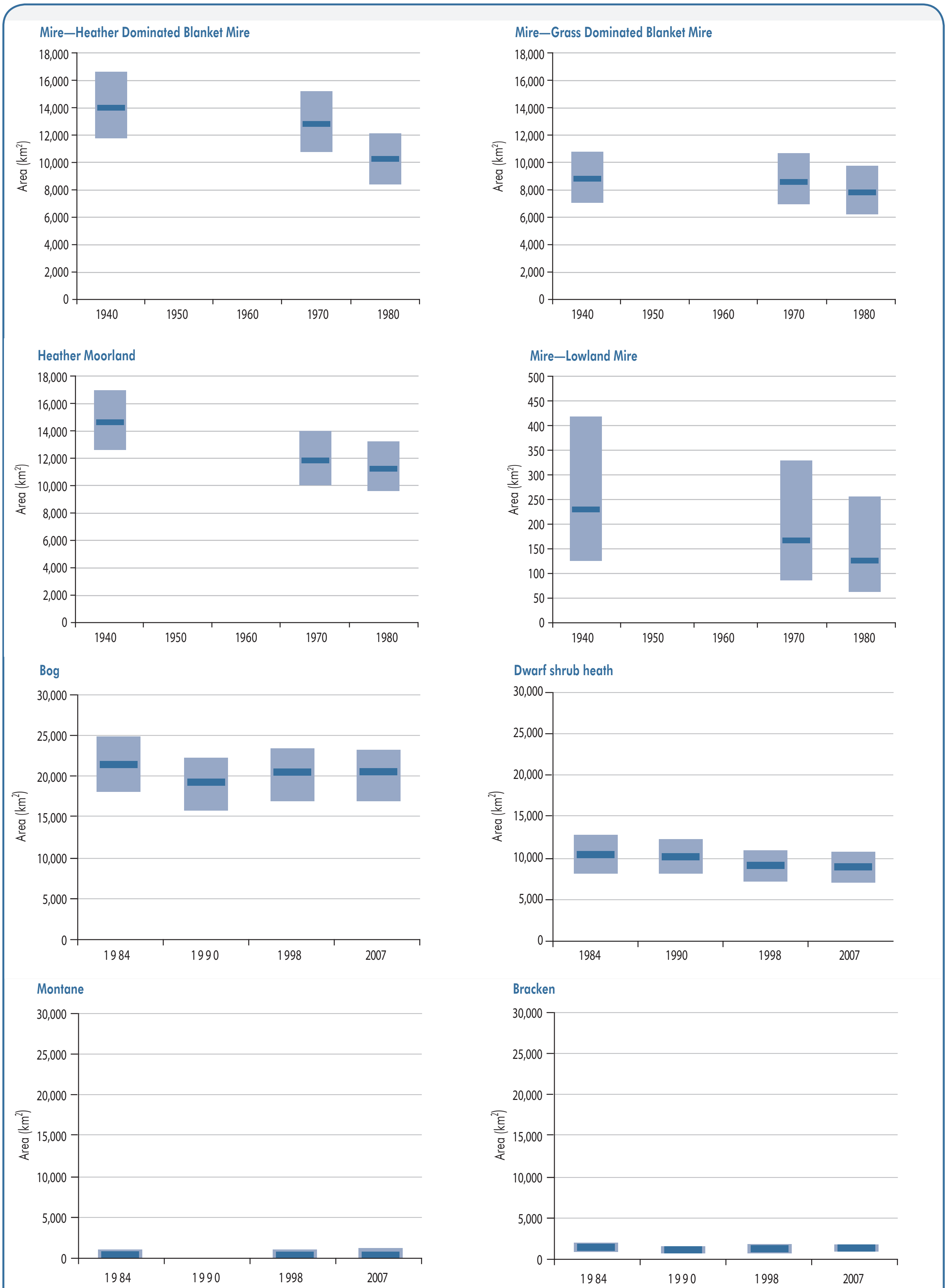


Figure 19.11 Area of Mountains, Moorlands and Heath component habitats in Scotland (1940s–1980s and 1984–2007). The height of the bars on the charts represents the 95% confidence limits around the estimated area of the habitat; the estimated area is shown as a line across the bar. Source: 1940s–1980s: National Countryside Monitoring Scheme (Mackey *et al.* 1998); 1984–2007: Countryside Survey (Norton *et al.* 2009). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

Changes in the duration of snow-lie are associated with changes in upland vegetation, especially snowbed plant communities, and have also had an impact on montane animals that depend on prolonged snow. Snow bunting (*Plectrophenax nivalis*) and ptarmigan (*Lagopus muta*), both birds of the Arctic, are found breeding at high elevations in Scotland's mountains. The snow bunting breeding population of Scotland is now estimated at about 50 pairs (Forrester *et al.* 2007), an increase from the very small numbers reported previously (Nethersole-Thompson 1966; Sharrock 1976; Thom 1986).

Upland areas are used for a variety of land uses, and deliver supporting, regulating, provisioning and cultural services. Upland areas act as source areas for human water supply, rainfall draining from gathering grounds being stored in reservoirs and lochs, from where water is piped to Scotland's cities and towns. Much of the uplands also provide rough grazing for livestock. Moorlands provide iconic landscapes supporting a variety of cultural ecosystem services. They can be of high aesthetic value and provide inspiration, 'heather-clad moors', invoking a sense of place, and frequently becoming intimately associated with 'wilderness' (Chapter 5) and with National Parks and National Nature Reserves (NNRs).

Moorland and upland areas are also increasingly attractive for recreation and leisure activities (Chapter 5). A wide variety of recreation and leisure activities take place in Scotland's uplands, including hiking, biking, climbing, skiing, camping, nature viewing, and hunting (fishing, deer-stalking, grouse shooting). These recreational activities provide significant income to local economies, and support employment. Upland ecosystems provide numerous opportunities for diversification in local economies. The high numbers of visits to upland areas can also be expected to have attendant benefits for individual health and well-being.

19.4.2 Semi-natural Grasslands

Grasslands cover about a quarter of Scotland's land area (see **Figure 19.6** and **Figure 19.10**) and are associated with brown earth, humus-iron podzols, and surface-water gley soils (see **Figure 19.9**). The range of associations with different soils reflects the overall variety of grasslands that are found in Scotland. Grassland ecosystems are extensive in upland areas and include 24% of the land area, with an annual average rainfall in excess of 1,500 mm. The extent of grasslands in a river catchment has been shown to have a strong positive association with suspended particulate matter and biologically active phosphorus in river waters downstream, and also to have potential as an indicator of river biogeochemical functioning (Stutter *et al.* 2007). Grasslands are an important habitat for carbon management in Scotland, soils under grassland habitats storing and sequestering carbon. Carbon is lost from grassland soils through a variety of management activities including conversion to arable uses (DECC 2009), and due to liming (Rangel-Castro *et al.* 2004; Foereid *et al.* 2006) and fertiliser application (Jones *et al.* 2005).

The Countryside Survey provides some data on the changing extent of Acid, Neutral and Calcareous Grasslands in Scotland since the 1980s (**Figure 19.12**). Calcareous Grassland is very restricted in extent and there has been some loss of the habitat over the last two decades. In 2007 the Countryside Survey estimated there to be about 26,000 ha, a decline from about 40,000 ha in 1990 (Norton *et al.* 2009). Acid grassland (983,000 ha) and Neutral Grassland (461,000 ha) are both more extensive and show relatively little decline over the period of the Countryside Survey (Norton *et al.* 2009). The data are inconclusive, however, regarding the extent to which there have been changes, as the differences in area estimated by each survey are less than the accuracy with which they are estimated. Better monitoring is needed for very rare and local habitats such as Semi-natural Grasslands in Scotland.

Despite the extent of grasslands in Scotland, Semi-natural Grasslands cover only about 17,800 ha, or less than 1% of the total grassland area of Scotland; they make up only about 8% of the Semi-natural Grasslands of the UK (**Table 19.4**).

Semi-natural Grasslands in Scotland include Calcareous Grassland, Machair[2], and maritime cliff-top grasslands that are associated with exposed conditions but also frequently with grazing. These grasslands are of particular importance, having a rich flora of native grasses and herbs, as well as associated specialised communities of birds, mammals

Table 19.4 Estimate of the extent of Semi-natural Grassland component habitats in Scotland and the UK. Source: UK Biodiversity Action Plan Targets Review (2006); Norton *et al.* 2009. Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

Biodiversity Action Plan Priority Grassland type	Area in Scotland (ha)	Proportion of Scotland's Semi-natural Grassland priority habitats (%)	Area in UK (ha)	Scotland as proportion of whole UK (%)
Lowland calcareous grassland	761	4.3	40,590	1.9
Lowland dry acid grassland	4,357	24.4	61,650	7.1
Lowland hay meadows	980	5.5	10,520	9.3
Upland hay meadows	27	0.2	897	3.0
Purple moor grass and rush pasture	6,768	37.8	79,390	8.5
Upland calcareous grassland	5,000	27.9	22,640	22.1
Total	**17,893**		**215,687**	**8.3**

2 Note, Machair is discussed in the coastal section of this chapter (19.4.7) and the Coastal Margin chapter of the UK NEA (Chapter 11); in the Semi-natural Grasslands chapter (Chapter 6), discussion is restricted to Acid, Neutral and Calcareous Grasslands.

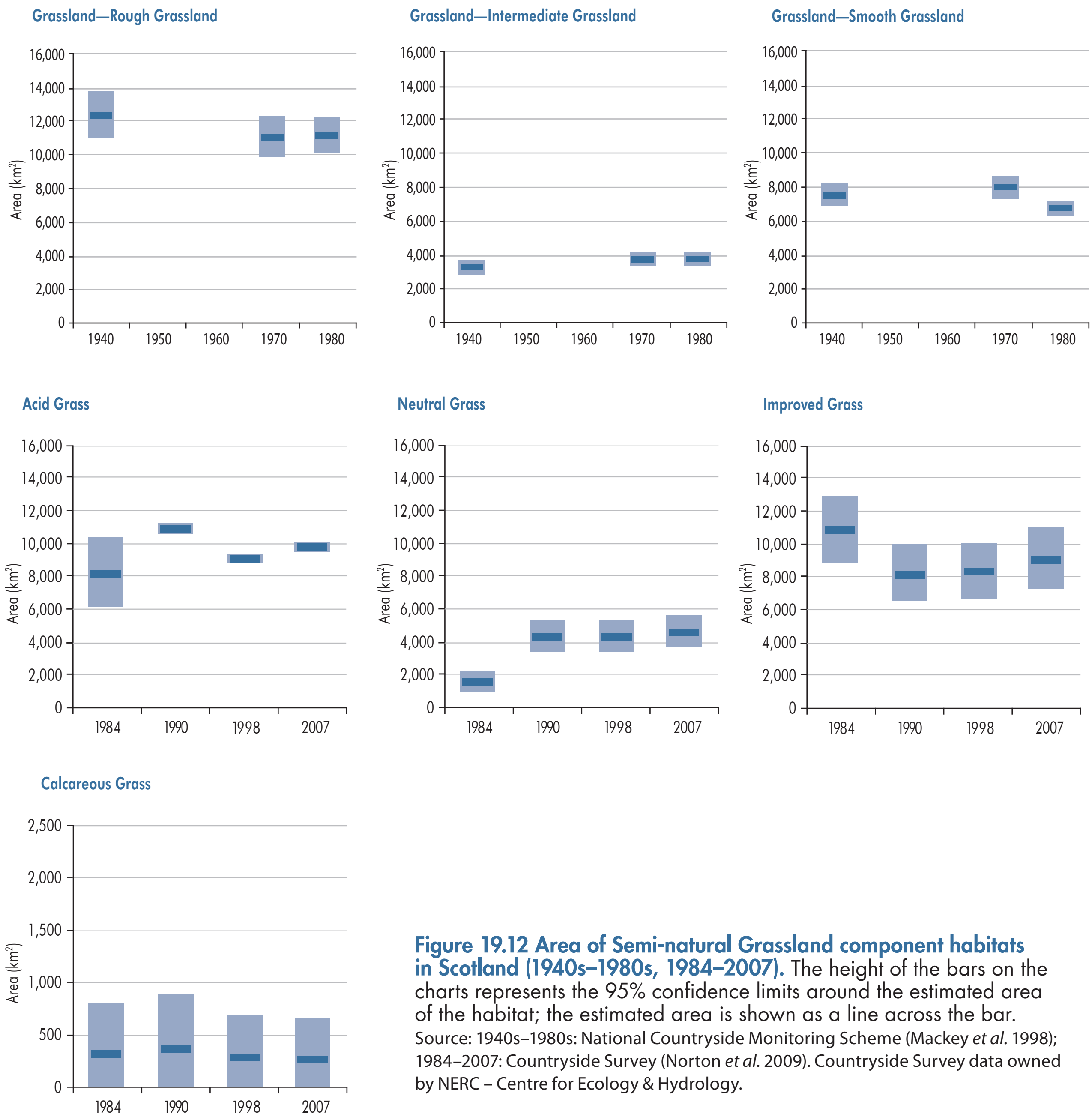


Figure 19.12 Area of Semi-natural Grassland component habitats in Scotland (1940s–1980s, 1984–2007). The height of the bars on the charts represents the 95% confidence limits around the estimated area of the habitat; the estimated area is shown as a line across the bar. Source: 1940s–1980s: National Countryside Monitoring Scheme (Mackey *et al.* 1998); 1984–2007: Countryside Survey (Norton *et al.* 2009). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

and invertebrates. Many of the sub-types of Semi-natural Grassland are of high conservation value and are listed as Priority Habitats in the UK and Scotland Biodiversity Strategy.

Scotland's Semi-natural Grasslands are of international significance for conservation of a variety of flora and fauna, including soil fungal populations that display complex seasonal dynamics (Newton *et al.* 2003). Grazing is an essential part of management of grasslands. Grazing of species-rich grasslands in riparian zones of upland forests has been shown to be important for biodiversity management, retaining high species diversity compared with ungrazed plots (Humphrey & Patterson 2000). Similarly, narrow buffer strips of grassland in riparian areas can increase carabid beetle density (Cole *et al.* 2008).

Scotland's Semi-natural Grasslands also support individual species of high conservation concern. For example, great yellow bumblebees (*Bombus distinguendus*) once widespread across agricultural grasslands, are now almost wholly restricted to unimproved Machair grassland with high floral diversity (Goulson *et al.* 2006), whilst both choughs (*Pyrrhocorax pyrrhocorax*) and corncrakes (*Crex crex*) now have populations that are heavily concentrated in areas where low-intensity grazing systems sustain areas of Semi-natural Grasslands (Whitehead *et al.* 2005; O'Brien *et al.* 2006).

Species diversity is also high in some Semi-natural Grassland types, linked to parent material and soils (e.g. limestone-rich areas and calcareous soils) and particularly to specific management practices. Bird populations of

Semi-natural Grasslands are similarly closely linked to land management practices (Green & Stowe 1993; Stowe *et al.* 1993; Green 1996; Gregory & Baillie 1998; Vickery *et al.* 2001).

The major threats to Semi-natural Grassland habitats include replacement with intensive rotational grassland mixes, which leads to a reduction of their area and fragmentation of remaining areas, intensification through use of fertilisers and pesticides, which reduces the diversity of their flora, and drainage and mechanisation of grassland management, which impacts particularly on associated faunal populations (Vickery *et al.* 2001). The products of intensification in Semi-natural Grassland ecosystems are the more widespread agriculturally improved grasslands, much of whose biodiversity has been lost through drainage, fertilisation, reseeding and grazing. Increasing public pressure also has an impact on Semi-natural Grasslands.

19.4.3 Enclosed Farmland

About 11% of Scotland's land area is arable agriculture, mainly on lower ground (<300 m) in the east of the country (Coppock 1976). There is a marked difference between the mainland of Scotland and the Islands in the extent of arable (see **Table 19.2** and **Figure 19.7**), over 97% of all the arable land in Scotland being on the mainland (Rural and Environment Research and Analysis Directorate 2009c). The arable areas on islands, which include the Machair, do however contain habitats and species of national and international significance for biodiversity.

A wide variety of agricultural activities are based on Enclosed Farmland land, including cereal production, horticulture, soft fruit, and livestock production (Rural and Environment Research and Analysis Directorate 1939-present; Coppock 1976; Rural and Environment Research and Analysis Directorate 2009b; **Figure 19.13**).

Many of the current patterns of agricultural landscapes in Scotland were established in the 19th Century during enclosure (Gibson 2007). There is a long history of arable agriculture in eastern Scotland, both in the north-east and extending southwards to Lothian (Wood 1931; Symon 1959; Coppock 1976). The production of cereals in these areas has historically been closely linked to meat production (through sheep and cattle fattening) as well as supplying the distilling industry (Coppock 1976; DTZ 2007). There has also been a reduction in the area of fodder crops in the lowlands; this has changed some of the relationships of Scottish agricultural systems, requiring increasing amounts of feed to be purchased.

Crofting also occurs throughout Scotland but especially in the Western Isles, West Coast, Orkney and Shetland Islands, and in the crofting counties. Crofting land is not generally included in the categories of arable land mapped

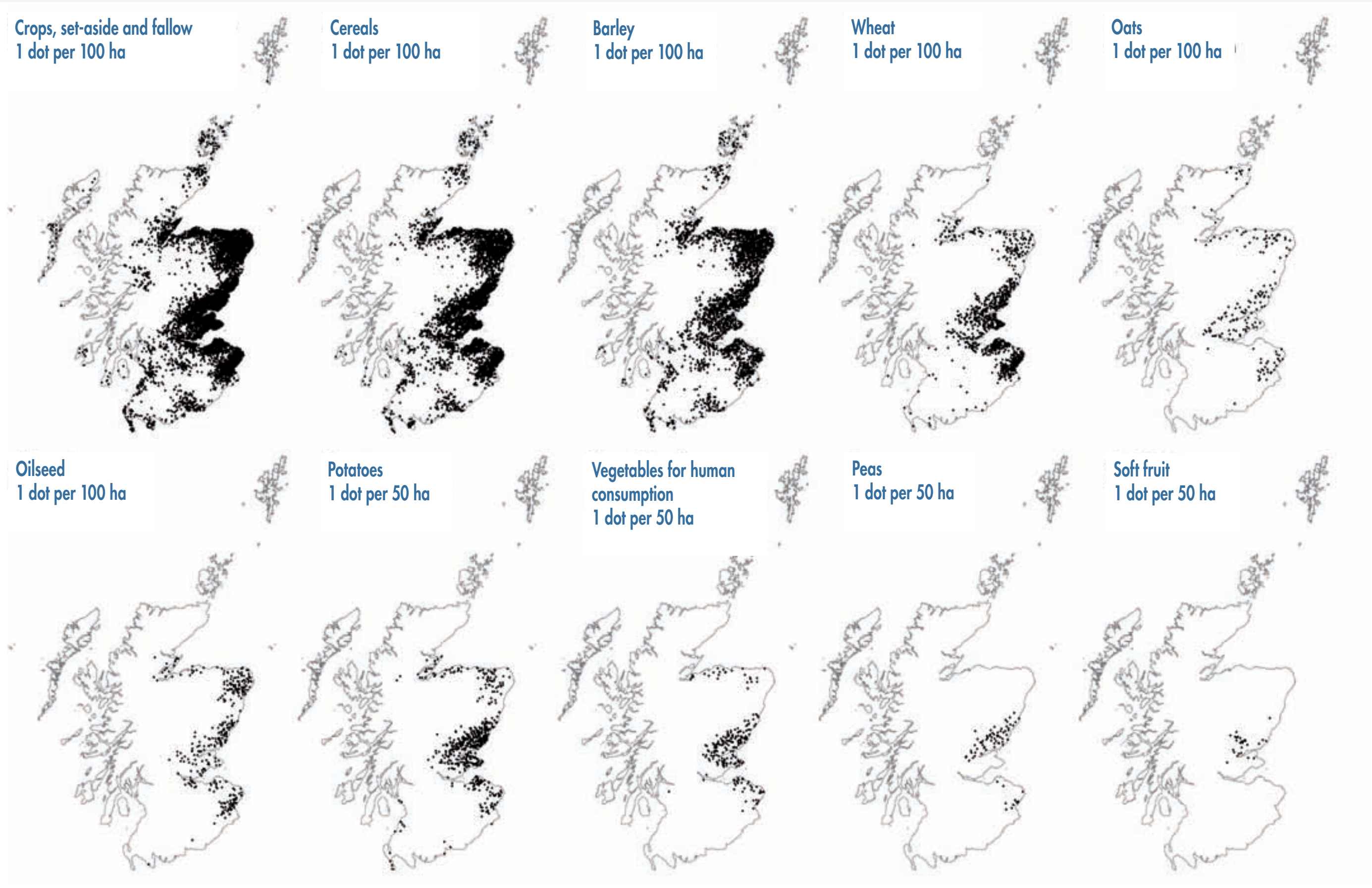


Figure 19.13 Location and areal extent of crops in Scotland in 2007. Source: Scottish Government Agricultural (June) Census, parish summary data 2007.

using air photos or satellite imagery (two of the main sources of synoptic survey data) although it can be recognised in agricultural census data (Rural and Environment Research and Analysis Directorate 1939-present).

Improved grasslands are also an important feature of Scotland's agricultural systems and of lowland and upland landscapes. Grassland expansion in the period following the Second World War (WWII) was intended to increase the fertility and productivity of marginal upland habitats to increase the domestic supply of meat and wool. These grasslands are dominated by relatively few species, including perennial rye-grass (*Lolium perenne*) and white clover (*Trifolium repens*) and continued grazing and occasional reseeding is needed to maintain their nutritional value for livestock. However, despite their lower botanical diversity, agriculturally improved grasslands can, if managed appropriately, still represent important nesting and feeding habitats for some wildlife, including, for example, the important populations of breeding waders that nest and feed on agricultural grasslands in Scotland (O'Brien *et al.* 2002). If active management is removed then most grassland areas will revert to poor fen, moorland, scrub and woodland. Grasslands created by human management of land generally are classified according to soil chemistry and include base-rich, acidic, and neutral grasslands.

The value of Improved grassland for grazing livestock and the productivity of grasses grown under Scottish environmental conditions has led to the creation of extensive areas of Improved grassland pastures across Scotland (**Figure 19.14**). The 1950s and 1960s saw an expansion of Improved grasslands for pasture as other habitats were converted to grassland for sheep and cattle grazing (**Figure 19.15**). Considerable research has been carried out on conversion of upland habitats to grassland, the use of grasslands for animal production and nutrition and the consequences of grazing management for conservation of native flora and fauna. Research shows that re-extensification of grazing over a 16-year period in upland grasslands in Scotland led to slow but continual changes in composition, with some increase in diversity compared to intensive grazing, but productivity did not decline with time (Marriott *et al.* 2009).

Sheep and beef cattle production are the major farming activities in the grass and heather uplands of Scotland. The number of livestock grazed in these habitats is influenced by a variety of factors, not least the availability of winter feed. Flocks of sheep and herds of cattle have been overwintered in the lowlands and have traditionally been fed on turnips and other fodder crops (Coppock 1976). Changes in agricultural practices since Britain joined the Common Market in 1973 have generally resulted in increased specialisation in farming in Scotland and, specifically, lowland areas have increased cereal production while production of fodder crops has declined. This reduces the capacity of lowland

Figure 19.14 Location and areal extent of livestock and grazing areas in Scotland in 2007. Source: Scottish Government Agricultural (June) Census, parish summary data 2007.

areas to support livestock in winter, although much cereal is used as animal feed. The dairy industry has historically been strongest on the grassland pastures of south west Scotland (Wood 1931; Coppock 1976; see **Figure 19.14**).

Synoptic surveys of grassland and change in grassland over time have necessarily mostly used air photos as a data source, despite some inherent difficulties in their use for this purpose. Classification of grasslands on air photos is typically based on the texture of the grassland, which appears clearly in photos, as opposed to the floristic character (Wright & Morrice 1997).

Changes in area of rough, intermediate and smooth grassland are shown in **Figure 19.12**. Rough grassland is the most extensive of the three types. There was a slight reduction between the 1940s and 1980s. Smooth grassland also showed a slight decrease between the 1940s and 1980s, with an increase apparent in the 1970s. Intermediate grasslands have increased in area since the 1940s.

Agricultural areas have been studied as agronomic systems (Clergue *et al.* 2005; Bockstaller *et al.* 2008), and as agri-environmental or agro-ecosystems, developing ecological approaches to understanding agriculture (Ormerod *et al.* 2003). A considerable amount is known about the status, quality, and economic, social and environmental value of agricultural areas. Agricultural development in Scotland has taken place over a sufficiently long time for important species and communities to have become associated with the land use (O'Connor & Shrubb 1986). For example, a number of plant, invertebrate and bird species are closely associated with habitats produced by specific land management practices and have breeding or feeding cycles and patterns that fit with the traditional land management practices and timing. Changes in agricultural management since the 1940s have had major consequences for these species (Hancock & Wilson 2003; Wilson *et al.* 2009; Wilson 2010), many of which are of conservation concern, e.g. corn bunting (Perkins *et al.* 2008; Watson *et al.* 2009), grey partridge (*Perdix perdix*) (Hancock & Wilson 2002), corncrake (O'Brien *et al.* 2006), and great yellow bumblebee (Goulson *et al.* 2006). Arable systems are generally managed to support mechanisation. They have also seen high inputs of fertilisers and other chemicals to control diseases and pests. In common with other countries, intensive management over the last 60 years has resulted in a decline in traditional arable specialist species which are now rare (Robinson & Sutherland 2002; Hyvonen & Huusela-Veistola 2008). Only species able to exploit the crop itself have benefited from highly intensive production practices. Examples include the growth in wood pigeon (*Columba palumbus*) populations after the introduction of oilseed rape (Inglis *et al.* 1997), and the recovery of populations of wintering geese of high conservation concern through feeding on nutrient-rich crops and grassland (MacMillan *et al.* 2004). Scotland is of international importance for populations of wintering geese. Islay is host to between 60 and 70% of the total Greenland population of barnacle goose (*Branta leucopsis*) and 30% of the total population of Greenland white-fronted goose (*Anser albifrons flavirostris*) (Hallanaro & Söderman

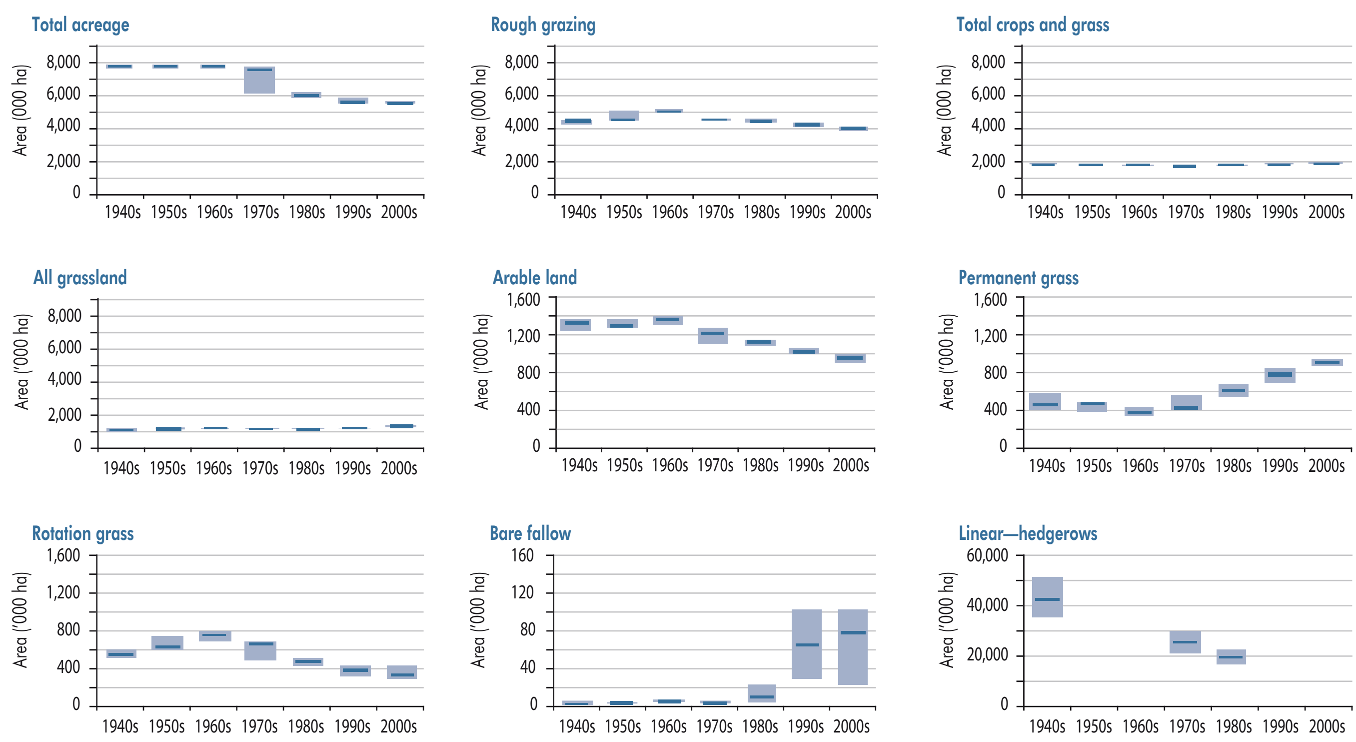


Figure 19.15 Area of agricultural land uses in Scotland for each decade (1940s–2000s) and length of hedgerows (1940s–1980s). Bars represent the maximum and minimum area of land uses in each decade for all variables except length of hedgerows for which the bars represent the standard deviation of the length estimate. Source: agricultural land uses: Annual (June) Agricultural Census tables, 1940–2009, published by the Scottish Government; data on the length of hedgerows from Mackey *et al.* (1998).

2002). Wintering geese feeding on agricultural pastures in Scotland create conflicts with agricultural production (Cope *et al.* 2003), providing challenges for land and conservation management.

Agri-environmental schemes have been shown to contribute to the conservation of avian and insect biodiversity in Scottish agricultural systems (Hancock & Wilson 2003; Parish & Sotherton 2004; Stoate *et al.* 2004; Tiley & Frame 2005; Conway *et al*. 2007; Perkins *et al.* 2008; Perkins *et al.* 2008; Lye *et al.* 2009) though there remain only a few species for which there is evidence that agri-environmental management at current levels of provision has proved capable of reversing losses on a national scale. One example is the corncrake (O'Brien *et al.* 2006) which has benefited from well-targeted management delivered to a high proportion of the population, and backed by good quality advice available to farmers and crofters.

Agricultural areas are also marked by the mosaic of habitats they provide. Field margins constructed of dry stone walls, flagstones or hedgerows not only divide the agricultural area into fields, but also contribute to the appearance of agricultural landscapes. These features and areas may also contribute to wider countryside conservation by providing a 'linear' habitat offering shelter, supporting biodiversity, and maintaining connectivity between habitats in the landscape (Donald & Evans 2006), although better evidence is needed of the circumstances under which this functionality is offered by the cereal margin 'skeleton' of the agricultural landscape (Hodgson *et al*. 2009). The National Countryside Monitoring Scheme and the Countryside Survey both report 'linear' features (see **Figure 19.15**). Lengths of hedgerows in Scotland declined from about 42,500 km in the 1940s to about 19,500 km in the 1980s (Mackey *et al.* 1998). Field boundaries, trees, and copses in an agricultural area provide a suite of ecosystem services that are different from the arable and grassland areas enclosed. Field margins can act as a buffer or filter of runoff, reducing impacts of chemicals and sediments on water quality. Urban trees, small blocks of trees and hedgerow trees are not counted in the carbon storing stock of woodland. As an indication of the extent and potential importance of field margins and trees in agricultural landscapes, the Land Cover of Scotland (1988)[3] (MLURI 1993) mapped 54,484 clumps of trees (outside urban areas) as 'point features' (i.e. less than the 2 ha minimum mapping unit needed to be mapped as an area of woodland) and 12,893 km of linear features composed of trees.

The practice of set-aside, starting in 1988 for two decades (see **Figure 19.15**), has also demonstrated the conservation and functional value and capacity of the mosaic of habitats within agricultural areas for maintenance of biodiversity. In Scotland up to 93,000 ha of land were in set-aside in any one year while the scheme ran (Rural and Environment Research and Analysis Directorate 1939-present). Fields set aside from arable production have been shown to have great value as nesting and foraging habitats for a wide variety of bird species (Sotherton 1988; Henderson *et al.* 2000). This illustrates a more general point that landscapes of even relatively intensive production can maintain substantial biodiversity value if heterogeneity within the cropping system (e.g. diverse, mixed rotations of crops and grassland) and between the cropped areas and patches of non-cropped habitat are used to provide space and time for the life cycles of non-crop organisms (Benton *et al.* 2003). For example, as part of a GB-wide survey of skylarks in 1997 it was found that the highest proportion of skylarks in Scotland occurred where farming systems provided a mix of grazed pasture, winter cereals and spring cereals (Browne *et al.* 2000). Mixed lowland farming systems of eastern Scotland continue to support bird communities that have largely been lost elsewhere in much of the UK as specialisation in arable or grassland enterprises has become more marked.

Throughout the 1940s and early 1950s the area of orchards in Scotland was over 500 ha, but declined steadily to less than 40 ha by the end of the 2000s. The total area of glasshouses also declined from over 100 ha in the 1950s to less than 30 ha by the end of the 2000s. However, there is a growing area of walk-in plastic structures used in agriculture and horticulture in Scotland, although their extent has only been recorded in agricultural statistics since 1982. The total area of glasshouses and walk-in plastic structures is now about 200 ha. Orchards are a particular type of woodland system that provides agricultural output; they not only provide food but may also provide some of the other ecosystem services associated with woodland. Glass/green/plastic houses provide an artificial and highly managed environment for high value foods; they have considerable value in terms of food production although their other environmental impacts are not yet known.

The diversity of species in arable systems has declined over the past 60 years, leading to many of the common weed species of pre-WWII arable agriculture being among present-day threatened species. Wildlife declines, either through change in distribution or abundance or both, are frequently linked to agricultural intensification (Chamberlain *et al.* 1999; Chamberlain *et al*. 2000) or pesticide and fertiliser use (Kleijn & Snoeijing 1997; Henderson *et al*. 2000; Vickery *et al.* 2001; Hart *et al.* 2006). It is recognised that despite their potential negative impact on crop yield and quality, weed species have an important role in maintaining farmland biodiversity (Smart *et al.* 2000). A study of common UK annual weeds, based on their eco-physiological traits, shows potentially beneficial species to have a relatively low competitive ability but high importance for invertebrates and birds (Storkey 2006). Timing of tillage is also important for encouraging (or limiting) plant species with particular life-history and germination traits (Smith 2006). A study of changes in summer numbers of adult corn buntings conducted on farmland from south Angus to central Aberdeenshire showed that following a period of relative stability in 1989–1995, large declines occurred in 1995–1996, 1998–1999 and 2003–2004 (Watson *et al.* 2009). Links between bird numbers on farmlands, invertebrate numbers and agricultural practice

3 The Land Cover of Scotland (1988) was produced from medium scale (1:24,000) aerial photography, interpreted using a hierarchical key that distinguished 126 land cover features as points, lines and areas. Mosaic categories, defined as mixtures of two land cover features, were also mapped. Area features were delimited where they were >10 ha for semi-natural vegetation, >5 ha for built up land and >2 ha for woodland.

suggest that agricultural change influences birds through changes in food quality and quantity (Benton *et al.* 2002).

Similarly, the establishment of grassy strips at the margins of arable fields, as part of recent agri-environment schemes, aims to provide resources for native flora and fauna and thus increase farmland biodiversity. Although these field margin interventions are typically targeted at farmland birds and pollinators (Douglas *et al.* 2009), the impact of such management on soil macrofauna has also been shown to be potentially beneficial, particularly if litter-dwelling invertebrates are encouraged by minimising soil cultivation to develop a substantial surface litter layer (Smith *et al.* 2008). Heterogeneity of mixed habitat agricultural landscapes is an important contributor to biodiversity at landscape and catchment scales (Dennis *et al.* 1999; Robinson *et al.* 2001; Benton *et al.* 2003).

Objectives of agri-environment schemes include conservation of biodiversity, an increase in the value of farmland for wildlife, and restoration of natural ecosystem functioning (Woodcock *et al.* 2007; Smith *et al.* 2008, 2009). Set-aside increases bird (Chamberlain *et al.* 1999; Henderson *et al.* 2000; Moorcroft *et al.* 2002) and insect (Carvell *et al.* 2007; Potts *et al.* 2009) abundance, although a need for regional variation in agri-environmental schemes has also been recognised (Robinson *et al.* 2001). To some degree the design of the agri-environmental scheme in Scotland, the Rural Development Contracts, responds to this need in its regional structure.

Arable agriculture is important for regulation of climate and water. The mineral soils of Scotland which dominate arable habitats (**Figure 19.9**) are relatively rich in carbon compared to mineral soils elsewhere in the UK (Section 19.5.2.1). Appropriate management of arable soils is important both for retaining carbon in the soil and for reducing the contribution of arable agriculture to Scotland's greenhouse gas emissions (MacLeod *et al.* 2010).

Arable agriculture contributes to global carbon emissions from diverse sources, including product manufacture and transport, as well as through direct and indirect soil greenhouse gas emissions. Recent assessment of farm survey data from the east of Scotland shows that across all crops and farm types, about 75% of total emissions are from organic and inorganic nitrogen fertiliser use (Hillier *et al.* 2009).

19.4.4 Woodlands

The native forest of Scotland was a western outlier of the transition between European temperate and boreal forests (Barbatti *et al.* 2007). Altitudinal, climatic and latitudinal limits exerted a strong influence on the forest which was dominated by Scots pine (*Pinus sylvestris*) and birch woods. Broad-leaved trees, including oaks, alder, elm and hazel, would have occupied lowland sites. As elsewhere in the UK, this forest was cleared over centuries for timber, charcoal, cultivation and grazing (Smout 2003).

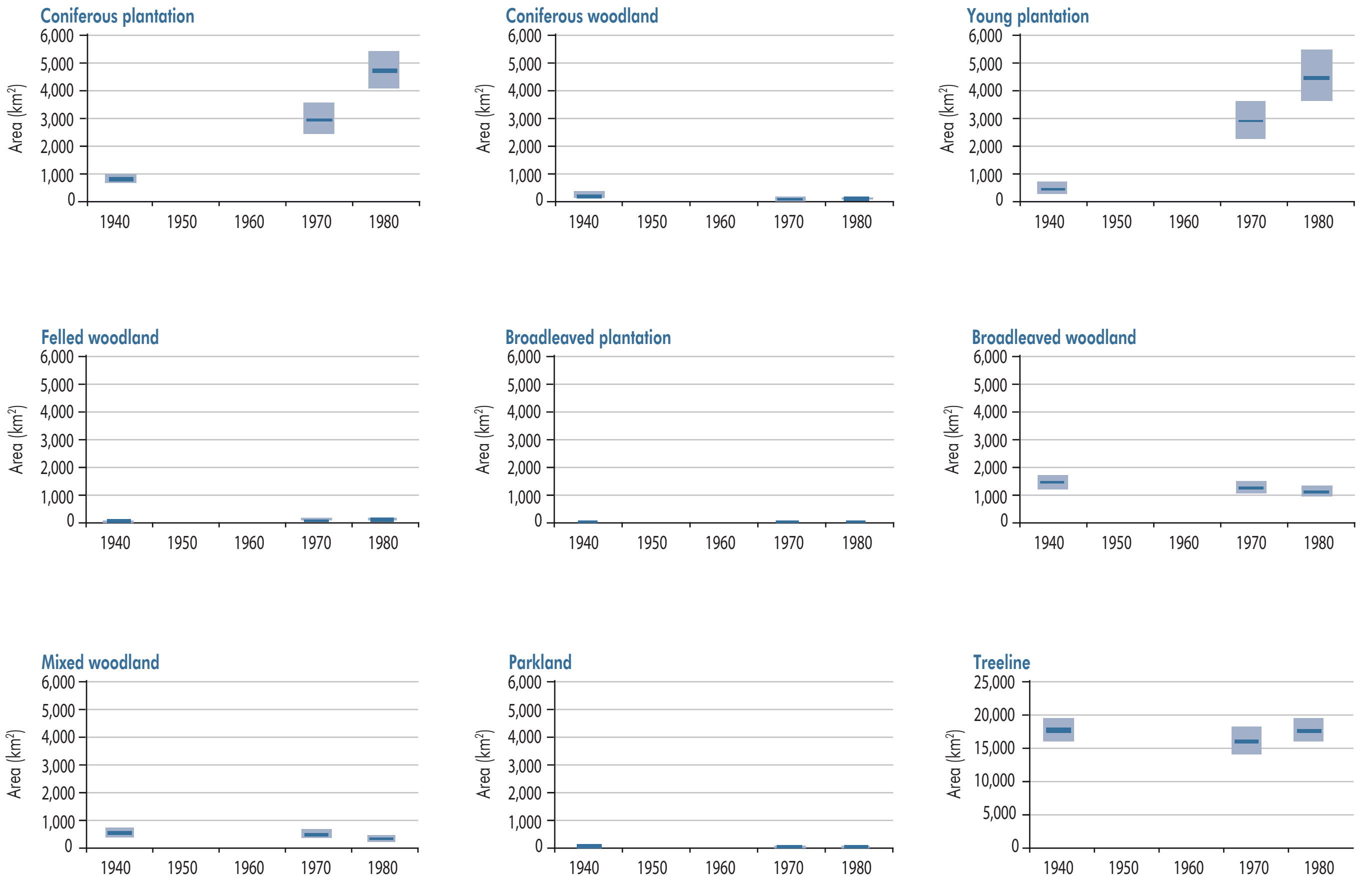
The extent of woodland in Scotland is estimated to have been between 4% and 5% of land area from the 13th Century until the end of the First World War (Smout 2003). The area of Woodland has increased over the last 90 years, partly as a result of governments encouraging reforestation to address domestic shortages of timber. This growth in Woodlands has mostly comprised non-native species in plantation woodlands (**Table 19.5**). Woodlands currently occupy about 17% of Scotland's land area (see **Figures 19.6** and **19.10**).

Despite the overall net increase in total area of Woodlands, the National Countryside Monitoring Scheme showed a decline in Broadleaved (1940s: 150,900 ha, 1980s: 116,400 ha) and Mixed Woodland (1940s: 54,200 ha, 1980s: 34,100 ha). The area of parkland woods appeared to be relatively stable, although at about 7,300 ha (Mackey *et al.* 1998), parkland woods occupy only a small area of Scotland (**Figure 19.16**). The notable increase in the area of commercial conifer plantation forestry took place primarily between the 1940s and 1988 (see **Figure 19.16**).

Commercial plantation forestry uses a variety of introduced species, such as Sitka spruce (*Picea sitchensis*) and lodgepole pine (*Pinus contorta*), that are selected for productivity under the particular climatic, soil and land

Table 19.5 Area of woodland types in Scotland.
Source: Forestry Commission 2003.

	Area ('000 ha)	Proportion of Scotland's forest area (%)	Proportion of area in GB (%)
Conifers			
Scots pine	140	10.9	61.7
Corsican pine	2	0.2	4.3
Lodgepole pine	122	9.5	90.4
Sitka spruce	528	41.3	76.3
Norway spruce	35	2.7	44.3
European larch	9	0.7	39.1
Japanese/Hybrid larch	56	4.4	50.5
Douglas fir	10	0.8	22.2
Other conifer	5	0.4	16.7
Mixed conifer	8	0.6	44.4
Total Conifers	**916**	**71.5**	**65.1**
Broadleaves			
Oak	21	1.6	9.4
Beech	10	0.8	12.0
Sycamore	11	0.9	16.4
Ash	5	0.4	3.9
Birch	78	6.1	48.8
Poplar	0	0.0	0
Sweet chestnut	0	0.0	0
Elm	1	0.1	20.0
Other broadleaves	18	1.4	15.0
Mixed broadleaves	62	4.8	38.8
Total Broadleaves	206	16.1	21.2
Coppice	1	0.1	4.2
Felled	23	1.8	48.9
Open Space	134	10.5	61.8
Total Woodland	**1,281**		**48.1**



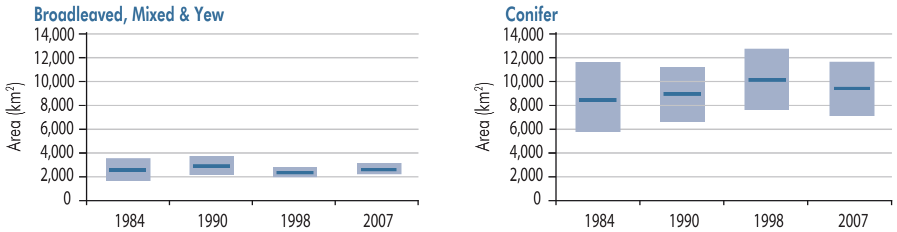


Figure 19.16 Area of Woodlands component habitat types in Scotland (1940s–1980s and 1984–2007). The height of the bars on the charts represents the 95% confidence limits around the estimated area of the habitat; the estimated area is shown as a line across the bar. Source: 1940s–1980s: National Countryside Monitoring Scheme (Mackey *et al.* 1998); 1984–2007: Countryside Survey (Norton *et al.* 2009). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

character of planting sites. The species composition of Scotland's forests is shown by the main tree species in **Table 19.5**. The main commercial species planted in Scotland are Sitka spruce, Scots pine, lodgepole pine and Japanese/hybrid larch (*Larix kaempferi*).

Much of the planting since 1940 has taken place on upland moors and grasslands (Robertson *et al.* 2001), with some replacement planting on existing ancient woodland sites. This pattern of planting was controversial as it led to loss of other valued habitats and species (Avery & Leslie 1990). Most recently there has been greater effort to increase forest area using native species, especially Scots pine, and this has led to benefits for biodiversity (Humphrey *et al.* 2003; Humphrey 2005; McIntosh 2006). In addition there has been greater attention to forest design (Anon 2004) including retention of open areas and protection of riparian zones (Quine & Ray 2010).

Table 19.6 shows the area of new planting in Scotland and the UK as a whole for 5-year periods from 1971 to 2006. Between 1976 and 2009 74% of all new planting of UK forests has been in Scotland, increasing the total area under forests by 48,200 ha. The area planted fell dramatically after 1989 (**Figure 19.17**) as a result of the 1988 UK Government Budget that removed tax support for forestry planting. Planting patterns under the pre-1988 tax incentives had previously encouraged planting but preferentially on land that was marginal for forestry (Macmillan 1993); this led to environmental damage and conflict (Warren 2000). Between 1976 and 1989, 87% of the new UK Coniferous and 38% of the UK Broadleaved planting was in Scotland. From 1990 to 2009, 84% of the new Coniferous and 47% of the total UK Broadleaved planting was in Scotland (**Figure 19.18**). In Scotland grant aid for native woodland expansion and improving connectivity of woodlands has recently been

Table 19.6 Area of new planting of woodland in Scotland for 5 year periods from 1971–1976 to 2001–2006. Source: Forestry Commission 2009.

		5 year period ending 31 March						
		1976	1981	1986	1991	1996	2001	2006
Area in Scotland ('000 ha)	Conifer	148.6	90.9	100.1	94.6	38.3	27.1	11.5
	Broadleaved	0.6	0.8	0.9	9.2	21.0	28.5	19.7
	Total	**149.3**	**91.7**	**100.9**	**103.8**	**5.3**	**55.6**	**31.2**
Area in UK (ha)	Conifer	184.7	108.9	114.3	105.8	45.9	33.0	25.0
	Broadleaved	3.2	2.7	3.8	20.4	45.9	53.3	51.6
	Total	**188.0**	**111.7**	**118.2**	**126.3**	**91.8**	**86.4**	**76.6**
Scotland as proportion of UK total (%)	Conifer	80.5	83.5	87.6	89.4	83.4	82.1	45.7
	Broadleaved	18.8	29.6	23.7	45.1	45.8	53.5	38.2
	Total	**79.4**	**82.1**	**85.4**	**82.2**	**64.6**	**64.4**	**40.8**

brought into the Scottish Rural Development Programme (SRDP).

The UK BAP woodland habitats relevant to Scotland are native pinewoods, upland oakwoods, upland ashwoods, upland birchwoods, wet woodlands, and lowland mixed broadleaved woodlands (Jones *et al.* 2002; Humphrey *et al.* 2006). There are about 148,000 ha of ancient woodland[4] in Scotland (Chapter 8), about 27% of the ancient woodland in the UK. Habitat Action Plans cover the woodland Priority Habitat types in Scotland, including targets for restoration and expansion of the habitats (Humphrey *et al.* 2006). The Countryside Survey records i) native conifer woodland and ii) broadleaf mixed and yew woodland habitats; estimates of their areas have remained 200,000–300,000 ha and 800,000–1,000,000 ha respectively over the duration of the Countryside Surveys (see **Figure 19.16**).

Diseases associated with pests and pathogens are of concern for woodland health and management. Pests and pathogens that are new to woodlands of the UK and Scotland include insects such as the pine-tree lappet moth (*Dendrolimus pini*) which can defoliate Scots pine. The oak processionary moth (*Thaumetopoea processionea*), Asian longhorn beetle (*Anoplophora glabripennis*) and emerald ash borer (*Agrilus planipennis*) are a threat to native broadleaved trees (Chapter 8) although not yet a current threat in Scotland. Pathogens include *Phytophthora ramorum*, which can attack a range of species including Japanese larch (see Brasier 2008; Brasier & Webber 2010), and red band needle blight (*Dothistroma septosporum),* which affects Scots, Corsican (*Pinus nigra subspecies laricio*) and lodgepole pine (Brown & Webber 2008). *Phytophthora lateralis* was found in Scotland for the first time in the UK, killing Lawson's cypress trees in a country park near Glasgow (Chapter 8, Woodlands). Further exotic pests and pathogens may well threaten valued woodland habitats as well as production from managed woodlands. Climate change and other climate-related stresses also influence woodland health (Gregory & Redfern 1998; Green & Ray 2009; Tubby & Webber 2010). Drought stress reduces the resistance of trees to diseases and pests, and wetter spring weather encourages fungal development.

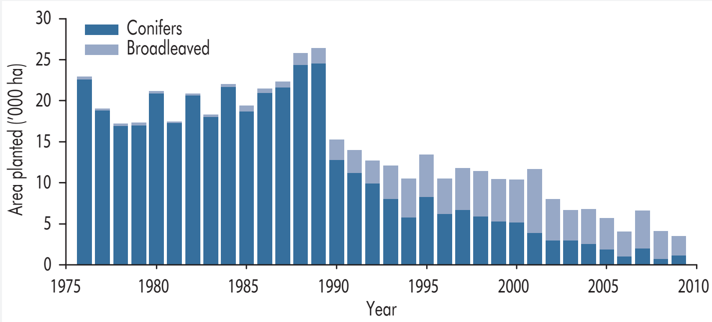


Figure 19.17 Annual area of new Woodlands planting in Scotland, 1976–2009. Source: Forestry Commission (2009).

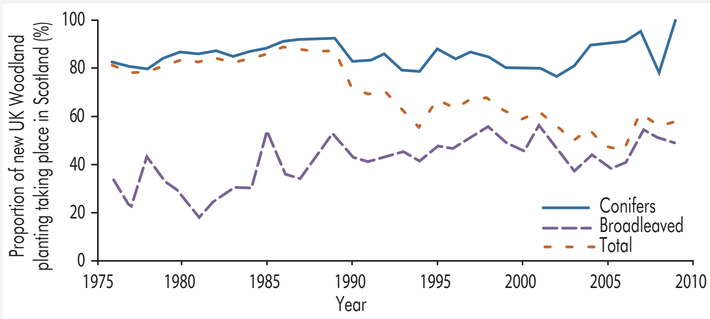


Figure 19.18 Percentage of new UK woodland planting taking place in Scotland, 1975–2009. Source: data from annual Forestry Statistics (Forestry Commission 2009) and the Scottish Government (2011).

As the historic climax vegetation for much of Scotland (Steven & Carlisle 1959), Scots pine forest (Caledonian forest) has a high iconic status. It also has high conservation value as an important habitat in Scotland (Steven & Carlisle 1959; Anderson, Campbell & Prosser 2003) and now receives strong protection and management for biodiversity (Mason *et al.* 2004; Humphrey 2006; McIntosh 2006). The forest type contains many species of conservation value, possibly more than many other habitats[5] (Eggleton *et al.* 2005) and many are iconic species of Scottish wildlife and Priority Species

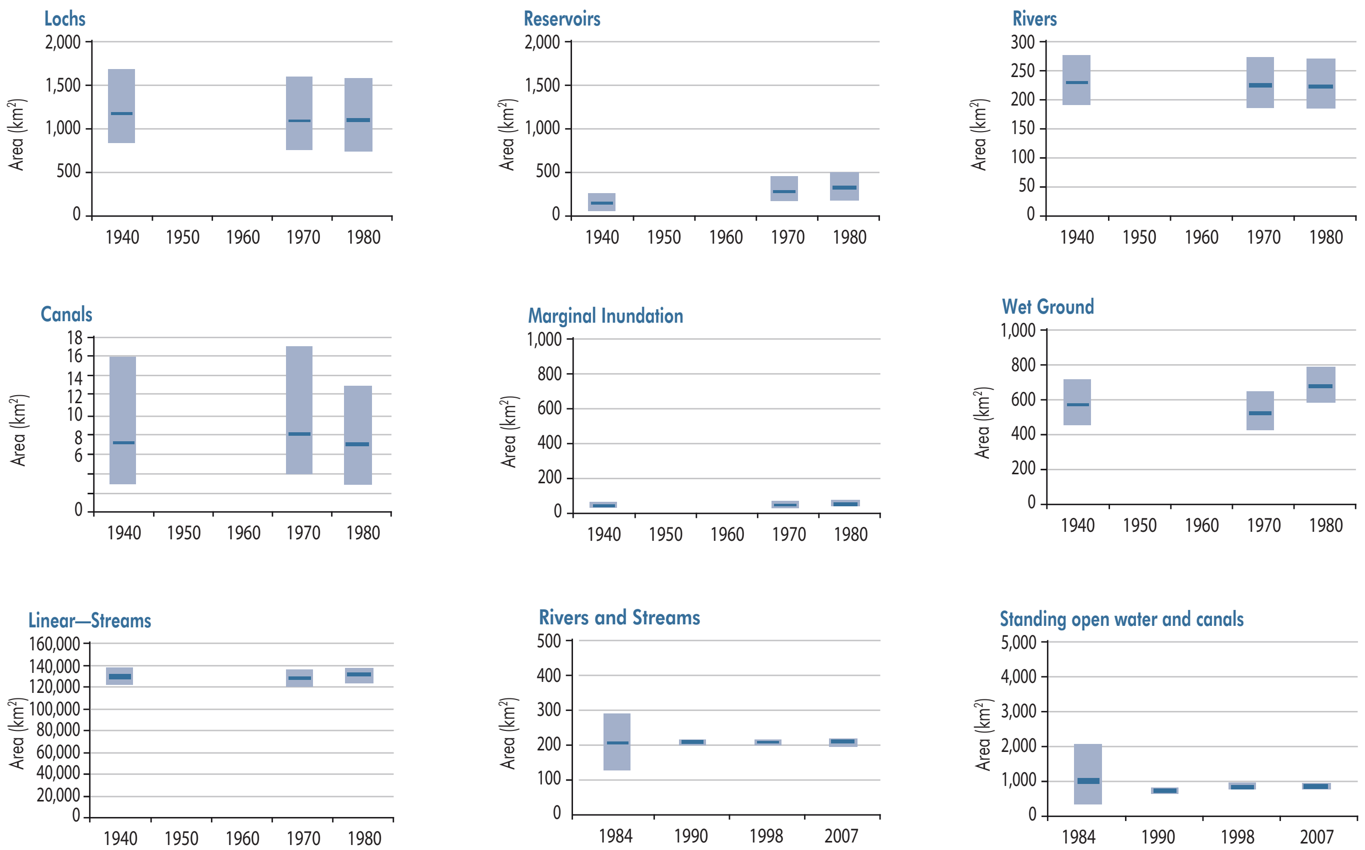
4 Ancient woodland in Scotland is defined as woodland that has been in continuous existence since 1750 (since 1600 elsewhere in the UK).
5 Habitats compared include: Caledonian forest, closed canopy pine plantation, broadleaved woodlands, riparian woodland, grassland habitats, improved grassland, arable fields.

under the UK BAP. Important species include Scots pine itself, flowering plants such as the twinflower (*Linnaea borealis*), creeping lady's tresses (*Goodyera repensi*), lesser twayblade (*Listera cordata*), chickweed wintergreen (*Trientalis europea*), St. Olaf's candlestick (*Moneses uniflora*), *Pyrola* species, birds and animals such as capercaillie, crested tit, Scottish crossbill (*Loxia scotica*), red squirrel (*Sciurus vulgaris*), pine marten (*Martes martes*) and wildcat (*Felis silvestris silvestris*), and invertebrates, bryophytes and lichens.

19.4.5 Freshwaters – Openwaters, Wetlands and Floodplains

The freshwater ecosystems and natural heritage of Scotland have been regularly and systematically reviewed over the past 50 years (Earp & Eden 1961; Gorrie 1961; Wilson 1961; Maitland *et al.* 1994; Doughty *et al.* 2002) although consistent and comparable data collection on aspects of water ecosystems other than flow have been developed only relatively recently (Doughty *et al.* 2002). In 2007 the Scottish Environment Protection Agency (SEPA) introduced a single comprehensive monitoring strategy for water bodies in Scotland, building on past data but creating a new monitoring network, using new methodologies and at new locations. Recent past data were summarised in Scotland's Water Environment Review 2000–2006 (SEPA 2006a). Other trends for rivers can be found from analysis of 56 sites since the mid-1970s under the Harmonised Monitoring Scheme (Anderson *et al.* 2010).

Scotland has abundant freshwater resources in lochs and rivers, with 90% of the volume of freshwater in the UK. Important wetland habitats are associated with these water resources. About 2.5% of the surface area of Scotland is freshwater (see **Figure 19.6** and **Figure 19.10**) and relatively little change in area has been recorded over the last 20 years for freshwater habitats (**Figure 19.19**). The total volume of water stored in lochs has been estimated at almost 35 billion cubic metres (m^3) (Lyle & Smith 1994). Scotland's freshwaters are diverse in processes, drainage patterns and riparian and other forms, reflecting geomorphological evolution over long timescales. Their quality is intimately



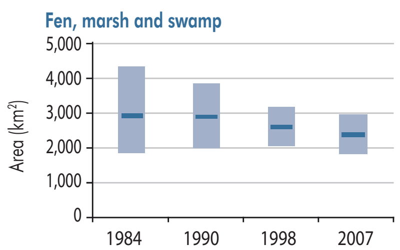


Figure 19.19 Area of Freshwater component habitats in Scotland (1940s–1980s and 1984–2007). The height of the bars on the charts represents the 95% confidence limits around the estimated area of the habitat; the estimated area is shown as a line across the bar. Source: 1940s–1980s: National Countryside Monitoring Scheme (Mackey *et al.* 1998); 1984–2007: Countryside Survey (Norton *et al.* 2009). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

linked to the land area of Scotland that they drain. There are also strong influences from topography, bedrock, and rainfall gradients (Werritty *et al.* 1994). Rainfall gradients are most notable from west to east, with over 3,000 mm of rain per year on the western highlands but typically less than 700 mm on the east coast.

There are 170 catchment systems larger than 10,000 ha in area that drain the land of Scotland. The largest of these systems by area, the River Tay system, also has the largest average flow of any river in the UK (167 cubic metres per second (m^3/s) at Perth), with a peak discharge in excess of 2000 m^3/s (Werritty *et al.* 1994). The typical annual pattern of river flow in Scotland's river shows a maximum volume of runoff in winter.

Climate change is having a major impact on river flows across Scotland (SNIFFER 2006; SEPA 2006b). Scotland has become wetter since 1961, an average increase of rainfall of about 20% having been measured across the country, with a 60% increase in the north and west (SNIFFER 2006). The period of snow cover in Scotland has also decreased over the last 40 years, milder autumn and spring temperatures resulting in later and less snowfall and earlier snowmelt (SNIFFER 2006). These changes have produced a measured increase in mean annual flow in rivers across Scotland since the 1960s and continuing to the present (Curran & Robertson 1991; Doughty *et al.* 2002). There is also an increase in the magnitude of high flow events (SEPA 2006b), particularly on rivers which rise in the west (Black 1996), with corresponding increased risks of flooding.

Annual average temperatures are also increasing in many Scottish rivers (Anderson *et al.* 2010), with implications for river ecology and salmon behaviour and populations. Some of the trends to warmer water may be a consequence of increased urbanisation. Most, however, is considered to be due to warmer air temperatures and the effect is most pronounced in the winter, when widespread warming has been observed (SNIFFER 2006).

Water bodies are affected by all the activities and changes in their catchments (Newson 2002). They can, therefore, monitor and signal environmental changes across whole landscapes (Baron *et al.* 2002). River and loch catchments in Scotland regulate both the quality and quantity of water entering the river and lochs of the freshwater system in Scotland.

Water quality and quantity in rivers, lochs and groundwater are monitored by SEPA. This was previously the responsibility of River Purification Boards. Monitoring methods have changed over time, making direct comparisons of recent and historic classifications problematic. The 2009 publication of River Basin Management Plans for the Scotland (Scottish Government 2009d) and Solway-Tweed River Basin Districts (Scottish Government 2009b) is a major step forward. Water quality is discussed as a regulating service in Section 19.5.2.8.

Climate change forecasts are for wetter, warmer and more seasonal conditions in Scotland. The flow regimes of upland river systems, especially those that depend on snowmelt, can be expected to become modified under a changing climate. Implications of changes in flow regimes of rivers with a major upland component may include increased periods of drought, but also increased floods and flooding as uplands lose the capacity to store water and moderate flows. There may also be changes in water chemistry and water supply. There will also be implications for salmon and trout production in rivers as water temperatures increase and water chemistry adjusts to new flow regimes. There is already evidence of washout of young salmon fry due to altered hydrological regimes in Scottish rivers.

Functionally intact and biologically complex aquatic ecosystems provide many economically valuable services and long-term benefits to society. Freshwater is used for consumption, irrigation and transport, and contributes to food supply. Freshwater systems contribute to flood control, purification of human and industrial wastes, and as habitat for plant and animal life. In the longer term, freshwater systems provide a capacity to respond to future environmental alterations, such as climate change.

19.4.6 Urban

About 2.5% of the land area of Scotland is Urban, the area of highest numbers and density of population being the Central Belt (see **Table 19.2, Figures 19.6** and **19.10**). About 82% of the population of Scotland lives in cities, towns and villages. Glasgow and the Edinburgh area each have a population exceeding 1 million, and Aberdeen and Dundee each exceed 100,000. In addition to these four major cities there are 52 towns with a population between 10,000 and 100,000, and 115 with a population of between 3,000 and 10,000. There are a further 187 villages with a population between 1,000 and 3,000 (see **Figure 19.2**). The area of Built land increased from about 160,000 ha in the 1940s to about 200,000 ha by the 1980s (**Figure 19.20;** (Tudor *et al.* 1994). Although Urban and Built land are included in the Countryside Survey, the survey focuses on developed land in Britain's rural environment; a new assessment of the extent of urban areas in Scotland is needed.

Urban development changes the nature of ecosystems and ecosystem processes fundamentally. Urbanisation is an intensive and effectively irreversible change (Williams *et al.* 2009). Natural processes of nutrient cycling, and energy and water flow are often replaced by engineering systems. Areas outside of, and geographically remote from, an urban area are required to support the urban population and urban 'ecosystem'. The relationships between urban and non-urban (rural) areas are central to issues of sustainability of human and environmental systems globally, as well as within Scotland and the UK. The physical and attitudinal separation of demand for ecosystem services in Urban areas and the supply of ecosystem goods and services from other land uses elsewhere is an important factor in developing an understanding of the role of ecosystems in supporting human health and well-being.

Urban areas in Scotland contain extensive areas of Greenspace (greenspace scotland 2009). Planning Advice Note 65 (PAN 2008) provides a typology for Greenspace and includes parks, public and private gardens, allotments, civic space, churchyards and cemeteries, and sports areas and playing fields. There are also substantial numbers of roadside and garden trees. Greenspace mapping is in progress for most

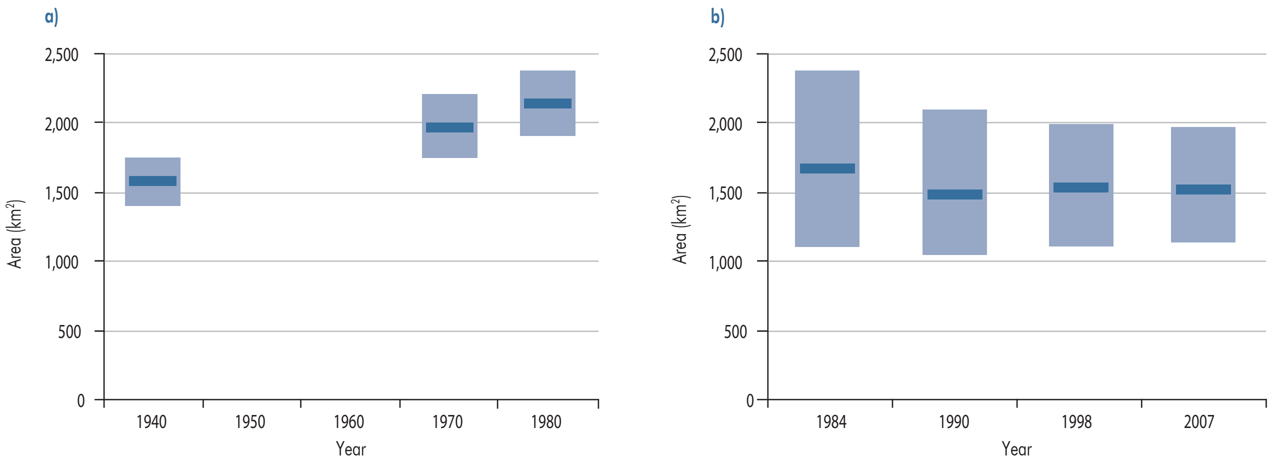


Figure 19.20 Area of a) built land (1940s–1980s) and b) built-up area and gardens in Scotland (1984–2007). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology. The height of the bars on the charts represents the 95% confidence limits around the estimated area of the habitat; the estimated area is shown as a line across the bar. Source: National Countryside Monitoring Scheme (Mackey *et al.* 1998); Countryside Survey (Norton *et al.* 2009).

local authority areas in Scotland following Planning Advice Note 65 (PAN 2008). The 2009 State of Scotland's Greenspace Report (greenspace scotland 2009) describes data from 20 local authorities in Scotland covering 34% of the land area and 70% of the population. These authorities record almost 85,000 ha of Greenspace, 30% of which consists of private gardens (**Table 19.7**). In 2009 there was about 10,800 ha of vacant and derelict land in Scotland (Scottish Government 2010). Scottish Natural Heritage (SNH) has summarised trends in urban Greenspace (SNH 2009). The results show a slowing of urban built development, a reduction in vacant and derelict land and an expansion of formal recreation land. In 2009 for 171 urban settlements in Scotland, 36,787 ha (25.2%) of the total area is covered by Greenspace policies. Of this 34,555 ha (16.9% of the Urban area) is designated as a protected area (green belt, nature conservation designation or landscape value). Public parks are about 0.8% of the total area of Urban areas (9% of Greenspace); natural/semi-natural Greenspace and green network policies apply to about 10,204 ha (7% of Urban areas).

Table 19.7 Types and percentage of greenspace in Scotland for categories in Planning Advice Note 65. Source: greenspace scotland 2009.

Type of Greenspace	Proportion in Scotland (%)	Description
Private gardens	30%	Areas of land normally enclosed and associated with a house or institution and reserved for private use.
Natural spaces	28%	Areas of undeveloped or previously developed land with residual natural habitats or which have been planted or colonised by vegetation and wildlife, including woodland and wetland areas.
Amenity space	15%	Landscaped areas providing visual amenity or separating different buildings or land uses for environmental, visual or safety reasons and used for a variety of informal or social activities such as sunbathing, picnics or kickabouts.
Sports areas	13%	Large and generally flat areas of grassland or specially designed surfaces, used primarily for designated sports (including playing fields, golf courses, tennis courts and bowling greens) and which are generally bookable.
Public parks and gardens	9%	Areas of land normally enclosed, designed, constructed, managed and maintained as a public park or garden. These may be owned or managed by community groups
Green corridors	3%	Routes including canals, river corridors and old railway lines, linking different areas within a town or city as part of a designated and managed network and used for walking, cycling or horse riding, or linking towns and cities to their surrounding countryside or country parks. These may link greenspaces together.
Cemeteries	1%	Includes churchyards and cemeteries.
Playspace	<1%	Areas providing safe and accessible opportunities for children's play, usually linked to housing areas.
Allotments	<1%	Areas of land for growing fruit, vegetables and other plants, either in individual allotments or as a community activity.
Civic space	<1%	Squares, streets and waterfront promenades, predominantly of hard landscaping that provide a focus for pedestrian activity and can make connections for people and for wildlife.
Other	1%	May be one or more types as required by local circumstances or priorities.

The cities of Glasgow, Edinburgh, Aberdeen and Dundee, and many other settlements, are also on estuaries of major rivers and/or on the coast, this having a strong influence on their character and their changing role in relation to ecosystem services. There is also growing evidence of the importance of urban form for biodiversity and provision of ecosystem services, notably positive relationships between social status of residents and tree cover, and provision of ecosystem services with house type (Tratalos *et al.* 2007b). As part of Greenspace audits, Councils in Scotland are reviewing biodiversity (greenspace scotland 2009).

Urban areas may provide artificial habitats that have functional similarities to natural ecosystems. Buildings organised along streets may be analogues of cliffs and canyons, and birds roost and nest on building ledges and roofs. Birds are a good indicator of the general state of biodiversity in urban areas because they can occupy a range of urban habitats and are at or near the top of the food chain. There are also long-term data for certain areas. Across Britain total avian species richness as well as data for urban indicator species shows an initial increase followed by a decrease as household density increases (Tratalos *et al.* 2007a). There are several bird species for which urban roosting and nesting is important, including peregrines (*Falco peregrinus*), feral pigeons (*Columba livia* domestic), gulls and starlings (*Sturnus vulgaris*). In addition to familiar urban birds, a number of seabird and freshwater bird species have colonised Glasgow (Campbell 2008); trends for these species for other cities in Scotland have not been studied.

Gardens and allotments occupy between 6% and 50% of the footprint of major Scottish towns and cities (Birnie *et al.* 2002; greenspace scotland 2009). Economic, social and environmental services provided by Greenspace in urban areas are beginning to be understood and the benefits through improved health and well-being increasingly recognised (Bell *et al.* 2008). Several studies of the direct and indirect benefits in Scotland are discussed in the section on cultural services. There are benefits from using gardens and allotments for food production, in terms of both the activity of growing the food and its consumption and increased abundance of pollinators (Andersson *et al.* 2007). The value of cultural services provided by parks and public gardens is high, largely because of ease of access and use by large numbers of people.

Greenspaces in urban areas also provide a variety of environmental benefits. Air quality can be improved, although more research is needed on types of plants and vegetation that perform best. Noise, the visual intrusion from traffic and flood risk from storm water are all reduced where there are areas of vegetation to intercept or absorb them in urban areas. Urban Greenspaces also provide a diverse habitat, mainly for bird and animal species. Golf courses represent Greenspaces that could be used intentionally for a variety of purposes beyond golf in Scotland; in particular more research could be targeted on management of golf courses to increase their biodiversity value, for use in reducing noise and flooding, and in providing health and well-being benefits from their green environments.

19.4.7 Coastal Margin and Marine

The Coastal Margin and Marine areas of Scotland are not yet fully documented and are the subject of considerable research and monitoring efforts (Saunders *et al.* 2002; Baxter *et al.* 2008; UKMMAS 2010). The state and condition of the coastal and marine areas of Scotland are the subject of a recent report (Baxter *et al.* 2008), and are an important part of Charting Progress 2, an assessment of the UK's seas, which was published in July 2010 (UKMMAS 2010). A detailed Marine Atlas for Scotland has also been published to provide information for the National Marine Plan (Baxter *et al.* 2011).

The length of Scotland's coastline[6] has been estimated at 11,803 km (MLURI 1993; SNH 2004a). The area of seabed contained within the 12 nm territorial limit is estimated to be about 88,600 km^2 (SNH 2004a), about 12% larger than the 78,840 km^2 (7.9 million ha) land area of Scotland. Extending the territorial limit to the UK Continental Shelf and the 200 nm limit attaches about 470,000 km^2 of marine area to Scotland (**Figure 19.21**).

Physical, chemical and biological processes and elements of marine ecosystems are strongly interrelated at a range of scales. There is also a strong influence of land-based activities on coastal and marine areas. The offshore environment around Scotland varies in depth from less than 250 m (with an average of approximately 100 m) on the shelf seas to greater than 2,000 m in the deep ocean regions of the Rockall Trough and Faroe-Shetland Channel to the west of the Outer Hebrides and Shetland Isles (Baxter *et al.* 2008). The shelf seas include the Malin and Hebrides shelf seas, Orkney and Shetland shelf seas, and the North Sea. The shelf seas contain banks (Viking Bank, Stanton Banks) and deep channels. The deep ocean topography is marked by steep ridges (Wyville-Thompson Ridge), seamounts (Anton Dohrn) and banks (Rockall Bank).

Scotland's seas are affected by ocean circulation systems, tidal currents, and freshwater from major rivers. The North Atlantic Current is driven partly by wind and partly by density differences between warmer southern water and cooler northern water. In addition to this surface current, there is a flow of cold water, the Thermohaline Current (or Meridional Overturning Circulation) returning from the Arctic to the Atlantic at depths of below 400–600 m. This flow moves south-eastwards through the Faroe-Shetland Channel and is then diverted westwards by the Wyville-Thompson Ridge into the Rockall Trough. This circulation is of particular interest as it is an important element of climate variability and because there is concern that it may be weakened by global climate change (Higgins & Vellinga 2004; Higgins & Schneider 2005; Kuhlbrodt *et al.* 2009). The Slope Current is a fast current (15–30 cm per second) that flows northwards along the edge of the continental slope at depths of approximately 400–500 m. This current

6 Coastline length is highly dependent on the scale of the data from which it is measured. Estimates of the length of Scotland's coastline range from over 10,000 km to 18,670 km (Angus *et al.* 2011). The length estimate provide here is based on measurement from 1:25,000 scale Ordnance Survey maps.

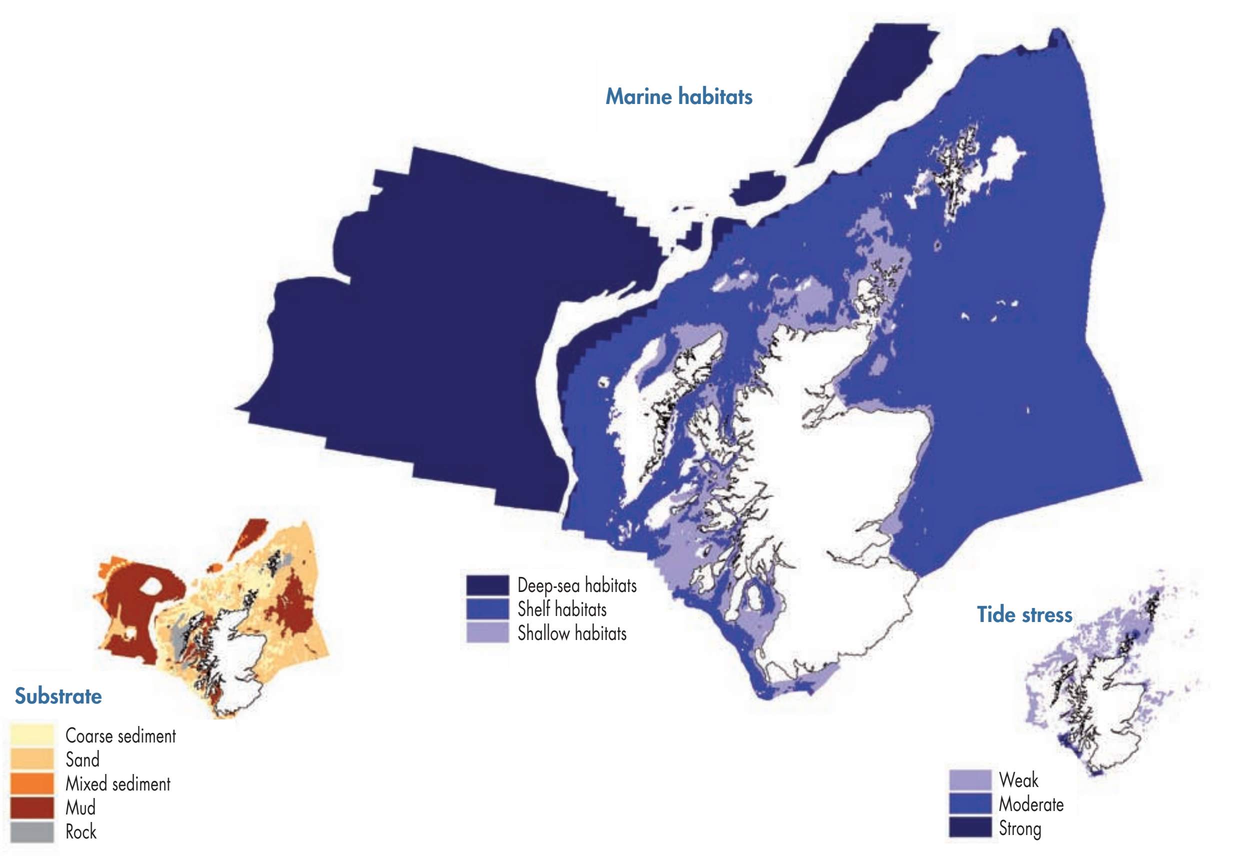


Figure 19.21 Marine habitats, substrate types and tide stress in Scotland's seas. Source: data from the Mapping European Seabed Habitats (MESH) project (http://www.searchmesh.net).

has its source in the Iberian region and part of the North Atlantic Current that reaches the Bay of Biscay; as a result it provides heat, nutrients and plankton to Scotland's waters, influencing fish distribution and feeding (Reid *et al.* 1997; Haugland *et al.* 2006).

A variety of tidal currents affect Scotland. These strong currents are found where the topographic controls constrain water movement and cause mixing within the water column. They are especially apparent around Orkney, Shetland, the Mull of Kintyre, the Hebrides, and in the Pentland Firth. The predominant circulation of water on the west shelf of Scotland is northwards, and is anticlockwise in the North Sea.

Sea temperatures around Scotland are affected both by the local climate and by heat transfer from ocean currents. Sea surface temperatures follow a cycle with a 1-month lag behind atmospheric temperature. In winter, sea temperatures are higher on the west coast than the east. In summer, sea temperatures are warmer in the North Sea on the east than off the West coast.

Salinity in coastal waters is affected by input of freshwater from land and rivers. The waters of the Firths of Solway, Clyde, Moray, Tay, and Forth, and estuaries of smaller rivers, receive considerable freshwater runoff. It is estimated that 73% of the freshwater falling as precipitation in Scotland becomes runoff into the coastal and marine waters of Scotland. West coast sea lochs with a sill at the mouth of the loch, as is characteristic of fjords, may have only limited water exchange with the seas (Hall *et al.* 1996).

Turbidity, a measure of the biological (phytoplankton) and mineral (sediment) suspended solids in water as well as coloured dissolved organic matter, is highest in coastal areas. The Scottish North Sea has local concentrations of suspended sediment that are greater than in the southern North Sea. Turbidity influences the depths at which photosynthesis can take place (Baxter *et al.* 2008).

The effects of salmon farm inputs on pelagic nutrient concentrations and planktonic microbial abundance and biomass were investigated in Loch Fyne on the west coast of Scotland. Ammonium and dissolved organic nitrogen concentrations as well as heterotrophic microbial abundance and biomass were highest nearest to fish farms, suggesting that these and other nutrients derived from the fish farm may be directly or indirectly enhancing heterotrophic microbial activity and that the heterotrophic microbial food web is responsible for processing matter and energy released into the pelagic environment from salmon farms (Navarro *et al.* 2008).

The physical characteristics of the water in the shelf seas have an important influence on the marine ecosystem. The dynamics of currents, tidal flows and water circulation patterns, the supply of sediments and other materials, as well as bathymetry and climatic factors in the seas, all influence the distribution of seabed sediments and the chemical and biological processes operating in the water column. The shelf seabed is variable and includes sediments from mud to rock. The sediments of the seabed in Scotland are sand- and gravelsized and derive from Quaternary deposits associated with the last glaciation (Baxter *et al.* 2008). Fine, muddy sediments occur nearshore where sediments are supplied by rivers, and offshore in areas where currents and tides are weak, for example at the Witch Ground, Fladen basin, and in the Minch, and at the bed of the deep waters of the Faroe-Shetland Channel and Rockall Trough. There are high concentrations of calcareous seabed material around Orkney and Shetland (Baxter *et al.* 2008).

The Coastal Margin and Marine habitats of Scotland reflect this variability in the physical coastal and marine environment. The Atlantic coast to the west is deeply indented with sea lochs, and with numerous islands, high sea cliffs and rocky skerries. The North Sea coast is predominantly low lying, with sedimentary beaches and fewer cliffs and with extensive firths (Moray, Tay and Forth). Islands form three major archipelagos in Shetland, Orkney and the Western Isles, each with a range of distinctive Coastal Margin habitats (Berry & Johnston 1980; Berry 1985; Boyd & Boyd 1990, 1996). Many of Scotland's islands are home to distinct endemic sub-species (e.g. Shetland *Troglodytes troglodytes zetlandicus*, Fair Isle *T.t. fridariensis*, Hebrides *T.t. hebridensis,* and St. Kilda *T.t. hirtensis* wrens) (Brewer 2001; Aspinall & Aspinall 2011), and the St. Kilda field mouse *Apodemus sylvaticus hirtensis* (Berry & Tricker 1969; Angus 2001), giving Scottish biodiversity another distinctive characteristic.

The coastline of Scotland is made up of a number of characteristic habitat types (**Table 19.8**, **Figure 19.22**). The proportion of rocky and shingle coastline is 73.4% of the total, both types being over 80% of the GB total of that type. On sublittoral hard coastline, such as rock and shingle coasts, plant and faunal communities reflect the physiographic nature of the coastline, salinity, wave exposure, and strength of tidal streams and depth (Hiscock 1992). More than two-thirds of the UK area of Sand Dune, Machair and Saline Lagoons are found in Scotland and over 50% of the UK length of Maritime Cliffs and Slopes (Table 19.8b).

Sand Dune systems and Shingle beaches are also important habitat types, not only for breeding birds but also

Table 19.8 Length of Coastal Margin habitats in Scotland.
Source: Ritchie & Mather 1984; Covey 1999; Dargie & Duncan 1999; Dargie 2000; Joint Nature Conservation Council 2011.

Habitat	Length at mean high water mark (km)	Proportion of Scottish Coast (%)	Scottish Coast as proportion of GB Total (%)
Rocky	5,674	48.1	84.6
Shingle	2,992	25.3	82.4
Mixed	1,179	10.0	51.6
Sandy	1,047	8.9	44.5
Saltmarsh	359	3.0	18.3
Muddy	282	2.4	15.7
No intertidal	270	2.3	45.4
Total	**11,803**	**100.0**	**61.0**

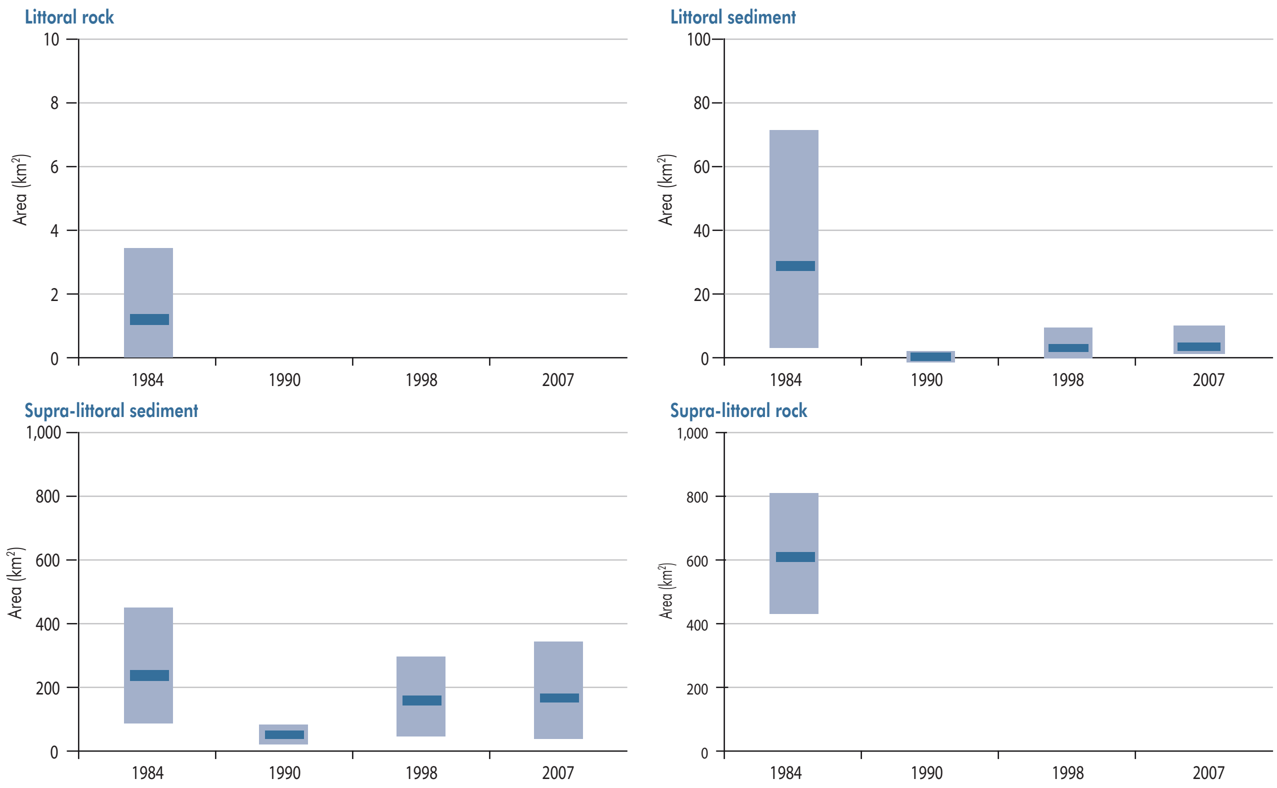


Figure 19.22 Area of Coastal Margin habitats in Scotland (1984–2007). The height of the bars on the charts represents the 95% confidence limits around the estimated area of the habitat; the estimated area is shown as a line across the bar. Source: Countryside Survey (Norton *et al.* 2009). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

for their inherent geomorphological interest and for their function for coastal protection. Similarly, Machair grassland represents a very distinct form of calcareous sand habitat, unique to the west of Scotland and Ireland. Saltmarshes, and intertidal sand and mud flats associated with estuaries, provide important wintering and migration stopover sites for migratory birds.

About 10% of the Hebrides is comprised of coastal Machair, with about 10% of South Uist but up to 33% of Tiree (Mather *et al.* 1975; Boyd & Boyd 1990). This ecosystem is unique to Scotland and Ireland (Hansom & McGlashan 2004) with about 67% of the total being in Scotland (Hanson & Angus 2001). It has been argued that Machair is a cultural as much as a physical or biological phenomenon (Angus 1999). Machair occurs on low-lying coasts comprised of shell sand and has a neutral to basic pH. It is traditionally used for grazing, although there is some cultivation for winter feed. The vegetation is species rich and contains a plant community that is adapted to periodic burial in sand (Owen *et al.* 2004; Kent *et al.* 2005) and with a rich seed bank (Owen *et al.* 2001). The area is also an internationally important nesting area for waders (Boyd & Boyd 1990; Fuller *et al.* 2010), corncrakes (*Crex crex*) (Stowe *et al.* 1993; O'Brien *et al.* 2006), and corn buntings (*Emberiza calandra*) (Wilson *et al.* 2007), and supports remnant populations of several scarce invertebrates now restricted to Semi-natural Grassland (Goulson *et al.* 2006). The survival of Machair is closely linked to continued management using traditional methods (Angus 1999). Use of artificial fertilisers and herbicides, increased stocking densities that increase grazing pressure, or reduction in grazing, all damage Machair and may lead to its loss.

The current estimate of the number of plant and animal species supported in the seas around Scotland is about 6,500 (Baxter *et al.* 2008). This number increases to in excess of 40,000 species if microbial flora are included. The territorial waters within the 12 nm limit support 7 of 9 Marine and 14 of 17 Coastal Margin habitats in Annex I, and nine of 10 marine species listed in Annex II of the European Habitats Directive (SNH 2004a). Northern and western areas of Scotland's seas are of major importance for whales (SNH 2004a).

There are notable seabed habitats and communities around Scotland, many of them being Priority Habitats in the UK BAP, with both species and habitats identified in the Scottish Biodiversity lists. Most have been reduced in extent and their condition damaged by human exploitation (Hughes & Nickell 2009). Seabed habitats are formed by sediments and the biogenic structures created by attached, burrowing, reef-forming and tube-building fauna. The biogenic structures provide important refuges for a high biodiversity of associated species that form the seabed community. The seabed fauna also provides food for fish populations.

Maerl beds (*Rhodophyta*), a Priority Habitat, occur on the west coast and are more frequent in Scotland than in any other European country (Scott & Moore 1996). Maerl beds are important as nursery grounds for scallops and other species (Kamenos *et al.* 2004a, b) but have been reduced and damaged by scallop dredging (Hall-Spencer & Moore 2000b) and salmon farming (Hall-Spencer *et al.* 2006).

Flame shell (*Limaria hians*) beds are recorded along the west coast of mainland Scotland on mixed muddy gravel or sand substrates in moderately strong tidal streams (Hall-Spencer & Moore 2000a; Trigg & Moore 2009; Hughes & Nickell 2009). As for maerl beds, damage to flame shell beds is attributed to scallop dredging (Hall-Spencer & Moore 2000a). *L. hians* nests support a rich fauna of invertebrates and larger animals as well as algae, contributing to total benthic biodiversity (Hall-Spencer & Moore 2000a).

Fan shells (*Atrina pectinata*) are found in mud, sand and gravel habitats along the west and east coasts of Scotland as well as Orkney and Shetland (Woodward 1985) but they are now generally very scarce in UK waters (Solandt 2003). The decline in *A. pectinata* is attributed to habitat destruction and direct damage by bottom trawling and dredging (Hughes & Nickell 2009).

Native oyster (*Ostrea edulis*), a Priority Species, is characteristic of productive estuarine and shallow Coastal Margin habitats on sediments from mud to gravel and where there is shelter from wave action; oysters can form extensive beds (Hughes & Nickell 2009). Oysters in Scotland now occur mainly in small and scattered low density populations around the west coast sea lochs (University Marine Biological Station Millport 2007). However, oysters once were widespread and abundant around Scotland's coast and were an important food from the Mesolithic to the mediaeval period. Oysters supported a commercial fishery by the 18th Century and there are estimates of the Newhaven oyster beds in the Firth of Forth yielding 30 million oysters per year in the first part of the 19th Century (Coull 1996). The decline and disappearance of oysters from Scotland's coastal areas is the result of human over-exploitation (Coull 1996; University Marine Biological Station Millport 2007). Over-exploitation led to the end of the Shetland, Moray Firth and Cromarty Firth oyster fisheries by the late 19th Century and the Orkney and Firth of Forth fisheries by the early 20th Century (University Marine Biological Station Millport 2007; Hughes & Nickell 2009).

In addition to their use as a food, oyster beds potentially also provide important ecosystem services through their impacts on water quality and their contribution to the health of coastal ecosystems through filtration of suspended matter, enhanced nutrient cycling, and creation of habitat for mobile animals. With the extinction of oysters from areas around Scotland these benefits can no longer be achieved, but the potential for beneficial impacts makes restoration of native oyster beds a highly desirable goal for coastal ecosystem management around Scotland (Hughes & Nickell 2009).

Reefs are constructed by a variety of marine organisms including horse mussels (*Modiolus modiolus*), the cold-water coral *Lophelia pertusa*, and the tube-building serpulid worm *Serpula vermicularis*. Serpulid reefs are a Priority Habitat in Scotland. They occur in two known locations, the sea loch Loch Creran, in Argyll (Scottish Biodiversity Forum 2003), and Loch Teacuis (Dodd *et al.* 2009) and are known from only two other places in the world (Baxter *et al.* 2011). Bottom trawling has had a damaging effect on biogenic reefs (UKMMAS 2010). Physical damage from trawling and from storms associated with climate change and sea level rise may combine to reduce the extent of reef habitats (UKMMAS 2010).

Land and marine areas are related, not only along the coast, through runoff and other processes that connect the land and marine environments. The EU Water Framework Directive (WFD), which came into force on 22 December 2000, influences Scottish water policy development and implementation, setting aquatic and wetland natural heritage targets, including for marine areas (Downie & Baxter 2004). Monitoring schemes are required to comply with the WFD regulations. For example, studies in Loch Linnhe in the early 1990s showed low concentrations of dissolved silicon, phosphate and nitrate (Hall *et al.* 1996), the values measured in the loch being considerably lower than those of coastal waters subject to larger anthropogenic burdens.

Designation is one mechanism for addressing issues over the status of habitat and species and concerns of the European Union Habitats Directive (Directive 92/43/EEC). By 2003 there were 430 SSSIs in Scotland with a coastal element, covering an area of some 327,504 ha (see SNH 2004a). However, SSSIs address only the land and intertidal components of the coast.

There are very few marine reserves although SACs (for species and habitats) and SPAs (for wild birds) do cover marine areas (Section 19.3.2). The Habitat Regulations Assessment for the UK Marine Policy Statement was published in 2010 (Defra 2010). This assessment for marine areas is required as part of a Marine Policy Statement under the EU Habitats Directive. The report notes the conservation status of SAC habitats in marine areas of the UK. The UK status for Marine habitats occurring in Scotland is *unknown* for sea caves, *inadequate* for lagoons, and *bad and deteriorating* for seven habitats (estuaries, sub-tidal sandbanks, intertidal mudflats and sandflats, shallow inlets and bays, annual vegetation of drift lines, glasswort and other annuals colonising mud and sand, Atlantic salt meadows) (Defra 2010; Joint Nature Conservation Council 2011); the specific status of these habitats in SACs in Scotland is not separately identified. Pressures on marine habitats include habitat loss and degradation due to infrastructure development on the coast, extraction of oil, gas and marine aggregates, damage from fishing practices, especially bottom-trawling and shellfish dredging, marine pollution, shipping, and pipelines (Defra 2010).

The conservation status of eight SAC Marine Species is *bad* for one species: allis shad (*Alosa alosa*), *inadequate* for two species: the twaite shad (*Alosa fallax*) and common seal (*Phoca vitulina*), *inadequate but improving* for one species: sea lamprey (*Petromyzon marinus*) and *favourable* for four species: bottlenose dolphin (*Tursiops truncatus*), harbour porpoise (*Phocoena phocoena*), grey seal, and otter (*Lutra lutra*). Climate change, marine pollution, human disturbance, fishing practices, invasive species, disease introduction, and changes in hydrological and coastal processes present threats to the long-term survival of these species (Defra 2010).

The condition and status of habitats and species in marine areas around the UK are of significant concern. The lack of information on their specific status and condition around Scotland represents an important knowledge gap.

19.5 Ecosystem Services

19.5.1 Supporting Services

Supporting services provide the foundational processes and functions (primary production, decomposition and nutrient cycling, water cycling on land and in freshwater and the seas, and the formation of soils on land) that are necessary for ecosystems to generate all other services (EASAC 2009).

19.5.1.1 Soil formation

Soils form from weathering of rocks and minerals and accumulation of organic matter; typically soil formation takes many hundreds or thousands of years, as rates of mineral soil formation are in the range of 0.04–0.08 mm per year (mm/yr) (EASAC 2009; Chapter 13). There is no reason to expect soil formation rates to be outside this range in Scotland.

Scotland's soils are diverse and differ markedly from those in the remainder of the UK (Towers *et al.* 2006). The majority have acidic and organic-rich surface layers including large areas of blanket bog up to 8 m thick (Chapman *et al.* 2009). Scotland's soils contribute to nature conservation, biodiversity and carbon storage and make a highly significant contribution to landscape value.

There is considerable variation in depth (and type) of different mineral soils of Scotland. This reflects the variability in the activity of physical, chemical and biological processes that form soil and the interaction of these process with the different soil forming factors (parent material, climate, topography, biota, and land management (Jenny 1941; Ragg 1973). In addition to mineral soils, Scotland has over 700,000 ha of organic peat soils, covering about 10% of the land area (Soil Survey of Scotland 1984). Rates of soil formation in organic peat soils are faster than in mineral soils, and peat depth is estimated to increase at a rate of up to 0.8 mm/yr in actively growing bogs of good status under ideal environmental conditions (Chapter 13). Peats of over 10 m depth have been recorded in Scotland although the mean depth is about 2 m (Chapman *et al.* 2009).

Rates of soil formation expressed as depths translate to stocks of soil and the materials they contain. In Europe the estimated limits of mineral soil formation gives increases in soil of between about 0.3 tonnes per hectare per year (t/ha/yr) and about 1.4 t/ha/yr (Verheijen *et al.* 2009). Soil is lost by erosion, a natural process intensified by land management and land use. In Europe rates of soil erosion for tilled arable land are estimated to be 3 to 40 times greater than the upper limit of soil formation (Verheijen *et al.* 2009). Soils can also be lost through urbanisation as land is sealed from further use by concrete, tarmac or buildings. When last assessed, for the period from 1995 to 2002, conversion of agricultural land to urban uses was occurring in Scotland at a rate of about 1,200 ha/yr (Towers *et al.* 2006).

A peat accumulation rate of 0.8 mm/yr is equivalent to an accumulation rate of carbon of about 0.5 tonnes of carbon per hectare per year (t C/ha/yr), although the average accumulation rate is closer to 0.1 t C/ha/yr. The total peatland carbon stock in Scotland has been estimated to be 1,620 megatonnes of carbon (Mt C) (Chapman *et al.* 2009). In comparison, although using different definitions, notably for depth, of peat, peat soils in England, Wales and Northern Ireland are estimated to contain 296, 116 and 90 Mt C respectively (Bradley *et al.* 2005; Smith *et al.* 2007; Chapman *et al.* 2009).

The current state and trends of Scotland's soil resource have been the subject of a recent review (Towers *et al.* 2006). Soil sealing has a profound effect on the ability of soils to perform other functions and is effectively irreversible. Evidence shows that agricultural land is being developed at twice the rate that it was in the mid-1990s (Towers *et al.* 2006), development occurring on some of Scotland's most versatile and productive soils. Towers *et al.* (2006) found little evidence of serious soil erosion, compaction or other problems related to land management. However, in addition to loss of soil through urbanisation, soils can be damaged. The main factors causing damage to soils in Scotland are intensive management, pollution, reduction in the levels of organic matter, alteration of the nutrient cycle and microbiological biodiversity, as well as climate change including sea level rise (Towers *et al.* 2006).

19.5.1.2 Nutrient cycling

Cycling of nutrients through biogeochemical pathways and processes is a fundamental activity in all ecosystems. Detailed data on different nutrient cycling in different habitats are relatively sparse. Several nutrients are of importance, particularly nitrogen and phosphorus, and carbon is of concern in relation to climate change.

Nitrogen and phosphorus. The two major trends in relation to nitrogen over the period since the 1940s are:

i) atmospheric nitrogen deposition which has enriched many habitats with nitrogen; and
ii) application of inorganic nitrogen fertilisers to agricultural land to maintain soil fertility and increase yields of agricultural crops.

For the UK as a whole, nitrogen deposition often exceeds 25 kg of nitrogen per hectare per year (kg N/ha/yr) although the fate of this nitrogen is uncertain. It is possible that soils in many habitats accumulate the nitrogen in soil organic matter (Phoenix *et al.* 2004) although plants may also sequester the additional nitrogen (Britton & Fisher 2007). Impacts of atmospheric nitrogen deposition are clearly observed in moorland and montane habitats in Scotland and include reduced species richness and reductions in lichen diversity (Britton & Fisher 2007b, 2008) and *Racomitrium* (van der Wal *et al.* 2003).

Inorganic nitrogen fertiliser applications can be at much higher rates than atmospheric deposition. In the Ythan catchment in north-east Scotland, increasing amounts of fertiliser nitrogen were applied annually over the period from the 1960s to 1990s (Domburg *et al.* 1998). By 1994 fertiliser applications were estimated to be equivalent to 194 kg N/ha/yr added to the catchment (Edwards *et al.* 2003). This increase was associated with an approximately threefold increase in surface water nitrate concentrations (Domburg *et al.* 1998), an increase in groundwater nitrate, and river water concentrations exceeding the maximum permitted level of 50 milligrams per litre (mg/l) (11.3 mg/l nitrate nitrogen; see Edwards *et al.* 2003), eutrophication of the estuary with significant impacts on the distribution and abundance of benthic invertebrates and their shorebird consumers (Raffaelli 1999a, Raffaelli *et al.* 1999), and with consequences for phytoplankton offshore in coastal waters (Balls 1994). The Ythan was designated as Scotland's first Nitrate Vulnerable Zone (NVZ), a mechanism for managing the impacts of nitrogen on the wider environment. The NVZ in the Ythan led to cooperation between farmers and the wider community of the Ythan catchment to protect and restore the river environment (Sang 2008).

In arable habitats nitrogen and phosphorus (as phosphate, slurry, manure and inorganic fertilisers) have been added to land to maintain soil fertility and increase yields (Section 19.5.3.1). The Economic Reports on Scottish Agriculture (SEERAD 2005) record that amounts of nitrogen and phosphorus fertiliser purchased by Scottish agriculture have fallen since the mid-1990s (**Figure 19.23**).

Carbon. Mires and blanket bogs, as peatland areas where organic material is actively developed and stored, are now recognised as an extremely important store of carbon. Recent estimates of the carbon store in peatland in Scotland are 1620 Mt C (Chapman *et al.* 2009). This is equivalent to about 125 times Scotland's (2005) yearly total carbon dioxide emissions (Jackson *et al.* 2008). Scotland's peatlands also have the capacity to accumulate about 0.4 Mt C per year, offsetting about 3% of Scotland's total carbon dioxide emissions. Climate change represents a threat to this store and capacity for carbon sequestration. Increased temperatures will increase decomposition rates, and changes in precipitation leading to summer droughts will not only cause the loss of *Sphagnum*, the species that builds peatlands, but also dry out the peat leading to erosion and increased emission of greenhouse gases (Chapman *et al.* 2009). Projects that block drains in peatland ecosystems can contribute to reversing carbon loss and also improve habitat for biodiversity management (Whittingham *et al.* 2001).

19.5.1.3 Water cycle

Freshwater is vital to human life and societal well-being. The water cycle connects land-based and aquatic habitats and ecosystems and is considered as water stores (soil, groundwater, floodplains, wetlands, lochs and ponds) and fluxes (rainfall, evapotranspiration, river flow) that transfer water between the stores. The health and functional capacity of the water cycle thus depends on complex dynamics that link the land, water and atmosphere. Water quality and quantity are both associated with the water cycle and are discussed in Section 19.5.2.8.

In Scotland precipitation has increased substantially since a dry period in the early 1970s, winter precipitation being notably higher, especially in the western Highlands (SNIFFER 2006). Rainfall seasonality has also changed with wet winters (November–April) increasingly common over the last 30 years. Intensity of rainfall has also increased. Changes in amount and seasonality of precipitation will alter hydrological regimes, the store and fluxes of the water cycle changing the timing and amount of water to accommodate. This changes the pattern of river flow throughout the year and can lead to increases in both flooding and drought. **Figure 19.24** shows the changes in mean daily discharge for winter, spring, summer and autumn for the River Tay for the 1950s to 2000s and for the River Tweed for the 1960s to 2000s. Winter and autumn discharges have increased for the Tay and winter discharge has also increased in the Tweed. The summer discharge appears to show little or no change. Spring discharges are variable from decade to decade although the Tweed appears to show a trend of decreasing discharge while the Tay shows a trend to increased discharge.

Scotland's lochs have been estimated to store almost 35 billion m³ of water (Lyle & Smith 1994). Soils, especially peats, are also a significant store of water; the soils of Scotland are estimated to be able to hold a total of up to 42 billion m³ of water, more than is contained in the lochs.

The water cycle across Scotland is strongly influenced by topography, geographic variation in rainfall, the distribution of vegetation types, and the underlying soils and parent materials. Montane and Moorland habitats, which extend to about 45% of Scotland's land area, include 70% of the land area with an annual average rainfall in excess of 2,000 mm. The large extent of Montane and Moorland vegetation in the uplands of Scotland gives them a particularly important role in relation to climate and the water cycle, including an influence in both water quantity and quality. Upland Montane and Moorland habitats are distributed across the headwaters of many streams and rivers in Scotland; the hydrological characteristics of upland ecosystems can have important influences on both the quantity and quality of streams, rivers and lochs (Soulsby *et al.* 2002). Peatlands are also natural wetlands with a large water storage capacity that can act to moderate peak flows and discharge in rivers and streams, including in areas downstream. Peatlands also act as filters for chemical and particulate deposits, helping to clean water before it enters streams and rivers. Potentially this plays an important role in carbon storage. Increasing losses of dissolved organic carbon are being measured in rivers, particularly during autumn flows, and this is a cause for concern as it indicates that peatland systems possibly are releasing carbon.

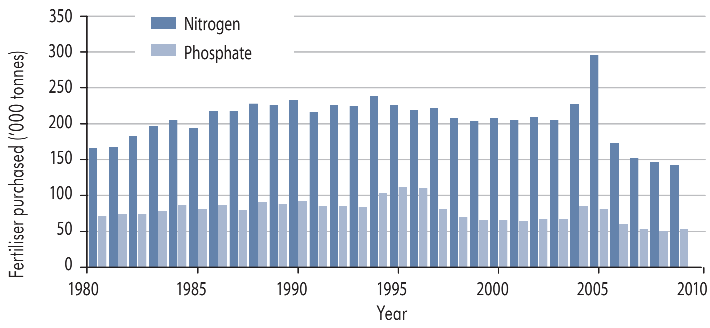


Figure 19.23 Nitrogen and phosphate fertiliser purchased by Scottish agriculture (1980–2009). Source: economic reports on Scottish agriculture, published by the Scottish Government.

19.5.1.4 Primary production

Primary production is the fixation of either atmospheric or aquatic carbon dioxide by plants and algae through the process of photosynthesis. Oxygen is released during photosynthesis, providing a critical component of the earth's atmosphere. A proportion of the carbon dioxide fixed by photosynthetic organisms is retained and the rest is lost in the respiration processes that maintain existing biomass. Gross primary production is the amount of organic carbon fixed. Net primary production is the amount retained after respiration. Net primary production is of greater relevance for ecosystem services because this is the component of primary production that it is available for food and timber harvesting in managed systems (Haberl *et al.* 2004; Haberl 2006), is the foundation of food webs in semi-natural and natural ecosystems, and underpins climate regulation by removing carbon dioxide from the atmosphere.

Primary production is influenced by a range of environmental conditions that affect plants and algae, notably temperature, sunlight duration and intensity, precipitation, and soil conditions including nutrients. Growth of plants is thus strongly seasonal. In grass systems about 50% of total annual production occurs during growth during about 8 weeks over May and June. A second flush of

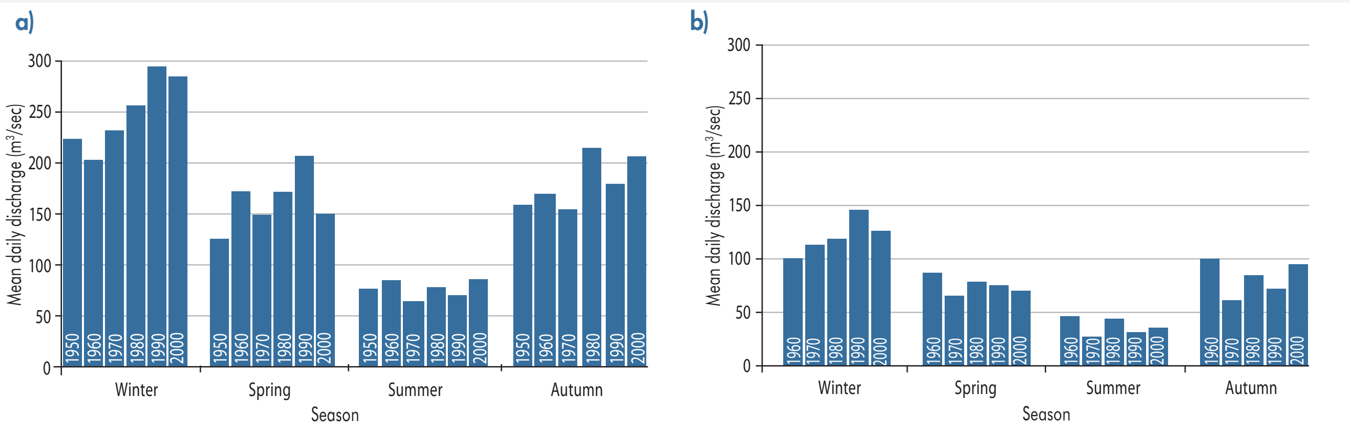


Figure 19.24 Mean daily discharge each decade from: a) the 1950s to the 2000s for the River Tay at Ballathie and b) from the 1960s to the 2000s for the River Tweed at Norham for winter (December–February), spring (March–May), summer (June–August) and autumn (September–November). Source: data provided by the Natural Environment Research Council, National River Flow Archive (NRFA). The Natural Environment Research Council, the Environment Agency, the Scottish Environment Protection Agency and the Rivers Agency (NI) accept no liability for any loss or damage, cost or claims arising directly or indirectly from their use.

growth of about 4 weeks' duration in July/August produces another 25% of total annual production. The remaining 25% of total annual production occurs over about 18 weeks in early spring, mid- and late summer (Hunt 1973).

The productivity of Scotland's coastal and marine areas similarly reflects the complexity of the physical environment. Primary productivity establishes the baseline productivity of the whole marine ecosystem. Estimation of annual primary productivity is important for understanding the function and health of coastal and marine ecosystems, and for understanding the sustainable yields.

Inorganic nutrient (nitrogen, phosphorus, silicon) and trace element (iron, copper) supply in the sunlit layers of the seas influences the amount of primary production that occurs through photosynthesis by phytoplankton, since nutrients and sunlight are required for plant growth. Production based on sources of new nutrients supplied annually to the ecosystem through transport, mixing or atmospheric deposition is termed 'new' production and represents the potential for growth and reproduction of higher trophic levels of the marine ecosystem (Baxter *et al.* 2008). Nutrients available through excretion from herbivores and bacterial decomposition of detritus are termed 'recycled' production, and represent the internal metabolism of the ecosystem itself. Estimates of annual primary new productivity in Scotland's seas over the past five decades (**Figure 19.25**) showed the highest rates to be in the Hebrides (90–170 grams of carbon per square metre per year, gC/m²/y), outer shelf areas in the West of Scotland (60–180 gC/m²/y), North Scotland Coast (60–130 gC/m²/y), and East Shetland (60–150 gC/m²/y). The lowest values were in inshore areas such as the Moray Firth (25–40 gC/m²/y), East Scotland Coast (30–50 gC/m²/y), Minches and Malin Sea (30–90 gC/m²/y), Irish Sea and Clyde (30–100 gC/m²/y), and towards the interior of the North Sea (Fladen Bank 40–70 gC/m²/y, Forties 40–80 gC/m²/y). Planktonic bacterial biomass shows seasonal and geographical variations in the North Sea related to phytoplankton development but with a delay of about 10 days (Billen *et al.* 1990).

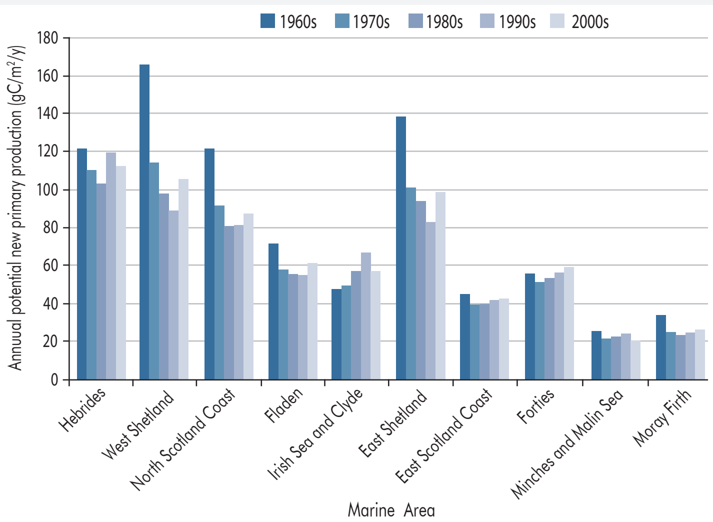


Figure 19.25 Annual potential new primary production (grams of carbon per metre square per year; g C/m²/yr) for marine areas around Scotland for each decade from the 1960s to the 2000s. Source: Baxter *et al.* (2008).

Globally, oceans contribute about half of net primary production (Wohlers *et al.* 2009) and Scotland's seas are potentially among the most biologically productive on the planet (SNH 2002, 2004a) and historically one of the richest fisheries (Lucas *et al.* 1961; Coull 1996). Economically, Scotland's seas are also highly productive (Baxter *et al.* 2008; UKMMAS 2010), economic productivity including £2.2 billion of marine related activity and 50,000 jobs (excluding oil and gas) to the Scottish economy (Baxter *et al.* 2008).

Climate change is expected to produce changes in carbon and energy flows within marine systems, altering the timing and magnitude of phytoplankton biomass production (Vargas *et al.* 2009). These changes may reduce the transfer of primary production to higher trophic levels, reducing fish and higher organism populations, and also weaken the ability of the ocean to act as a carbon sink (Wohlers *et al.* 2009). Changes in the distribution of plankton species that can be linked to climate changes are already evident in Scotland's seas. Warm water plankton have shifted their distribution northwards by about 10° latitude, cold water plankton retreating by the same amount (Edwards *et al.* 2007; UKMMAS 2010) linked to warming sea temperatures associated with climate change (Baxter *et al.* 2008).

19.5.2 Regulating Services

19.5.2.1 Climate regulation

Ecosystems regulate climate through biogeochemical effects that operate at regional and global scales, and through biophysical effects that operate at local and regional scales. For example, woodland has direct biophysical impacts on climatic regulation at local scales through effects on microclimate from shelter, shading and changes in evapotranspiration, as well as slowing wind speeds. In urban areas greenspaces may provide local cooling effects that ameliorate urban heat island effects (Bell *et al.* 2008; Gill *et al.* 2008), although wind is considered more of a problem in urban areas in Scotland (Bell *et al.* 2008). Biogeochemical effects arise from ecosystems acting as sources and sinks of greenhouse gases, and as sources of aerosols. Biophysical effects relate to the physical characteristics of ecosystems.

Ecosystems act as both sources and sinks of greenhouse gases depending on their management and condition. **Table 19.9** shows the sources and sinks of carbon dioxide, methane, and nitrous oxide for different land uses and ecosystem types for 1990 and 2007 in Scotland in megatonnes of carbon dioxide (Mt CO_2) equivalent (Mt CO_2e). The main land use and ecosystem sources of greenhouse gases are croplands, settlements and agriculture. In 2007 cropland in Scotland is estimated to have been a source of 6.6 Mt CO_2 and settlements 1.7 Mt CO_2 (12% and 3% respectively of the annual net emissions of 54.4 Mt CO_2 for Scotland in 2007). Agriculture releases carbon dioxide through fuel and agrochemical use, conversion of cropland and soil management, and releases methane and nitrous oxide through enteric fermentation in livestock (methane), manure management and management of agricultural soils (nitrous oxide). The total amounts of

Table 19.9 Greenhouse gas emissions from different land uses in Scotland for 1990 and 2007. All values are in mega tonnes of carbon dioxide equivalents (Mt CO_2e). CO_2: carbon dioxide; CH_4: methane; N_2O: nitrous oxide. Source: Jackson *et al.* 2009.

	1990			2007		
	CO_2 (Mt CO_2e)	CH_4 (Mt CO_2e)	N_2O (Mt CO_2e)	CO_2 (Mt CO_2e)	CH_4 (Mt CO_2e)	N_2O (Mt CO_2e)
Land uses, land use change and forestry						
Cropland	6.10			6.61		
Settlements	1.77	0.00		1.68	0.00	
Woodland and forestry	-8.30	0.00	0.01	-10.09	0.01	0.00
Grassland	-2.10			-2.65		
Total: Land uses, land use change and forestry	**-2.53**			**-4.45**		
Agriculture						
Soils: nitrogen management			4.91			3.55
Soils: other management	0.26	0.02	0.01	0.19	0.00	0.00
Fuel and agrochemical use	0.90	0.00	0.10	0.73	0.00	0.09
Cropland conversion	3.74			3.78		
Livestock: manure storage		0.38			0.37	
Livestock: enteric fermentation		3.13			2.79	
Total: Agriculture	**4.90**	**3.54**	**5.39**	**4.70**	**3.16**	**3.95**

these gases emitted by agriculture in Scotland have declined from 4.9 Mt CO_2e (carbon dioxide), 3.5 Mt CO_2e (methane) and 5.4 Mt CO_2e (nitrous oxide) in 1990 to 4.7 Mt CO_2e (carbon dixoide), 3.2 Mt CO_2e (methane) and 4.0 Mt CO_2e (nitrous oxide) in 2007 (Jackson *et al.* 2009). These are reductions of 4.0%, 10.7% and 26.8% over the 1990 total for carbon dixode, methane and nitrous oxide respectively and a total of 14.7% for agriculture in total.

Appropriately managed, Semi-natural Grasslands and Woodlands are important habitats for climate regulation through sequestration and storage of carbon. Grasslands sequester carbon below ground in soils and roots (Leake *et al.* 2006) while Woodlands add the timber volume as an important carbon store. Both Semi-natural Grasslands and Woodlands currently act as net sinks of carbon dioxide in Scotland (DECC 2009; Jackson *et al.* 2009). In 2007 Semi-natural Grasslands in Scotland are estimated to have been a net sink for 2.7 Mt CO_2 (Jackson *et al.* 2009); this is about 5% of the annual net carbon emission of 54.4 Mt CO_2 produced in Scotland in 2007. Woodlands are estimated to have been a net sink for 9.3 Mt CO_2 in Scotland in 2007 (Jackson *et al.* 2009), about 17% of the annual net carbon emissions.

Peat soils can also act as a sink and store of carbon and thereby contribute to climate regulation. The current rate of carbon fixation for peatland in the UK is difficult to determine but it is likely to between 0.3 Mt C/yr (Chapter 14) and 0.7 Mt C/yr (Cannell *et al.* 1999). The higher rate is for peatlands that are in good condition. Drainage, agriculture and peat cutting, overgrazing of peatland vegetation and erosion result in loss of carbon from peatlands, estimates of loss in the UK being about 1.0 Mt C/yr (Cannell *et al.* 1999). Loss of carbon is both to the atmosphere as carbon dioxide and to waters as dissolved organic carbon and particulate organic matter. **Figure 19.26** shows the topsoil organic carbon contents of Scotland's organic and mineral soils.

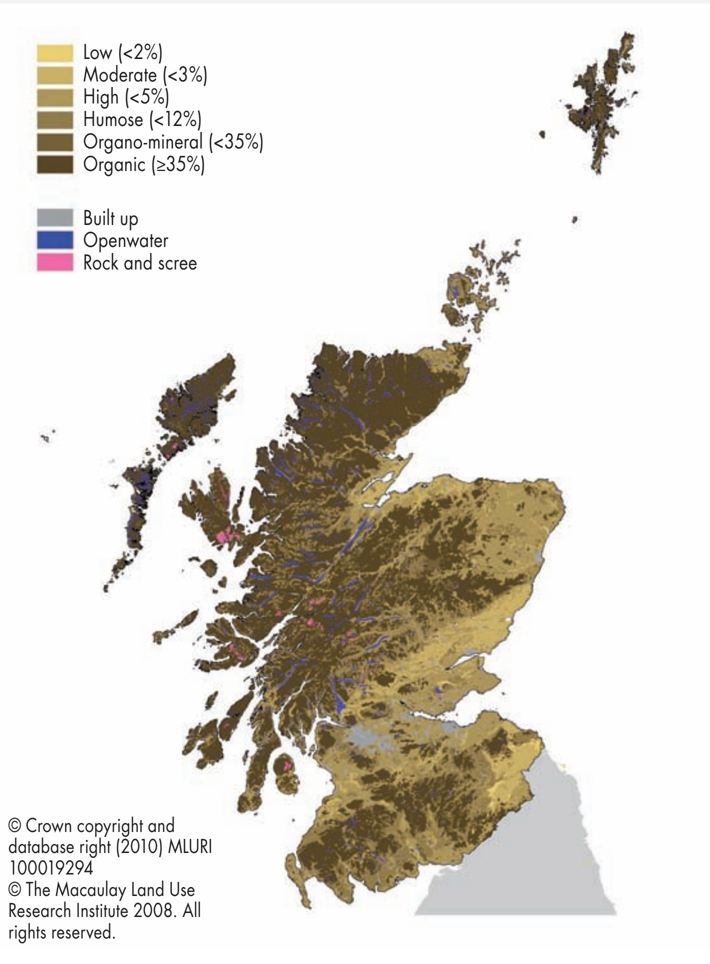


Figure 19.26 Topsoil organic carbon content of Scotland's soils. Source: Macaulay Land Use Research Institute.

The marine environment, including Scotland's large marine area, also contributes to regulation of global atmospheric carbon. Sea water stores carbon, although it becomes increasingly acidic as carbon dioxide is absorbed (Brierley & Kingsford 2009). Threats to the integrity of marine and coastal ecosystems occur throughout Scotland's seas. Land based activities, notably nitrate enhanced runoff to estuaries, has a direct impact on water quality and sediments, and leads to an increase in mat-forming macro-algae and decreases in invertebrates and shorebirds (Raffaelli 1999a; Raffaelli *et al.* 1999). The role of decomposition and the composition of the decomposer community in Coastal Margin habitats has important implications for biogeochemical nutrient cycling in estuarine systems (Godbold *et al.* 2009), but is little studied.

The marine environment, together with the same hemisphere-scaled climate and oceanic factors that influence the nature of Scotland's marine ecosystems (Section 19.4.6), has a considerable influence in regulation of the weather and climate on Scotland's land-based ecosystems. Climate is moderated in summer and winter, marine and coastal influences on weather being particularly apparent.

19.5.2.2 Hazard regulation

Environmental hazards are a function of topographic, geomorphic and weather conditions as well as human activities. Functioning ecosystems help to regulate many of these hazards.

Coastal areas receive natural protection from flooding and erosion by beaches, dunes and salt marshes through natural processes that reduce energy from waves and protect inland areas from seawater. About 12% of Scotland's coastline is experiencing erosion (Masselink & Russell 2008), this representing not only a significant loss of coastal habitat but also reducing the capacity for regulation of coastal hazards. The ability of coastal landforms and habitats to regulate erosion is threatened by sea-level rise, by changes in frequency and severity of storms, and by low sediment availability (de la Vega-Leinert & Nicholls 2008) associated with lack of supply (Hansom 2001; Orford & Pethick 2006) evidenced by coastal steepening (Hansom 2010). Sea-level rise is also apparent in Scotland (Pethick 1999). Recent analysis suggests that isostatic uplift of the Scottish land mass no longer reduces the adverse effects of sea level rise on the Scottish coast. Relative sea level rise rates of between 2.6 and 6.2 mm/yr have been observed in Scotland since 1992 (Rennie & Hansom 2011), higher than the longer-term averages for the 20th Century. The consequences of such rates of relative sea level rise potentially include relocation of coastlines to areas currently well inland. Strategic planning in Scotland will need to address the consequences of more rapidly rising regional relative sea level rises, also recognising that coastal changes associated with sea level rise expected over the next several decades are likely to differ markedly from those in the past (Rennie & Hansom 2011).

Flooding is also increasing in frequency in riparian floodplain areas in Scotland as more intense rainfall events and changed seasonal rainfall patterns (SNIFFER 2006) alter hydrological regimes of catchments. Floodplains are a natural geomorphic response to high flows in rivers. However, many human activities are located on floodplains, including housing and agriculture. Increasing urbanisation of floodplains is a particular issue. Urbanisation exacerbates flooding by shortening the time for water to reach rivers and increasing the peak flows, which increase the incidence and magnitude of floods (Charlesworth *et al.* 2003). Locating homes and other buildings in floodplains puts these structures and populations in areas prone to the very severe flooding that the urbanisation exacerbates.

Flooding and erosion of the land surface both add materials and nutrients to water, increasing chemical and physical particulate pollution (Stutter *et al.* 2008). This also contributes to soil degradation. Erosion in upland Scotland occurs on about 12% of the land area studied (**Table 19.10**). The most significant form of erosion is peat erosion (Grieve *et al.* 1995), its severity varying geographically with the most severe erosion being in areas of eastern Scotland. Grieve *et al.* (1995) also found gully erosion of slopes on mineral soils in almost 5% of the area they sampled, particularly in areas with large variation of relief.

Regulation of flood impacts is not only an issue of water quantity, but also is a social and economic issue. Increasingly, attention is being focused on a catchment-wide approach to reducing flood risk. For example, the new Flood Risk Management (Scotland) Act 2009 examines the potential for interventions in upstream land management alongside the more traditional solutions found in engineering and flood defences downstream. This approach places the regulating capacity of wetlands to the fore, with upland bogs, afforested hillsides, floodplain wetlands and valley woodlands all potentially being available to reduce the generation of overland flow, store excess water, and slow the movement of flood waters and sediment downstream. The science behind these practices is still developing, but it may be possible to use improved understanding of freshwater ecosystems and catchment hydrology to manage the risk of increased floods.

19.5.2.3 Disease and pest regulation

The main drivers of disease and pest incidence since 1945 have been agricultural intensification, accidental (and

Table 19.10 Estimated extent of soil erosion in upland Scotland (1988–1989). Source: Grieve *et al.* 1995.

Erosion type	Proportion of total sampled area (%)	Ranges amongst 16 regions (Proportion (%) of sampled area)
Eroded peat	6.02	0.47–20.43
Gullied area	4.69	0.00–15.40
Debris flow/cone	0.61	0.00–6.80
Sheet erosion	0.61	0.00–2.71
Landslide	0.08	0.00–0.35
	Density (m/km²)	**Ranges amongst 16 regions (m/km²)**
Linear gullies	80	0–236
Vehicle tracks	40	0–183
Footpaths	5	

deliberate) introduction of pest and pathogen organisms, and changes in both land and wildlife management (Chapter 14). In future, changes in climate are also likely to become an important driver, as has recently been shown for vector-borne diseases (Purse *et al.* 2007; Lancelot *et al.* 2009; Gilbert 2010). Analysis of Biological Records atlas data for the UK and Scotland showed that at least 12% of the flora of Scotland had changed significantly between the 1930–1960 period and the late 1980s, while introduced species had increased (Rich & Woodruff 1996).

Agricultural intensification with more frequent use of broad spectrum herbicides has resulted in the decline of the traditional weeds at the base of the arable food web but an increase in other species, often crops such as oilseed rape, becoming weeds of different crops (Squire *et al.* 2009). Agricultural intensification with high densities and extensive areas of homogenous crop genotypes provides ideal conditions for both higher incidence of pests and diseases and their spread across the landscape (Matson *et al.* 1997). Similarly, intensification of livestock systems and long-distance transport of animals for slaughter and sale provides conditions in which diseases such as Foot and Mouth Disease can spread rapidly (Gibbens *et al.* 2001). High density salmon farming in fish farms has been shown to have an impact on wild salmon catch and abundance. The survival and abundance of wild salmon and sea trout are reduced in areas with salmon farming, most probably by pathogens, parasites and diseases spreading from the farmed to the wild fish (Ford & Myers 2008).

Climate change may alter the incidence of diseases, pests, pathogens and the various vectors of disease in future. This may allow new diseases and pests to become established as their geographic range expands to include Scotland and conditions within Scotland become more conducive to spread of disease. For example, bluetongue virus, a pathogen of ruminants transmitted by *Culicoides* midges, has spread rapidly across Europe since 1998 and was first detected in Scotland in September 2007. In part, the rate and extent of spread of bluetongue virus was probably underestimated because of the limitations of surveillance methods used (Carpenter *et al.* 2008). It is also possible that the disease is now spread by a wider range of species of *Culicoides* than previously known, for example with ranges throughout northern Europe (Purse *et al.* 2007) including Scotland. There is evidence of new strains of diseases such as bluetongue virus as a response to vaccines used for management of the disease (Carpenter *et al.* 2009). Further climate change could support the establishment of other diseases in Scotland such as African horse sickness, partly through changes in the susceptibility of European midge species to infection (Chapter 14).

Lyme disease, a tick-borne infection, has increased in incidence in Scotland. Changes in the incidence of Lyme disease may be associated with expansion of woodland and scrub habitat, with an increase in deer numbers associated with milder winters and earlier spring linked to climate change. As deer are reproductive hosts for adult ticks (Gilbert 2010), changes in incidence of Lyme disease may also be linked to increased public access to areas of woodland and scrub habitats where deer occur.

Global trade in plants and animals also provides a mechanism for the spread and establishment of diseases and pests (Brasier 2008). *Dickeya dianthicola* is a disease which causes soft rots in potato and is transmitted via infection from a host, soil, and water (Toth & Elphinstone 2009). The disease was reported from the Netherlands in the 1970s and was first found in English seed potatoes in 2001. It has since been recorded in Scotland. Scotland is the centre of the UK seed potato industry and seed certification has been used to protect the Scottish crop. With the arrival of *D. dianthicola* in the UK and Scotland, certification appears insufficient to protect against the disease and research on prevention and treatment is urgently needed.

Dutch elm disease (*Ophiostoma novo-ulmi*) is known for its impact on the UK landscape. Similarly, *Phytophthora ramorum* and *P. kernoviae* are invasive fungal pathogens that are known to cause death in over 130 species of tree and shrub including oak, beech, *Rhododendron* and *Vaccinium*. The disease is also known as Sudden Oak Death for its impact on oak species on the west coast of the USA (Condeso & Meentemeyer 2007; Meentemeyer *et al.* 2008). *Phytophtora* was first recorded in the UK in 2002 and probably spread from garden centres. The pathogen presents a threat to moorland and heathland vegetation in Scotland as it has already been established that it infects *Vaccinium myrtillus* (Beales *et al.* 2009), a common plant in communities associated with heathland habitats and in which other species may also be susceptible.

There are many other diseases of specific plants, crops and animals that are dispersed through the environment and that affect human health and well-being. Lyme disease and a variety of gastrointestinal bacteria from farm animals, notably *Campylobacter* and *Escherichia coli* O157, and protozoan parasites such as *Giardia* species and *Cryptosporidium* species can all infect humans (Smith *et al.* 2006).

The capacity of ecosystems to regulate diseases and pests is thought to depend on different components of biodiversity, including habitat diversity, species richness, host and vector population densities, and genetic diversity (Chapter 14). Relationships between biodiversity and pest and disease regulation remain a significant knowledge gap. Active surveillance programmes are necessary to monitor the incidence of diseases already known to be present but also diseases that may establish themselves in Scotland.

19.5.2.4 Pollination

Pollination is both biotic (mainly bees and other insects) and abiotic (primarily wind). In 2007, crops dependent on insect pollination[7] were grown on about 7.5% (oilseed rape 6.5%) of the total cropped area of Scotland. Consumers are also dependent upon pollination services contributing to imported foodstuffs, since the UK only produces a small proportion of its own pollinator-dependent crop products. The production value of pollinators to Scottish agriculture can be estimated with methods developed by Gallai (Gallai *et*

7 Including oilseed rape, berries, currants and orchard fruit.

al. 2009) and is, conservatively, about £43 million per annum (**Table 19.11**); this is about 5% of the value of all crops grown in Scotland or almost 9% of the value of horticulture and crops other than cereals.

Most of the wild plants that make up the vegetation of Semi-natural Grasslands, Mountains, Moorlands, Heathlands, Woodlands, and Coastal Margin habitats are also dependent on pollination. Between 62% and 73% of species are pollination limited (Burd 1994; Ashman *et al.* 2004). At a UK level there has been a greater decline in plants pollinated by bees and hoverflies than in self- or wind-pollinated species (Biesmeijer 2006), while 76% of plants used for forage by bumblebees have decreased in both range and frequency (Carvell *et al.* 2006).

Honeybees (managed bees) and wild pollinators (non-managed bees, bumblebees and hoverflies) have declined over the last 30 years (Goulson *et al.* 2005). Causes of decline include agricultural intensification (Fitzpatrick *et al.* 2007; Potts *et al.* 2009), inappropriate use of agro-chemicals, loss of semi-natural habitat (Goulson *et al.* 2005; Pywell *et al.* 2005), pathogens, and climate change (Williams 2005). Managed colonies of honeybees (*Apis mellifera*) which are used principally to provide honey although also providing pollination services, have declined seriously since 1985 (15% reduction by 2005 (Potts *et al.* 2010). Honeybees are not as effective at pollinating crops (berries, fruit) as wild pollinators (Free 1993). The value of pollination services in non-agricultural ecosystems is not yet known but is likely to be high, not least because these ecosystems provide a reservoir of wild pollinators that are beneficial in all ecosystems.

19.5.2.5 Noise regulation

Noise regulation describes the capacity of an ecosystem to reduce unwanted sounds that can have a negative effect on human well-being and other species. Most studies of the noise environment are conducted in urban areas (Bolund & Hunhammar 1999; Koren & Butler 2006) or in relation to air, road and rail traffic , although noise impacts of wind turbines are also receiving attention on land (Keith *et al.* 2008) and in underwater coastal and marine environments (Gill 2005).

Table 19.11 Estimated economic value of pollination services to agriculture in Scotland in 2007. Source: from Agricultural (June) Census data for Scotland (Rural and Environment Research and Analysis Directorate 2009c) using the method of Gallai *et al.* 2009.

Crop	Dependence on Pollinators (%)	Value per annum (£ million)	Value due to pollination per annum (£ million)
Oilseed rape	25	38.40	9.60
Strawberry	45	38.92	17.51
Raspberry	45	15.73	7.08
Blackcurrant	25	3.23	0.81
Orchard Fruit	65–85	4.82	3.62
Protected crops	0–40	33.20	4.98
Total		**207.97**	**43.60**

Road construction can lower property prices, a study in Glasgow showing a 0.2% decrease in property price for each decibel increase in road noise (Lake *et al.* 2000). Trees, non-woody vegetation and soil bunds can dampen noise, reducing the decibel levels, especially from road traffic.

In Scotland, maps of noise have been produced that model the noise from traffic at a postcode level in Edinburgh and Glasgow (www.scottishnoisemapping.org/). This is part of Scotland's response to the European Environmental Noise Directive[8] (END). The Directive also requires the relevant authority to draw up action plans to 'reduce noise where necessary' and 'maintain environmental noise quality where it is good'. Models are useful for this but measurements of noise in the environment are limited, especially in rural areas.

19.5.2.6 Soil quality regulation

Maintenance of soil quality is an important regulating service, along with air and water quality. Many of the benefits of soils in storage, capture and release of carbon, nutrients and water have been described under the supporting services of soil formation (Section 19.5.1.1) and nutrient cycling (Section 19.5.1.2) in Supporting services. Soil quality measures the capacity of soils to regulate environmental functions.

The capacity for soil to provide regulating services is related to its function, which is dependent on its physical integrity, chemical composition, the structure and activity of soil biodiversity. The inherent regulating capacity of soil varies with soil type. The capacity of soils to buffer against atmospheric deposition has been used to identify critical loads, notably for acid deposition (Langan & Wilson 1994; Metcalfe *et al.* 1995; Tervet *et al.* 1995).

Indicators of soil quality relevant to regulating services in Scotland have been reviewed for monitoring purposes and to support policy decisions (Aalders *et al.* 2009). Current assessment of soil quality and trends in Scotland depends on large-scale and long-term surveys and experiments such as the National Soils Database for Scotland maintained by the Macaulay Land Use Research Institute and the National Soil Inventory for Scotland.

19.5.2.7 Air quality regulation

Ecosystems can have positive effects on air quality through interception, deposition and removal of pollutants present and transported in the atmosphere. The main atmospheric pollutants of concern are particulate matter, ozone, nitrogen oxides, ammonia and deposition of nitrogen and sulphur. All of these except sulphur deposition can have effects on human health. Ozone also reduces crop and forest yields and can lead to changes in the species composition of vegetation. Nitrogen (nitrogen oxides, ammonia, deposition) can cause eutrophication and acidification of ecosystems, and sulphur causes ecosystem acidification. The percentage of sensitive habitats in Scotland at risk from atmospheric acid and nitrogen deposition from 1996–2007 to 2004–2006 are shown in **Figure 19.27**. Between 40% and 50% of sensitive habitats remain at risk.

8 European Parliament and Council Directive for Assessment and Management of Environmental Noise 2002/49/EC.

Atmospheric pollutants are not independent of one another, oxidised nitrogen playing a role in the formation of ozone near the ground surface (Fowler *et al.* 1998). In coastal areas particulate matter is dominated by sodium chloride from the marine environment, while in urban areas local element carbon, soil, ammonium sulphate, ammonium nitrate and organic hydrocarbon dominate (Gibson *et al.* 2009).

The recent trends for atmospheric pollutants in different regions of Scotland are shown in **Figure 19.28**. Particulate matter and sulphur dioxide are decreasing. Ground level ozone and nitrogen dioxide are more variable and show no clear trend. Improvements in air quality are mainly due to reduced anthropogenic emissions.

19.5.2.8 Water quality regulation

The capacity for water quality regulation is related to catchment characteristics and hydrological processes, including plant and microbial nutrient cycling, pollutant input, storage breakdown and transport, buffering of acidity and denitrification. Many habitats, such as grasslands, are important for the regulation of water quality and quantity. Upland grassland regions of Scotland are a main water

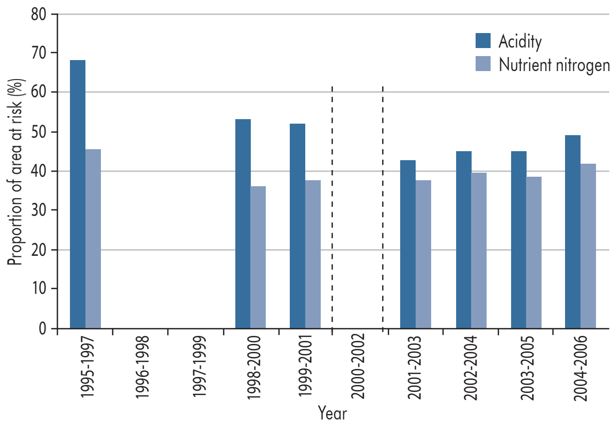


Figure 19.27 Proportion of area of sensitive habitats at risk from acid and nutient nitrogen deposition 1995–1997 to 2004–2006. Source: Centre for Ecology and Hydrology (2011). © NERC (CEH). Three-year averages are used to reduce substantial year to year variability. Deposition data for 1995–1997 to 1999–2001 are based on the same methodology; data for 2001–2003 onwards also include nitric acid and those from 2002–2004 onwards include aerosol deposition of ammonium, nitrate, and sulphate.

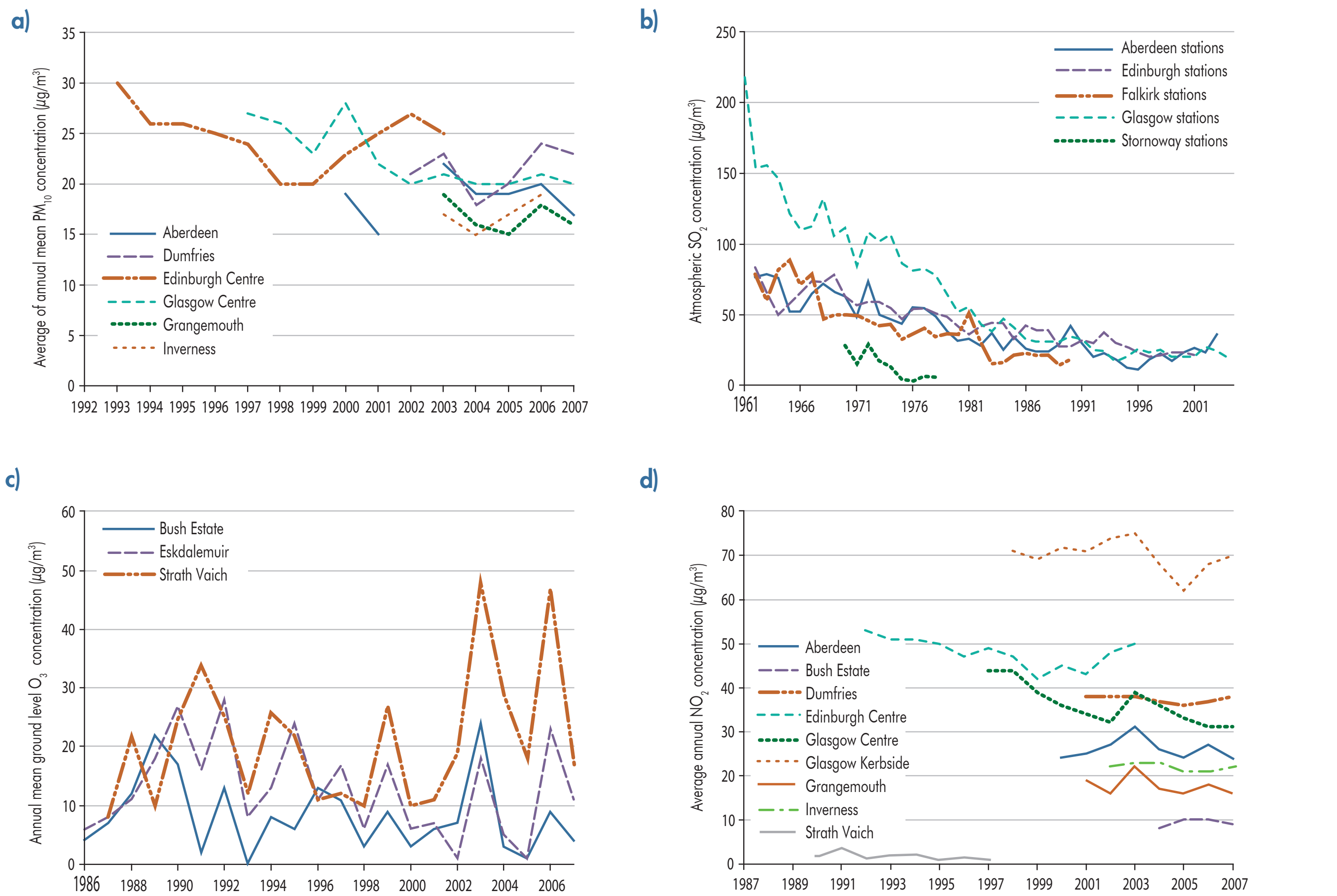


Figure 19.28 Trends in atmospheric pollutants in Scotland: a) particulate matter (PM_{10}) concentrations (1992–2007), b) long-term atmospheric sulphur dioxide (SO_2) concentrations (1961–2004)*, c) ground-level ozone (O_3) concentrations (1986–2007), d) nitrogen dioxide (NO_3) concentrations (1987–2007) in micrograms per cubic metre (µg/m³). Source: UK National Air Quality Information Archive (2011). *Measurements are made using the non-automatic Net Acidity method, expressed as SO_2 equivalent. In recent years as ambient levels of SO_2 have fallen this method has increasingly tended to overestimate actual SO_2.

source, not only locally but also for cities and lowland areas, water falling on and flowing through upland grassland habitats being stored in reservoirs and rivers to support Scotland's piped water supply.

About 65% of the 3,095 water bodies surveyed in Scotland by SEPA achieved good or better ecological status, with rivers at 57%, lochs 66% and groundwater 76%. Diffuse pollution, largely from agricultural sources, and hydromorphological modification of channels and banks (often historic) are the two main reasons for failure to meet good ecological status of water in Scotland. The majority of failing waters are in the Central Belt, despite improvements achieved from better treatment of sewage, closure of polluting heavy industries, and from areas of improved agriculture (Doughty *et al.* 2002).

Until the late 1980s lochs were sparsely monitored, but the current network has improved this situation. One particular aspect of loch waters, acidification of freshwaters by sulphur and nitrogen oxide deposition in the 1970s and 1980s, has seen more focus, and resulted in the establishment of the UK Acid Waters Monitoring Network in 1988 which included six lochs and three stream sites in Scotland. Acidification had marked effects on aquatic food webs. There was a reduction in aquatic invertebrate abundance and diversity, and resultant low reproductive success and population density of predatory species such as dippers (*Cinclus cinclus*) on acidified streams and rivers (Vickery 1991, 1992). The more systematic survey of loch water quality by the UK Acid Waters Monitoring Network led to numerous scientific investigations of causes and changes and the 15-year report from the UK Acid Waters Monitoring Network (Monteith 2003) reveals evidence of biological recovery at some sites and a modest chemical response. Changes in diatom and invertebrate communities at Loch Chon and Loch Grannoch indicate that recovery from acidification is in progress. The general pattern of recovery from acidification was associated with a rapid decline in the deposition of non-marine sulphate (by over 50%) and emissions of nitrogen oxides (by 14%; see Montieth & Evans 2000). It appears that the acid neutralising capacity of lochs is recovering as water improves (Ferrier *et al.* 2001).

When the capacity of an ecosystem's plants and microorganisms to assimilate, buffer and process pollutants, or of soils to sequester them, is exceeded, the ecosystem loses its ability to purify water and water quality associated with the ecosystem is degraded. Drainage can dilute pollutants (e.g. from point sources) to safe levels, store pollutants in (e.g. in lochs and wetlands), or transfer pollutants from the land to the ocean. Estuarine pollution is typically caused by land-based pollution. This is often associated with agricultural activity, for example in the Ythan estuary in north-east Scotland (Domburg *et al.* 1998; Raffaelli 1999b; Raffaelli *et al.* 1999; Raffaelli 2000; Green 2005; Sang 2008), and Firth of Forth (Marsden *et al.* 1997), with petrochemical and other heavy industries in the Forth (Sulaiman *et al.* 1991) and Clyde (Edgar *et al.* 1999), and from sewage in the Tay (Owens & Balls 1997; Reeves & Patton 2005).

Direct long-term monitoring is needed of the ecosystem processes which regulate water quality. Most monitoring is carried out on rivers that drain large, mixed catchments, notably the Harmonised Monitoring Scheme (HMS) including 56 catchments that are a subset of the rivers monitored by SEPA. There are no HMS catchments on islands, nor are there sufficient catchments draining to the west of Scotland in the HMS catchments. The catchments in the HMS are influenced by direct pollutant inputs from agricultural and other land uses.

Catchment monitoring was started by the Scottish River Purification Boards in the mid-1970s and has been continued by SEPA since 1996. Concentrations and fluxes of pollutants have been analysed together for the HMS rivers. Monthly, seasonal and annual trends in physical and chemical parameters of these Scottish rivers are presented in an Atlas of River Water Quality in Scotland (Anderson *et al.* 2010). Physical parameters include river flow, water temperature and suspended sediments; these are affected by changing climate. Suspended sediment is also affected by changing agricultural practice and urban sewage treatment processes. Chemical parameters include Biochemical Oxygen Demand (BOD), ammoniacal nitrogen and total phosphorus concentrations. Biochemical oxygen demand is a broad measure of water quality, high levels of BOD being associated with industrial and sewage pollution. Ammoniacal nitrogen comes from fertilisers, livestock and sewage. High total phosphorus concentrations indicate that a river is affected by sewage, industrial activity or agricultural runoff.

Two opposite trends are apparent in the annual concentration of suspended solids in Scotland. Concentrations are declining in catchments in the centre and south of the country, probably as a result of improvements in sewage treatment and industrial processes. Concentrations are increasing in the north east, possibly related to increased erosion. This pattern is more obvious in trends for spring when the timing of the increase coincides with increased land management activity in rural and agricultural catchments.

Biochemical oxygen demand has declined in almost all rivers in Scotland, although there are possible increasing trends in BOD concentrations in the Water of Leith and the River Tyne. Concentrations of ammoniacal nitrogen are declining in rivers across Scotland, although the River Don shows an increasing trend. The flux of ammoniacal nitrogen shows a different trend, as the trend to increasing flow in many rivers offsets some of the reductions in concentration.

Total phosphorus concentrations are very low in rivers in the north of Scotland and are higher in agricultural and urban areas. High total phosphorus concentrations in summer are linked to sewage effluent, while high concentrations in winter and spring are mainly associated with sediment losses from agricultural catchments. Concentrations of total phosphorus are declining in many urbanised rivers, an improvement in water quality associated with improved sewage treatment and reduced use of phosphate-containing detergents. Increases in total phosphorus flux in summer in some catchments are linked to historical patterns of fertiliser use, increases in the total volume of sewage discharges in northern areas and climate change.

Water quality in upland ecosystems (Montane, Moorlands, Semi-natural Grasslands) is strongly coupled to ecosystem processes, but poorly recorded in standard monitoring regimes. Although upland waters are not subject to agricultural impacts to the same extent as lowland ecosystems, water in upland areas is subject to other environmental pressures, including atmospheric deposition. Upland areas also contain important wetland and aquatic habitats and are a major source of clean drinking water for urban areas. Being relatively unpolluted, water draining the uplands performs a key regulatory service by diluting pollution before it travels downstream in river systems.

A variety of specific ecosystems can also contribute to water quality regulation. Woodlands can help to regulate both water quality and quantity, floodplain woodland contributing to flood control by slowing water velocities and rates of runoff. Freshwater ecosystems also regulate the quality and quantity of water, including flood and drought management.

The main threats to the regulating capacity of freshwater systems in Scotland for water quality, and for flood and drought moderation via water quantity regulation, are land management and land use changes. These include conifer afforestation, although forest management guidelines (Forestry Commission 1993) and modern management practices are a significant improvement (Nisbet *et al.* 2002). Other land use related issues include diffuse pollution from agriculture, especially nitrate in ground and surface water (Ball *et al.* 2005). Identification of NVZs (Edwards *et al.* 2003), adjustments to management practices (Rode *et al.* 2009) and, potentially, management and modification of forage (Abberton *et al.* 2008), can all contribute to management and reduction of diffuse pollution in freshwaters. Locally, environmental pollution associated with fish farming can damage freshwater ecosystems (Allcock & Buchanan 1994; Bailey-Watts 1994).

The regulating capacity of water systems does not depend solely on land use and other activities in the catchment area. The function of the water ecosystem itself is also of importance (Baron *et al.* 2002). Losses and reductions in native biodiversity associated with pollution events and earlier periods of acidification and pollution (Doughty *et al.* 2002) have altered the biological capacity of rivers and lochs. Fish species have been lost or shown considerable declines (Doughty *et al.* 2002), macro-invertebrates (Fozzard *et al.* 1994) and aquatic flora (Palmer *et al.* 1994) have also declined. There is little evidence of biological recovery of freshwaters from earlier damage (Doughty *et al.* 2002). Alien species and eutrophication are of increasing concern (Holbrook & Hall 2002), particularly the spread of non-native invasive aquatic species such as signal crayfish (*Pacifastacus leniusculus*), and riparian invasives such as Australian stonecrop (*Crassula helmsii*), giant hogweed (*Heracleum mantegazzianum*), Himalayan balsam (*Impatiens grandulifera*) and Japanese knotweed (*Fallopia japonica*). The biological components of freshwater ecosystems are recognised as centrally important elements of system health, contributing to the effectiveness of freshwaters in regulatory services (Palmer 2009; Palmer & Filoso 2009).

19.5.3 Provisioning Services

Provisioning services—the products that we obtain from ecosystems for human use—are very well known in comparison with most other ecosystem services. They include a variety of foods, as well as raw materials for food, fibre, timber and forest products, peat for fuel and horticulture, ornamental resources such as flowers, genetic resources, water and renewable energy. Many of the products making up provisioning services have been recorded on an annual basis for a considerable period. This means that it is possible to track changes in many of the provisioning services of Scotland over time with some accuracy, and in more detail than the other ecosystem services (supporting, regulating and cultural).

19.5.3.1 Food from agriculture

Table 19.12 shows the mean annual value of output for the period 2004–2008 and the mean percentage of agricultural output for the period 2000–2008 for different components of agricultural production in Scotland. Agricultural output is about £1.8 billion for raw materials before further value is added.

Crops. During the 2000s crop production accounted for about 27% of the value of agriculture in Scotland (see **Table 19.12**). The major crops at present are cereals, especially barley and wheat, potatoes, vegetables and soft fruit.

Cereals. **Figure 19.29a** shows the change in area planted with wheat, barley and oats in Scotland since 1940. Three major changes are clear in this record. First, there has been a considerable decline in the area of oats planted, starting in the 1940s. Second, as the area of oats declined there was an increase in the area of barley to a peak in 1980. Third, there has been an increase in the area of wheat since the 1980s, largely on land previously used for barley. These changes are associated with i) rapid mechanisation of agriculture following WWII; ii) a corresponding decline in the number of agricultural horses as mechanisation replaced horses with tractors for farm work; iii) improved varieties of barley and wheat that are productive under a wider range of environmental conditions in Scotland; iv) changed husbandry methods, including artificial fertilisers, herbicides and pesticides; and v) changes in policy, particularly price support for wheat and barley under the Common Agricultural Policy (CAP) in the 1980s. Additionally there has been an increase in the relative proportion of winter sown barley during the last three decades. This has had a detrimental effect on wintering farmland birds (Tucker 1992; Perkins *et al.* 2008). Retention of winter stubbles in spring sown cereal fields may also be important in reducing soil erosion.

A further characteristic of the changes in planting with cereals in Scotland is that the total area has changed relatively little, even though the balance of wheat, barley and oats has changed dramatically. Despite this relatively constant cropped area, the effective area for crop production has increased in Scotland since the 1940s. Leach (1976) has estimated that about 30% of the area of the oat crop was used to feed the livestock that were used for work on the farms. Mechanisation has meant that land previously used to grow food for horses is now used to produce cereals (wheat and barley) for human uses and as feed for meat production.

Figure 19.29b shows the mean annual yield of wheat, barley and oats since 1940. Oats have increased from an average of about 2 tonnes/ha in the 1940s to 5.5 tonnes/ha since 2000, barley from 2.5 tonnes/ha in the 1940s to 6 tonnes/ha since 2000, and wheat from 2.8 tonnes/ha in the 1940s to over 8 tonnes/ha since 2000. Yields for all three

Table 19.12 Mean annual economic value of agricultural products (2004–2008) and mean percentage contribution of agricultural products to total agricultural output by value (2000–2008). Source: economic reports on Scottish agriculture, Scottish Government.

	Agricultural product	Mean annual value of output between 2004–2008 (£ millions)	Mean annual contribution to total agricultural output (2000–2008) (%)
Cereals			
	Wheat	88.9	4.6
	Barley	178.6	10.6
	Oats	11.4	0.7
	Total: Cereals	**279.7**	**15.9**
Other Crops			
	Potatoes	184.9	8.7
	Fodder crops	9.5	0.5
	Oilseed rape	27.5	1.6
	Total: Other Crops	**501.1**	**26.7**
Horticulture			
	Vegetables for human consumption	86.2	4.1
	Soft fruit	61.5	2.6
	Flowers, bulbs, nursery stock	49.7	2.5
	Total: Horticulture	**197.4**	**9.2**
Livestock			
	Cattle	453.3	28.3
	Sheep	145.6	10.0
	Pigs	59.9	3.5
	Poultry	78.2	4.7
	Total: Livestock	**752.6**	**47.5**
Livestock Products			
	Milk and milk products	265.6	14.4
	Eggs	33.8	1.8
	Clipwool	3.3	0.2
	Total: Livestock Products	**305.9**	**16.6**
	Total: Livestock and Livestock Products	**1058.4**	**64.1**
All Agricultural Products			
	Total: Agricultural Output Value	**1756.9**	

crops have increased as a result of technological changes driven by scientific research, including breeding of new varieties and changed husbandry methods.

Crop production is a function of area planted and yield. **Figure 19.29c** shows the annual production of wheat, barley and oats for Scotland. The annual production of oats has declined from over 800,000 tonnes in the 1940s to less than 120,000 tonnes since 1990. Barley production was 10 times higher in the 2000s than it was in the 1940s (average of 176,000 tonnes in 1940s to 1.8 million tonnes in the 2000s, with a peak in the 1980s of over 2 million tonnes). Wheat increased from 117,500 tonnes in the 1940s to over 800,000 tonnes in the 2000s. In 2009 cropping contributed about 21% of gross agricultural output, the same proportion as in 2000 (22%; Rural and Environment Research and Analysis Directorate 2010). Barley is the leading cash crop in Scotland, accounting for 10.6% of agricultural output since 2000 (wheat: 4.6%).

Cereals are used for human consumption, for distilling and malting, and for stock feed. In 2007, a report for the Scottish Government noted that about half of the wheat crop and 33% of the barley crop is used for distilling and malting (DTZ 2007). Between 2000 and 2008, 13.8% of wheat, 64.2% of barley, and 13.1% of oats were used as stock feed (1964–1972 figures: wheat 47.6%; barley: 52.2%; oats: 33.7%).

Potatoes. The area planted with potatoes has fallen from a peak of almost 100,000 ha during the later years of WWII to about 30,000 ha since 1990 (**Figure 19.30a**). **Figure 19.30b** shows the increase in potato yields (averaged across seed, early ware, and main crop ware potatoes). The increases in yields have compensated for the decline in area planted such that annual production has been between 1 and 1.4 million tonnes per annum since the 1950s (**Figure 19.30c**). Potatoes contribute between 6 and 10% of the value of agricultural output in Scotland and were the leading cash crop in Scotland until the late 1960s, accounting for 6.7% of agricultural output and 36% of the output from crops in 1965 (Coppock 1976). Between 2000 and 2008 an average of 11% of potato production has been used as stockfeed (1964–1972: 3.5%). Since 2000 potatoes have accounted for 8.7% of agricultural output in Scotland. About 40% of the area planted in potatoes and 46% of the potato crop produced (by weight) consists of seed potatoes.

Oilseed. The area of oilseed rape planted in Scotland since 1982 is shown in **Figure 19.30a**. The area increased rapidly during the 1980s to a peak in the mid-1990s and then declined to around 40,000 ha. Yield of oilseed rape has not increased over time but has remained at about 3–3.5 tonnes/ha (see **Figure 19.30b**) and as a result production reflects the area planted (see **Figure 19.30c**). Since 2000 oilseed rape has accounted for 1.6% of agricultural output.

Table 19.12 shows the relative contribution of wheat, barley, oats, potatoes and oilseed to the value of crop production in Scotland.

Horticulture. In 2009 horticulture contributed about 11% of the gross output of Scottish farming at basic prices, an increase from 6% in 2000 (Rural and Environment Research and Analysis Directorate 2010). Over the period 2000–2008, horticulture has averaged 9.2% of gross output. **Figure 19.31** shows the area of Scotland planted in vegetables for human consumption, soft fruit, and flowers, nursery stock and bulbs from 1940 to present. Increases in the yields of horticultural crops, similar to those for cereals and potatoes, have also been produced over the last 70 years.

The total land area used for growing vegetables for human consumption grew from about 4,000 to 5,000 ha during the 1940s to 1960s, to over 11,000 ha in the 1990s and 2000s. Soft fruit occupies a very small area (about 2,000 ha in the 2000s), the principal area for soft fruit production being based in Perthshire and Angus near Blairgowrie, Dundee and Forfar (Coppock 1976). Despite the small area used, since 2000 soft fruit has accounted for 2.6% of agricultural output.

Flowers, bulbs and nursery stock are grown on a total of less than 1,000 ha of Scotland (see **Figure 19.31**). In 2009, 33 ha of bedding and pot plants as well as nursery stock

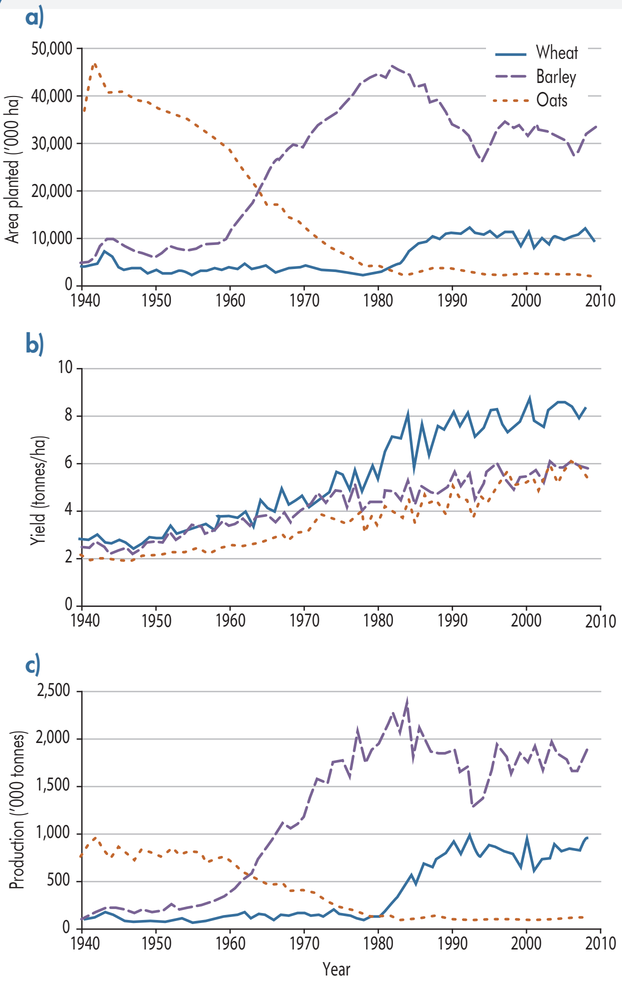


Figure 19.29 Wheat, barley and oat production in Scotland from 1940 to 2009: a) area planted, b) average yield, c) production. Source: annual (June) Agricultural Census tables, 1940–2009, published by the Scottish Government.

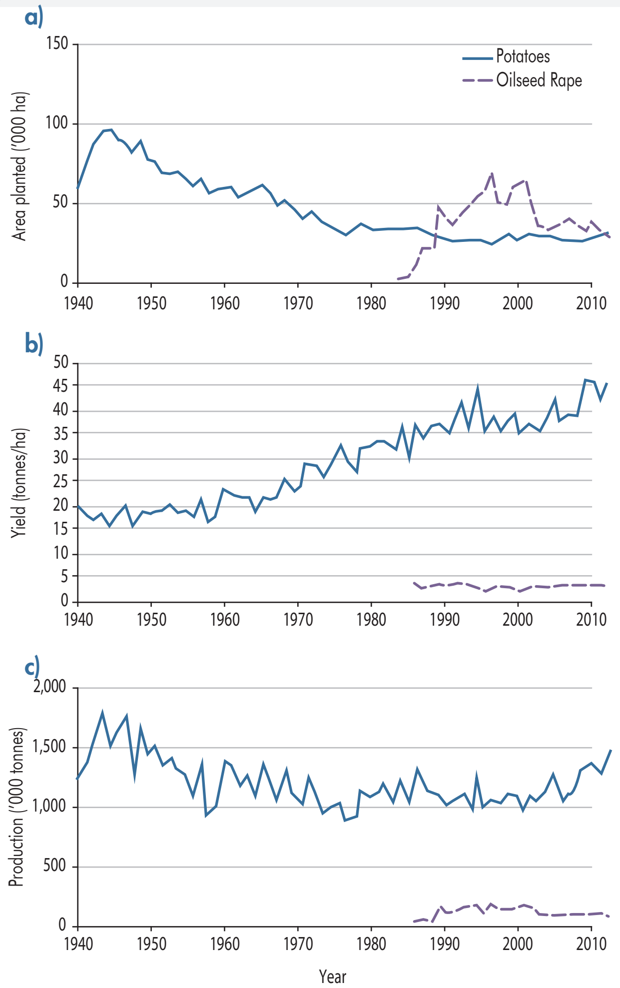


Figure 19.30 Potato and oilseed rape production in Scotland from 1940 to 2009: a) area planted, b) average yield, c) production. Source: annual (June) Agricultural Census tables, 1940–2009, published by the Scottish Government.

were grown in glasshouses and plastic structures, making up 18% of the total glasshouse and plastic structure area of 180 ha. Although flowers, bulbs and nursery stock occupy only a small land area, they are high value crops and since 2000 have accounted for 2.5% of agricultural output. The output value of horticultural crops from 2000 to 2009 is shown in **Table 19.12**.

Fodder crops. The area of agricultural Improved Grasslands in Scotland has varied between 950,000 and 1.3 million ha since 1940 (**Figures 19.15** and **19.32**). The decline in grassland between 1940 and 1945 was associated with wartime ploughing to increase domestic crop production. Following WWII the area of Improved Grassland has stayed relatively constant. Despite this, the split between permanent grassland and temporary (rotational) grassland shows contrasting patterns. Permanent grassland increased from between 400,000 and 600,000 ha during the period from the 1940s to 1970s, to about 900,000 ha in the 2000s. Conversely, temporary grassland declined from a maximum area of almost 800,000 ha in the 1860s to under 400,000 ha in the 2000s. The abrupt break in the trends for permanent and temporary grassland in **Figure 19.32** represents a change in census methodology in 1959 when the distinction between permanent and temporary grass was altered and a question about age of grassland was included in Scotland (Coppock 1976). Prior to 1959 these were distinguished as permanent grass, which was rarely or never ploughed and which was not counted as part of arable land, and temporary (or rotation) grass which was part of agricultural rotations. From 1959 new definitions were used for agricultural grassland (Department of Agriculture and Fisheries for Scotland 1962): grassland of 7 years old and over (treated as equivalent to permanent grass) and grass under 7 years old (treated as equivalent to temporary grass). This change resulted in some grassland being moved from permanent to temporary (Coppock 1971). Later, in 1978, these categories were redefined to grass of 5 years and over and grass of less than 5 years[9]; the change is apparent in **Figure 19.32** in a second abrupt break in the plots for permanent and temporary grassland that occurred in 1979.

The relative extent of grasslands used for mowing and grazing is also shown in **Figure 19.32**. Between 1940 and 1960 about 20% of the grassland was mown, increasing gradually to over 30% between 1970 and the end of the 1990s and then declining to the current 25% by the early 2000s. Mown grasslands provide hay, silage, seed and dry grass (Coppock 1976) and can also be grazed after the grass is mown.

The area of fodder crops is shown in **Figure 19.33**. The marked decline from about 140,000 ha in 1950 to about 20,000 ha in 2009 is clear. The main fodder crop comprises turnips and swedes and the area of these grown is also shown in **Figure 19.33**; the small area of kale/cabbage and vetches/tares is also shown. The area of turnip and swede cropping has declined from about 120,000 ha in 1950 to about 5,000 ha by 2009. Turnips and swedes are used for stock feed. Traditionally the turnip and swede crop has been mostly used as part of a rotation and consumed on the farm where it is grown, being fed to sheep while still in the ground (Coppock 1976). This provides winter food for the sheep, the sheep in turn providing manure to support the fertility of the soils. Fodder crops are also important for conservation of arable weed and wintering farmland bird populations (Hancock & Wilson 2003).

The remarkable decline in the area of fodder crops in the last 70 years reflects increased specialisation farming, especially a reduction in mixed farming, the increasing use of inorganic fertilisers that reduce the reliance on both crop rotations and livestock to maintain fertility of agricultural soils, and increased use of stock feed purchased from other sources, changing methods of livestock production. Since 2000, fodder crops have accounted for 0.5% of agricultural output, a reduction from 2.6% in the 1950s, although since they are often not sold, this underestimates their value to agriculture, particularly when they were more widespread.

Livestock. Livestock are the dominant agricultural product, by value, from Scottish agriculture (Rural and Environment Research and Analysis Directorate 2009a). Livestock contributes 47.5% and livestock products (milk,

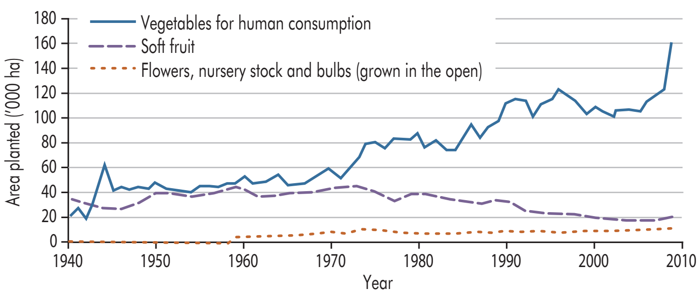


Figure 19.31 Annual area planted with vegetables for human consumption, soft fruit, and flowers, nursery stock and bulbs (grown in the open) in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, published by the Scottish Government.

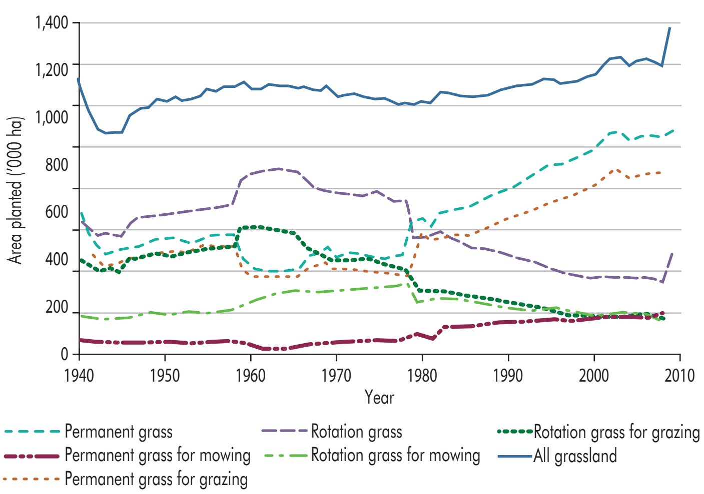


Figure 19.32 Annual area of agricultural grasslands in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, published by the Scottish Government.

9 For simplicity, permanent and temporary grass are used here to refer to the different classes recorded in the Agricultural (June) Census.

milk products, eggs, wool) provide a further 16.6% of annual agricultural output by value. The average annual contribution between 2004 and 2008 was £1,757 million. This is about 64% of Scotland's agricultural output by value. The main products are dairy, meat, eggs and wool.

Some upland vegetation is used to graze cattle and sheep, particularly during the summer months. Rough grazings and deer forest are considered in the agricultural returns for Scotland (the June Census) and recognised for their contribution as grazings for livestock. Not all of the value of livestock production can be allocated to the uplands and livestock production in Scotland is most appropriately considered as an integrated system that uses upland (rough and improved) grazings as well as elements of lowland agriculture, including fodder crops and grain produced in cereal systems (as discussed in this Section above).

Dairy. The number of dairy cattle in Scotland and the milk production from 1940 to present are shown in **Figure 19.34**. The decline in the size of the dairy herd since the 1950s is clearly apparent from 800,000 cattle in the 1950s to 350,000 cattle in the 2000s[10]. Milk production increased rapidly from the 1950s to a peak of over 1,400 million litres in 1980 and remains at over 1,100 million litres per year. Milk and milk products contribute about £266 million to the value of agricultural output, or 14.4% of the total (see **Table 19.12**).

Beef. **Figure 19.35** shows the number of beef cattle and the production of beef from 1940 to present. Numbers of beef cattle increased from about half a million in the 1940s to about 2 million by 1973 and fell since to just over 1 million in the 2000s. The abrupt break in the graph in 1973–1974 is due to a change in allocation of cattle under 1 year old within the census. Beef production generally has increased over the last 70 years. The large decline in 2001 shows the influence of the foot-and-mouth outbreak. Beef production has the largest share of output of Scottish agriculture, with an average value between 2004 and 2008 of £453 million, or 28.3% of value between 2000 and 2008 (see **Table 19.12**).

Sheep. The number of sheep fluctuated widely between about 6 million in 1947 and almost 10 million throughout the 1990s (**Figure 19.36**). Changes reflect severe weather (e.g. the decline associated with the severe winter of 1946–1947), and policy (e.g. the increases of the 1980s associated with introduction of headage payments). Lamb meat production has closely followed the pattern of sheep numbers. Sheep production had an average value between 2004 and 2008 of £146 million, or 10.0% of value between 2000 and 2008 (see **Table 19.12**).

Pigs. The number of pigs varied between about 150,000 in the 1940s to almost 700,000 in the 1970s and 1990s (**Figure 19.37**). The production of pork shows a very similar pattern (**Figure 19.37**) with a maximum of 91,000 tonnes produced in 1998. The value of pork production between 2004 and 2008 averaged £60 million, or about 3.5% of agricultural output during the 2000s.

Poultry. Poultry numbers increased from between 6 and 8 million during the 1940s to about 9 to 10 million in the 1950s and 1960s (**Figure 19.38**). The Agricultural Census records a rapid expansion in the poultry flock in 1970 (Department of Agriculture and Fisheries for Scotland 1971). Since the 1970s, poultry numbers have remained between 11.5 and 16 million. The production of chicken meat is also shown in **Figure 19.38**. This has increased rapidly from less than 20,000 tonnes per year in the 1950s and first half of the

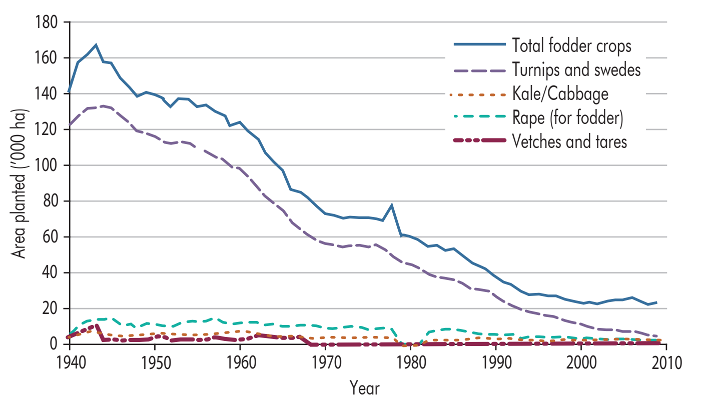


Figure 19.33 Annual area of fodder crops planted in Scotland from 1940 to 2009: total fodder crops, turnips and swedes, kale/cabbage and vetches/tares. Source: annual (June) Agricultural Census tables, 1940–2009, published by the Scottish Government.

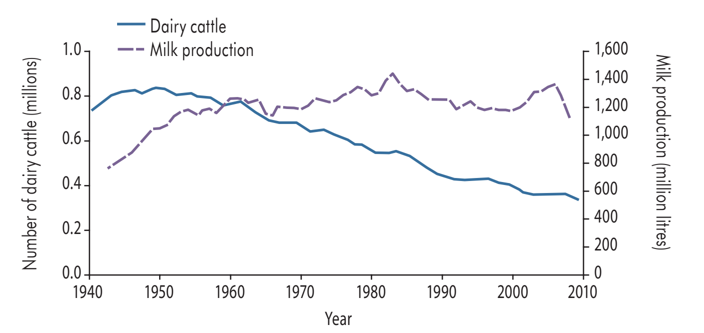


Figure 19.34 Annual numbers of dairy cattle and milk production in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, and Economic Reports on Scottish Agriculture, published by the Scottish Government.

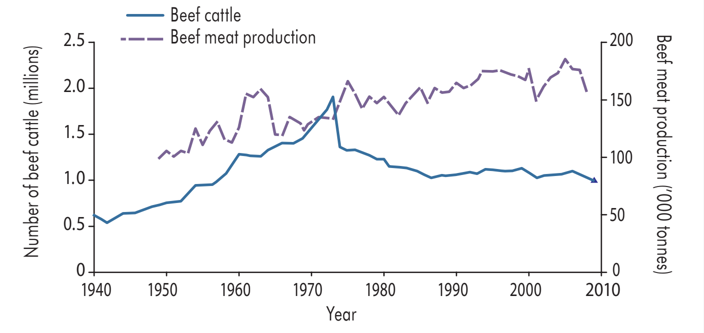


Figure 19.35 Annual numbers of beef cattle and beef production in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, and Economic Reports on Scottish Agriculture, published by the Scottish Government.

10 The data here use the pre-1974 definition of dairy cattle that includes dairy cattle under 1 year old.

1960s to a peak of almost 160,000 tonnes in 1997. During the 2000s the amount of poultry meat produced has declined to about 92,000 tonnes in 2008. Between 2004 and 2008 poultry contributed an average of £78 million to the value of agricultural output, and an average of 4.7% of value between 2000 and 2008 (see **Table 19.12**).

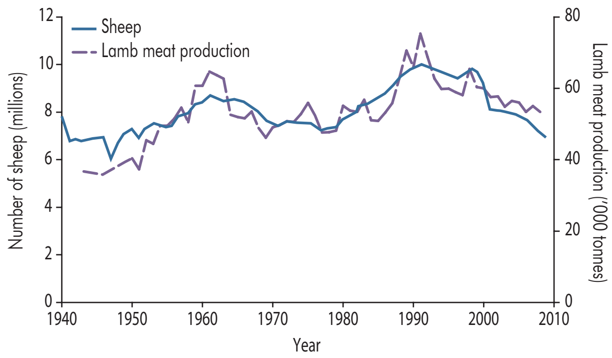


Figure 19.36 Annual numbers of sheep and lamb production in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, and Economic Reports on Scottish Agriculture, published by the Scottish Government.

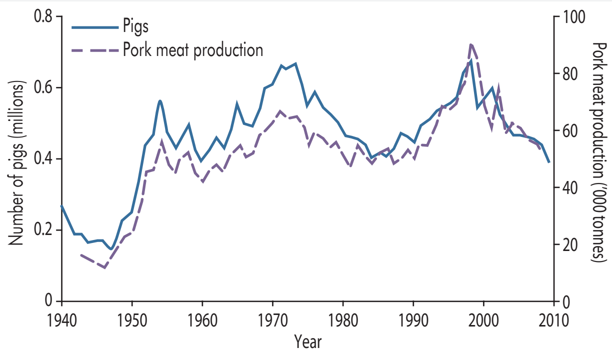


Figure 19.37 Annual numbers of pigs and pork production in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, and Economic Reports on Scottish Agriculture, published by the Scottish Government.

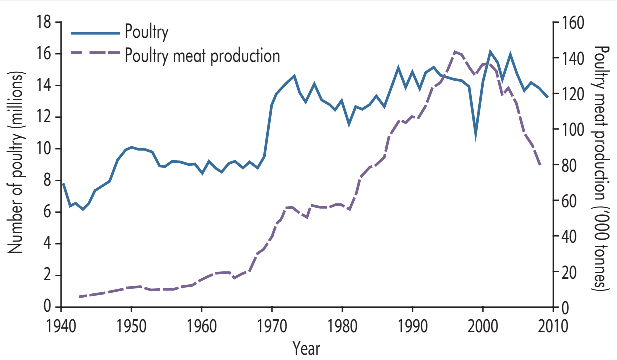


Figure 19.38 Annual numbers of poultry and poultry meat production in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, and Economic Reports on Scottish Agriculture, published by the Scottish Government.

19.5.3.2 Fibre from agriculture

Plant. Plants appear no longer to be used as a source of fibre, at least not in sufficient quantities to be recorded in census statistics. The area of flax grown during the war years to produce linen was in excess of 2,000 ha, a maximum of 3,560 ha being planted in 1944. Production ceased at the end of WWII.

Animal. Fibre from animals, specifically wool from sheep, has long been a major product derived from Scotland's agriculture. **Figure 19.39** shows the number of sheep (previously discussed) and the production of clipwool since 1940. The amount of wool, fairly obviously, bears a direct relation to the number of sheep. Wool production increased from about 7 million kg of wool in the 1940s to a maximum of 11.5 million kg in 1990 and declined to the 1940s levels again by the end of the 2000s. Between 2004 and 2008 clipwool has provided about £78 million of value to agricultural output, or about 0.2% of value in the 2000s.

19.5.3.3 Fish from marine systems

Coastal and marine ecosystems around Scotland support commercial fisheries. About 5% of the approximately 1,000 species of fish in the north-east Atlantic and North Sea are commercially valuable and the Scottish sea fishing industry has a very long history (Coull 1996). The sea fisheries of Scotland exploit demersal fish (e.g. cod, haddock, whiting, and flatfish) that live near the sea bed, pelagic species (e.g. herring, mackerel, sprats), and shellfish, including scallops, cockles, mussels, lobsters, crabs, and Norway lobster (*Nephrops*). The north-east Atlantic mackerel stock supports the most valuable finfish fishery in UK waters, operating mainly from Scotland. The catch has varied considerably since the 1940s (**Figure 19.40**) as fishing methods have changed, as stocks have declined, and as quotas and other conservation measures have been put in place. The recent increase in the shellfish sea fishery reflects a shift away from offshore demersal fishing for finfish towards fishing inshore waters for Norway lobster (*Nephrops norvegicus*) and other shellfish as well as mixed demersal species (UKMMAS 2010).

The value of the sea fisheries catch to Scotland at landing is shown in **Table 19.13**. During the 2000s the average

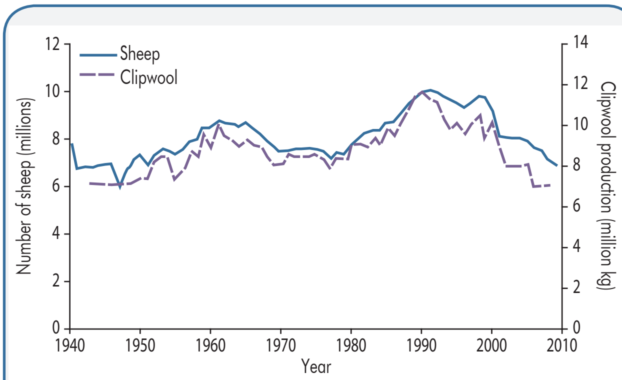


Figure 19.39 Annual numbers of sheep and total clipwool produced in Scotland from 1940 to 2009. Source: annual (June) Agricultural Census tables, 1940–2009, and Economic Reports on Scottish Agriculture, published by the Scottish Government.

annual catch has been 314 thousand tonnes, wet fish being 81.3% of the catch by weight. Between 2004 and 2008 the average annual value of the catch was £318 million. Wet fish (demersal and pelagic) contribute 60.7% of the value of the catch, shellfish contributing 30.3%. This is markedly different to the situation in the 1950s when wet fish contributed 96.3% (by value).

Demersal. **Figure 19.40a** shows the total catch of demersal fish landed in Scotland by British vessels since 1940. Cod, haddock and other demersal fish are shown. Between 1940 and the present, cod and haddock have been over half (by weight) of demersal fish landed. 'Other demersal' species include hake, halibut, lemon sole, Dover sole, plaice, skate, whiting, and others.

Two main characteristics of the record of catches are apparent. First, there is a cyclical pattern to the catch, especially of haddock. Second, there has been a decline in the catch since the second half of the 1980s. The cyclical pattern may reflect the increased capacity of fisheries to catch fish and the lack of development of conservation measures that ensure populations remain healthy (Coull 1996). In this case, the cycles may have been a signal of the lack of match between fishery yields and health of fish stocks. The decline in catch of demersal species from the second half of the 1990s represents quotas and other conservation measures that limit the catch in the interests of conservation and management of fish stocks.

The value of the demersal fishery to Scotland is shown in **Table 19.13**. Between 2004 and 2008 the average annual value was £112 million; since 2000 demersal fish have contributed 40.9% of the value of fish caught.

Pelagic. The catch of pelagic fish landed in Scotland by British vessels since 1940 is shown in **Figure 19.40b**. Herring, mackerel and 'other pelagic' species (sprats) are shown. Herring and mackerel have been, on average, 89% (by weight) of pelagic fish landed since 1940. Herring comprised over 90% of the pelagic fish caught (by weight) until 1962; since 2000 they have averaged 30%. The 6-year closure of the herring fishery in the late 1970s and early 1980s as a result of severe depletion of the stock is clearly seen in the figure. Catches since the fishery reopened have been controlled. Mackerel averaged less than 3% of pelagic fish caught each year from 1940 until 1974. The increase in mackerel catch occurred when the herring fishery was closed. Since 2000 mackerel have averaged 54% of the pelagic catch (by weight).

The value of the pelagic fishery to Scotland is shown in **Table 19.13**. Between 2004 and 2008 the average annual value was £74 million; since 2000 pelagic fish have contributed 19.8% of the value of fish caught.

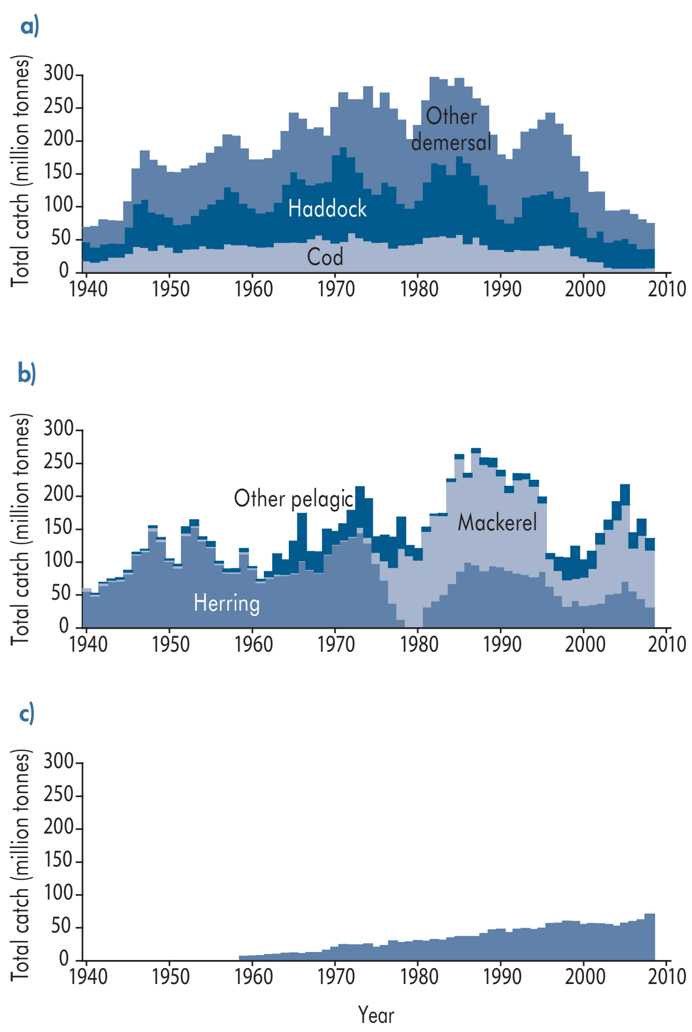


Figure 19.40 Annual catch of a) demersal finfish, b) pelagic finfish and c) shellfish landed in Scotland by British vessels from 1940 to 2009. Source: annual Scottish Sea Fisheries Statistical Tables, 1950–2010, published by the Scottish Government.

Table 19.13 Mean annual weight of fish landed in Scotland by British vessels (2000–2008) and mean annual value of output (2004–2008). Source: Scottish Sea Fisheries Statistics, Scottish Government.

	Mean annual weight of fish landed between 2000–2008 ('000 tonnes)	Mean annual contribution to total weight of fish landed (2000–2008) (%)	Mean annual value of output between 2004–2008 (£ millions)	Mean annual contribution to total value of fish landed (2000–2008) (%)
Demersal	102	32.7	112	40.9
Pelagic	153	48.6	74	19.8
Total wet fish	**256**	**81.3**	**186**	**60.7**
Shellfish	58	18.7	132	39.3
Total Fisheries	**314**		**318**	

Shellfish. The value of the commercial shellfish sea fishery to Scotland is shown in **Table 19.13**. Between 2004 and 2008 the average annual value was £132 million; since 2000 shellfish have contributed 39.3% of the value of fish caught. In 2006 British boats landed 57,280 tonnes of shellfish in Scotland (see **Figure 19.40c**), including 1,203 tonnes of mussels, 8,600 tonnes of scallops, and 29,616 tonnes of *Nephrops*, with a total value of £138 million (Scottish Government 2007).

19.5.3.4 Fish from aquaculture

Provisioning services from marine and coastal ecosystems include inshore mariculture, with finfish and shellfish farming. This is located almost exclusively on the west coast, with Argyll and Bute, and Shetland the main centres of production.

Aquaculture had an annual turnover of £280 million in 2005 (£260 million from farmed salmon, £10 million from rainbow, brown and sea trout, about £2 million from halibut and cod, and £67 million from shellfish). The total value of all fish exports, including from aquaculture, in 2005 was £420 million. This is 60% of all food exports from Scotland by value.

Salmon and trout. Commercial salmon farming started in 1969 and has grown rapidly. **Figure 19.41** shows the annual production of salmon in Scotland from aquaculture since 1989. Production increased rapidly through the 1990s and first half of the 2000s and since 2005 has averaged about 130,000 tonnes. As a representative year, in 2006 131,847 tonnes of Atlantic salmon were produced by 44 companies farming at 252 sites; 11 of these companies produced over 90% of the salmon (Baxter *et al.* 2008). Rainbow trout (7,492 tonnes, of which 2,341 tonnes were from saltwater sites), and brown and sea trout, cod and halibut (total 1,047 tonnes) are also farmed in the coastal environment using cages. In comparison, 272 tonnes of wild Atlantic salmon were caught with fixed engine, net and coble, and rod and line in 2002 (Section 19.5.3.5).

Salmon farming directly employed 1,142 people in 2006. Rainbow trout farming directly employed 143, with other species supporting 92 full-time and 17 part-time jobs.

The use of vaccines and chemicals to control disease and infection of farmed fish, as well as build-up of toxins in the fish and pollution of the coastal waters present significant management challenges and pollution problems for fish farming in coastal environments (Hansen & Jacobsen 2003; Marshall 2003; Read & Fernandes 2003; Hall-Spencer *et al.* 2006; Telfer *et al.* 2006). Monitoring is also needed to prevent contaminated fish being used in the food chain (Read & Fernandes 2003).

Shellfish. Shellfish farming has also grown rapidly, 173 companies producing 4,594 tonnes of shellfish from 156 sites out of a total of 327 sites in 2006 (Baxter *et al.* 2008). This total included 4,287 tonnes of mussels, 251 tonnes of Pacific oysters (*Crassostrea gigas*), 60 tonnes of queen scallops (*Aequipecten opercularis*), 40 tonnes of scallops and 40 tonnes of native oysters (*Ostrea edulis*). The shellfish sector of aquaculture employs 160 full-time equivalent employees (FTEs), 160 part-time employees and 80 casual workers. There is also indirect employment in processing.

19.5.3.5 Capture of salmon and migratory trout in estuaries and freshwaters

Salmon, sea trout and brown trout are of particular importance in Scottish freshwater fisheries, although data are collected systematically only for salmon and sea trout as these are the two species that have traditionally had the most significant economic value. Salmon occur in almost 400 rivers in Scotland (Baxter & Hutchinson 2002).

Returns of catches since 1952 (Fisheries Research Services 2008), and earlier estimates based on railway company records of salmon shipments (Pyefinch 1961), provide an indication of the extent of the annual catch of salmon and sea trout for the last 60 years (**Figure 19.42**). The annual catch of salmon, by method of catching, since 1952 for Scotland is shown in **Figure 19.43**.

During the 1950s, 1960s and 1970s the average annual number of salmon caught for each decade was in excess of 375,000 fish and 1,400–1,600 tonnes (**Table 19.14**). Since the 1970s there has been a decline in the number and total weight of salmon caught (Baxter & Hutchinson 2002; SNH 2004b). During the 2000s the average annual catch was about 100,000 salmon with an annual average weight of just over 345 tonnes (**Table 19.14**). Some of the decline in

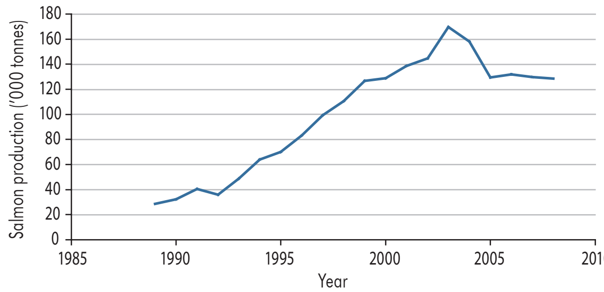


Figure 19.41 Annual production of farmed salmon in Scotland between 1989 and 2008. Source: data derived from Walker 2010. The data are Crown copyright, used with the permission of Marine Scotland Science. Marine Scotland is not responsible for interpretation of these data by third parties.

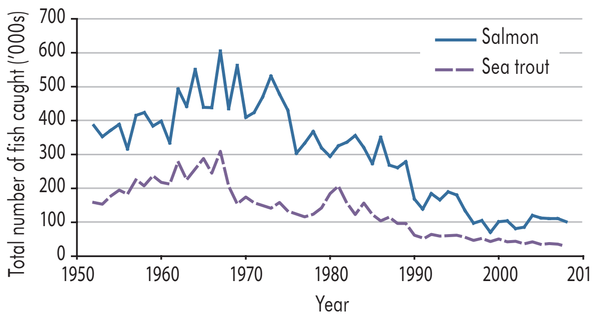


Figure 19.42 Total number of salmon and sea trout caught in estuaries and freshwaters in Scotland between 1952 and 2009. Source: the data used in this figure are Crown copyright, used with the permission of Marine Scotland Science. Marine Scotland is not responsible for interpretation of these data by third parties.

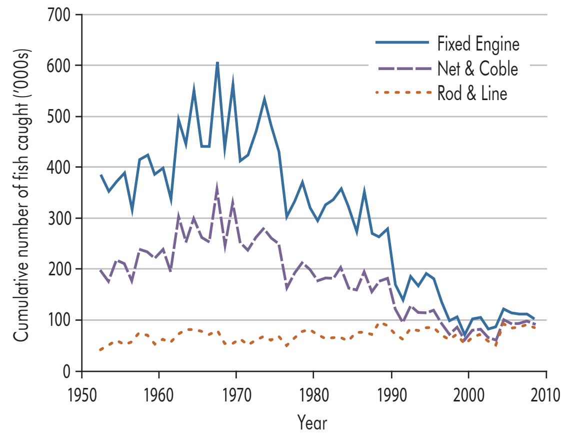


Figure 19.43 Annual catch of Atlantic salmon by method of fishing from 1952 to 2009. Rod and line includes catch and release data. Source: the data used in this figure are Crown copyright, used with the permission of Marine Scotland Science. Marine Scotland is not responsible for interpretation of these data by third parties.

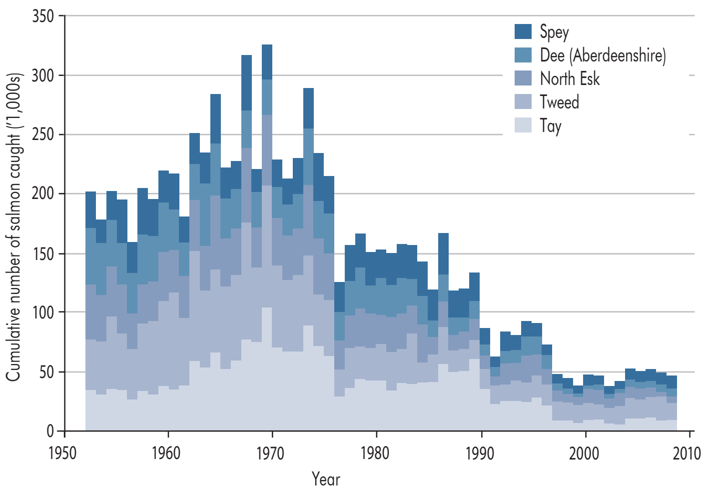


Figure 19.44 Salmon caught in the Tay, Tweed, North Esk, Dee (Aberdeenshire) and Spey between 1952 and 2009. Source: the data used in this figure are Crown copyright, used with the permission of Marine Scotland Science. Marine Scotland is not responsible for interpretation of these data by third parties.

Table 19.14 Mean annual catch of salmon and sea trout for each decade between the 1950s and 2000s by number of fish and weight. Source: the data used in this figure are Crown copyright, used with the permission of Marine Scotland Science. Marine Scotland is not responsible for interpretation of these data by third parties.

Decade	Salmon		Sea Trout	
	Mean annual number caught ('000)	Mean annual total weight (tonnes)	Mean annual number caught ('000)	Mean annual total weight (tonnes)
1950s	379	1,437	192	187
1960s	469	1,691	240	252
1970s	407	1,439	142	146
1980s	306	1,055	136	143
1990s	144	492	55	56
2000s	103	345	39	39

catch can be attributed to the decline of fixed engine and net and coble fishing as netting rights have been bought out (Williamson & Beveridge 1994; Maitland 1994) and fishing effort has decreased (Fisheries Research Services 2008). The rod and line catch has also declined since the 1990s and there are now catch and release schemes in place to conserve declining stocks (**Figure 19.43**).

In 2007, 13,618, 6,279 and 35,581 wild salmon and grilse were reported as caught and retained in fixed engine, net and coble, and rod and line fisheries, respectively; 55,472 wild salmon and grilse were caught and released by the rod fishery (Fisheries Research Services 2008). In total, five salmon rivers have produced over 50% of the total annual catch for Scotland since 1952 (the Tweed, Tay, Spey, Dee, and North Esk). The trends in salmon caught in these rivers are shown in **Figure 19.44**. The trends follow the same pattern as the trends in the data for all Scotland and are also found in many other catchments (**Figure 19.45**).

Sea trout show similar patterns to salmon, with smaller total numbers and total weights caught (see **Figure 19.42**

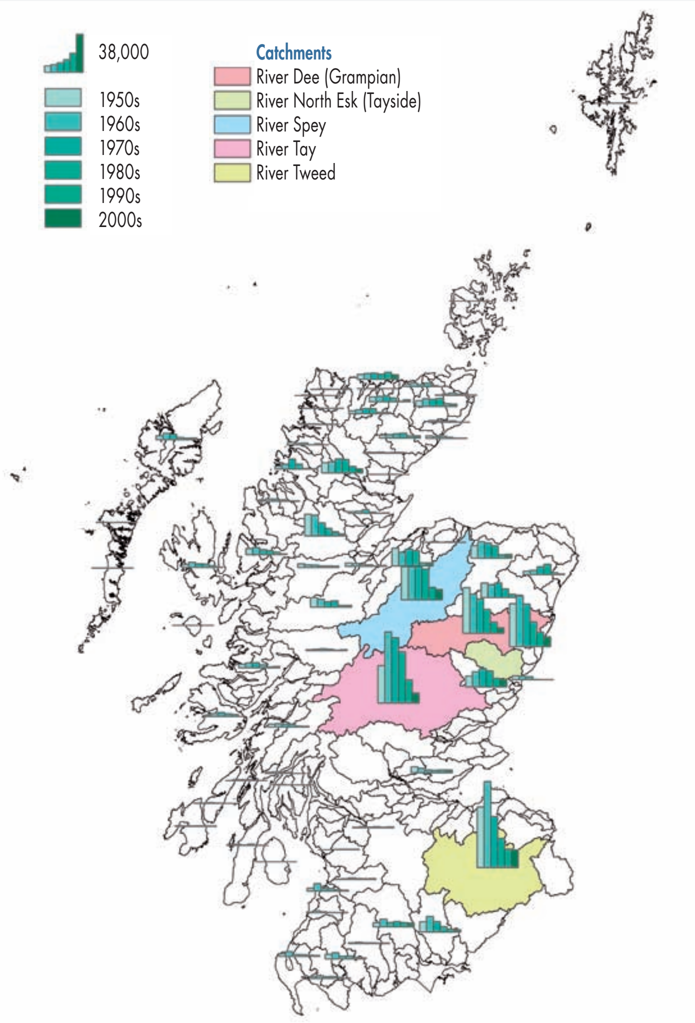


Figure 19.45 Mean annual catch of salmon for each decade from the 1950s to the 2000s for catchments in Scotland. Source: the data used in this figure are Crown copyright, used with the permission of Marine Scotland Science. Marine Scotland is not responsible for interpretation of these data by third parties.

and **Table 19.14**). The pattern of change since the 1950s according to method of fishing (**Figure 19.46**) also reflects the patterns shown by salmon, and for similar reasons. In 2007, 2,671, 2,903 and 10,383 sea trout were reported caught and retained in fixed engine, net and coble and rod and line fisheries, respectively, with another 11,158 sea trout caught and released by rod fisheries (Fisheries Research Services 2008).

Salmon and trout are of high economic value. In the late 1950s the cash value of salmon and sea trout was equivalent to about one-eleventh of the value of all marine wet fish landings in Scotland, although the weight was only one two-hundredth (Pyefinch 1961). There was additional related value through jobs, the economic contribution of angling, and value added to the product. For example, in the 1950s there were 1,600–1,700 people directly employed in the commercial wild (non-farmed) salmon fishery industry, as well as ghillies and water bailiffs. Today there are estimated to be a similar number employed in salmon and sea trout related work (approximately 1,800) of a total of about 2,800 jobs supported by angling. Annual expenditure on salmon and sea trout fishing was £50 million in 1988 and £74 million in 2003 (Scottish Executive 2003). Angling was estimated to be worth about £113 million per annum to the Scottish economy in 2003 (Glasgow Caledonian University & Cogentsi Research International Ltd. 2004). This is additional to the value of the fish.

A 2003 study of rod fisheries for Atlantic salmon, brown, rainbow and sea trout, and pike on the River Spey estimated the capital value of the salmon and sea trout rod fishery as £57 million in the catchment (Butler *et al.* 2009). Some 54,746 angler days were spent on the river, of which 74% were for salmon and sea trout. Angler expenditure was estimated as £12 million per annum (£11 million from salmon and sea trout anglers). With multiplier effects, fisheries contributed £13 million (salmon and sea trout £12 million) to household incomes and 420 FTE jobs (salmon and sea trout 401 jobs). On average this is equivalent to approximately £970 per salmon or sea trout to household incomes. Although the Spey has a high comparative value measured against other national surveys of angler expenditure, the relative impact of salmon and sea trout in the Spey catchment's economy is among the highest in the country.

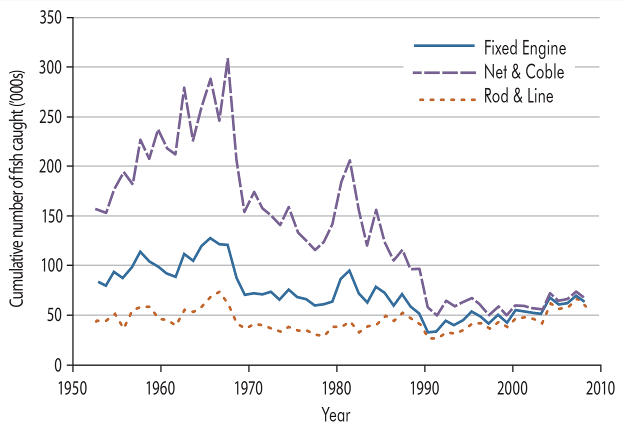


Figure 19.46 Annual catch of sea trout by method of fishing from 1952 to 2009. Source: the data used in this figure are Crown copyright, used with the permission of Marine Scotland Science. Marine Scotland is not responsible for interpretation of these data by third parties.

19.5.3.6 Game—food from birds and mammals provided from hunting

A wide range of bird and mammal species are hunted in Scotland, field sports providing significant economic income to sporting estates, especially in moorland ecosystems. Sporting estates are estimated to cover some 4.4 million ha or 20% of the land area of Scotland (Slee *et al.* 2009). They are managed by about 8,800 shooting providers and valued at about £130 million per annum (RPA and Cambridge Econometrics 2008). Sporting shooting is estimated to support about 88,000 workers, although most jobs are seasonal or part-time and this is equivalent to about 11,000 full-time jobs; the GVA (gross value added) of sporting shooting was estimated at £240 million (Public and Corporate Economic Consultants 2006a). Land management for hunting is thus important for shaping the appearance of upland landscapes. The Game & Wildlife Conservation Trust has carried out analyses of long-term game bags from across the UK that provide an indication of trends in game birds (Aebischer & Harradine 2007) and mammals (Davey & Aebischer 2008).

Birds. Moorland management using burning is the traditional mechanism for maintaining grouse habitat. There are about 296 grouse shooting moors in Scotland (about two-thirds of the UK total), shooting moors in the Scottish Highlands being about twice the size of southern Scottish and English moors (Chapter 5). The number of grouse shot annually in Scotland has declined, particularly since the mid-1970s (**Figure 19.47**) as management of Moorlands has lessened in intensity and with increased pressure from sheep grazing and afforestation. In Scotland during 2000 about 940 FTE employees were supported by grouse shooting.

A variety of other wild bird species are also hunted. In Scotland there have been long-term increases in bag sizes since 1961 for Canada goose, a number of duck species (wigeon *Anas penelope*, gadwall *Anas strepera*, teal *Anas crecca*, mallard *Anas platyrhynchos*), and some game birds (red-legged partridge *Alectoris rufa*, pheasant *Phasianus colchicus*, woodcock *Scolopax rusticola*); there have been long-term decreases for greylag goose (*Anser anser*), grey partridge and wood pigeon (Aebischer & Harradine 2007). It is not clear whether these changes reflect changes in hunting effort or changes in population sizes. Pheasant and red-legged partridge are commonly bred for hunting, especially in habitats on lower ground.

Mammals. Moorland estates also provide deer stalking. There was an increase in the Game and Wildlife Conservation Trust index of bag density for red deer in the UK between 1961 and 2006, the majority of sites reporting red deer being from Scotland (Davey & Aebischer 2008). Roe deer similarly showed an increase in the index of bag density between 1961 and 2006 in Scotland, increases in the lowlands of Scotland being particularly significant (Davey & Aebischer 2008). Other mammal species hunted include rabbit, mountain (*Lepus timidus*) and brown hares (*Lepus*

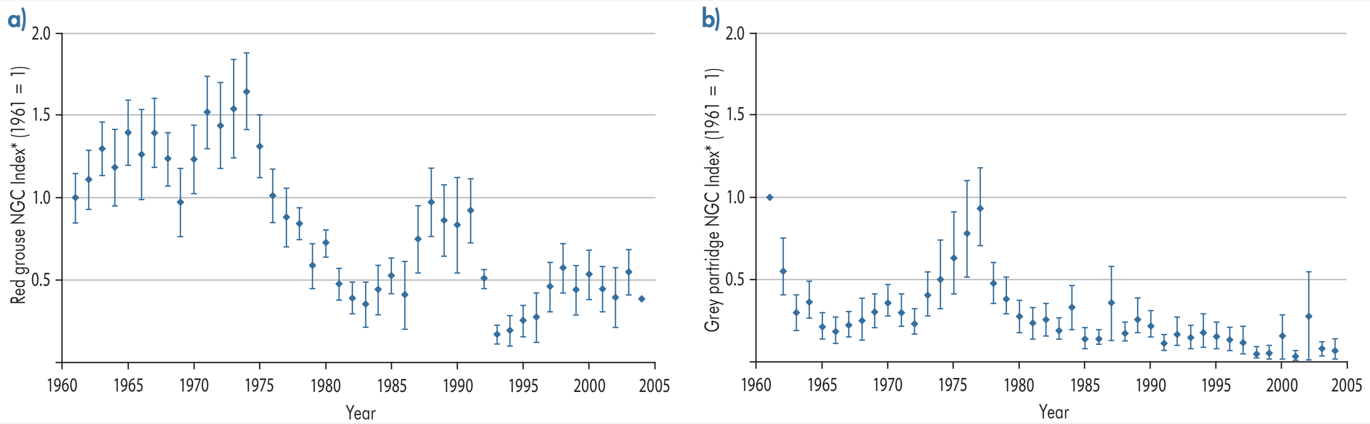


Figure 19.47 Game bird bag indices for a) red grouse and b) grey partridge in Scotland from 1961 to 2004. *NGC index: National Gamebag Census index. Source: data from the Game & Wildlife Conservation Trust's National Gamebag Census (Aebischer & Harradine 2007).

europaeus). Rabbit and brown hare bag densities show a decline over time in Scotland while mountain hare is cyclical (Davey & Aebischer 2008). As in the case of birds, it is not clear whether these changes reflect changes in hunting effort or changes in population sizes.

A 2006 study of the contribution of deer management (for sporting and other purposes) estimated direct and indirect employment at 2,520 FTEs and a GVA of £70 million (Public and Corporate Economic Consultants 2006b). This figure does not include the value of venison and other deer products.

19.5.3.7 Timber and forest products

Timber. **Figure 19.48** shows the standing volume of timber harvested in Scotland since 1976. Softwood provides more than 99% of the wood harvested in Scotland. The amount of softwood increased from about 1.1 million m^3 (0.93 million tonnes) in 1976 to 6.5 million m^3 (5.32 million tonnes) in 2008. Annual hardwood harvests are low and fell from about 109,000 m^3 (98 thousand tonnes) in 1976 to about 37,000 m^3 (33.6 thousand tonnes) in 2008 (Forestry Commission 2009; Scottish Government 2011). The wood is used for timber and the manufacture of paper products. Although the area felled is often restocked, the harvest has an influence on forest structure and biodiversity by altering the age and structure of woodland areas; there are also impacts on the physical environment through changes to land cover and drainage regimes.

In 2008 the total GVA associated with the Scottish forestry sector was estimated to be about £460 million (£304 million direct, £86 million indirect and £69 million induced[11], (Edwards *et al.* 2009). About 13,200 FTE jobs are also supported (10,300 direct, 1,500 indirect and 1,400 induced). Wood processing is about £111 million of this, forest planting and harvesting contributing about £60 million and £46 million respectively, contributing 3,294 and 2,447 FTE jobs in direct employment (Edwards *et al.* 2009).

Wood products produced domestically. In 2000 there were about 87 sawmills in Scotland processing British timber, of which 56 produced in excess of 1,000 m^3 of sawnwood (Forestry Commission 2000). Sawmills consumed some 1.8 million green tonnes of softwoods and produced 989,000 m^3 of sawnwood. This is about 44% of GB softwood production. By 2007 over 2.6 million green tonnes of softwood were consumed in Scotland and about 1.5 million m^3 of sawn softwood produced (Forestry Commission 2008). Hardwood consumption in Scotland's sawmills in 2000 was about 8,000 m^3 of underbark and production about 5,000 m^3 (Forestry Commission 2000); this is about 4% of the GB total for hardwoods. In 2007 about 27,000 green tonnes of softwood was sold to bioenergy plants (Forestry Commission 2008). In Scotland in 2007 94% of softwood logs used in larger sawmills came from Scotland, 6% from England (Forestry Commission 2008). Wood biomass is also an important part of renewable energy generation in Scotland.

Christmas trees. Data for Christmas trees grown and sold in Scotland are not available separately from the rest of the UK. The British Christmas Tree Growers Association estimated that about 7.5 million trees were sold in the UK in 2004, of which about 1 million were imported. The imported trees are mainly species that grow less well in the UK. The annual farm gate value of the Christmas trees in the UK is

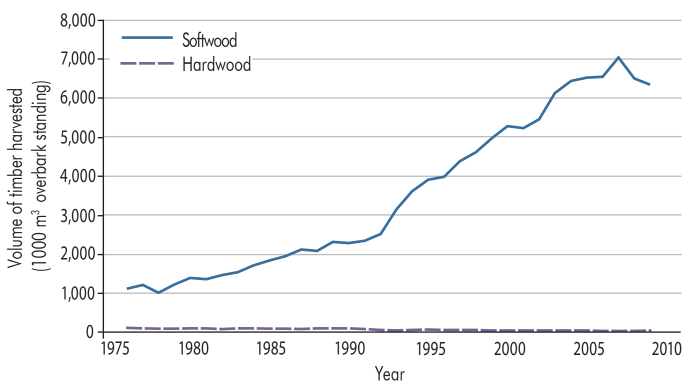


Figure 19.48 Annual volume of softwood and hardwood harvested in Scotland from 1976 to 2009. Source: data from annual statistical reports of the Forestry Commission, and High Level Summary of Statistics: Agriculture, Fisheries and Rural published by the Scottish Government (Scottish Government 2011).

11 Direct GVA arises from employment and activities carried out in forestry. Indirect GVA arises from businesses supplying forestry businesses with goods and services. Induced GVA arises from spending by those who earn their income directly or indirectly from the forestry sector.

about £140 million and the estimated value at retail outlets around double this.

Non-timber forest products (NTFPs). A wide variety of NTFPs are produced and used in Scotland. A survey in 2004 reported over 200 products from 97 vascular plants and 76 fungi and non-vascular species (Emery *et al.* 2006). The survey identified six main types of product: edible (110 species), craft (81 species), beverage (34 species), medicinal (18 species), other, for example toys (10 species) and garden (9 species). The edible category was not only most important as measured in number of species but also in range of products and frequency of uses. Examples of edible products include berries (bramble, raspberry, bilberry, elder, sloe, rowan, rosehips), flowers (elder, nettle), nuts (hazel) and a variety of fungi, notably chanterelle (*Cantharellus cibarius*), boletes (*Boletus* species), field mushroom (*Agaricus campestris*), horse mushroom (*Agaricus arvensis*), hedgehog mushroom (*Hydnum repandum*), puffball (*Lycoperdon* species), giant puffball (*Calvatia gigantea*), parasol (*Macrolepiota procera*), inkcap (*Coprinopsis atramentaria*) and wood blewitt (*Clitocybe nude*). Edible use is dominated by personal consumption of the products, although there is increasing commercial collection and sale of fungi. Craft uses include dyeing of wool as well as production of walking sticks and baskets. Medicinal uses are less common now than in the early- to mid-20th Century (Darwin 1996; Milliken & Bridgewater 2006).

Emery and her colleagues identify a number of benefits beyond the economic value of NTFPs. Collecting provides a sense of physical and emotional well-being and reinforces regular exercise, contributes to collectors' diets, brings beauty into homes, and helps to preserve cultural heritage (Emery *et al.* 2006).

Commercial uses of non-timber forest products focus primarily on edible products. In the late 1990s the total wild mushroom harvest in Scotland was worth approximately £406,000 per year, with 20 jobs directly attributable to the harvest and a further 350 pickers benefiting from casual earnings (Dyke & Newton 1999).

Biochemicals. Biochemicals, with potential uses as flavours, fragrances, nutritional supplements and chemical precursors, can be extracted from a variety of plants and plant materials such as forestry brash. There is scope for commercial exploitation of biochemicals.

19.5.3.8 Peat

Peat has long been used as a resource in Scotland and is cut traditionally by hand and also with large-scale and mechanised methods in commercial cuttings. Peat is used as fuel for heating and also for horticultural compost and in the whisky industry. Peat fires are used in some distilleries to dry the malt, smoke from the fires entering the barley and imparting characteristic flavours and tastes to the whisky. Domestic uses of peat for gardening exceed the demands from the commercial sector, which has sought peat-free substitutes since the late 1990s.

The area of peat extraction has fallen recently. The EU Habitats Directive specifies active raised and blanket bogs as Priority Habitats; as a consequence many of these habitats are designated as SACs and are protected from development. In 1999 392,000 m^3 derived from Scotland were used in GB while by 2008 this had fallen to 265,000 m^3 (Chapter 15).

19.5.3.9 Ornamental resources

Plants, animals and minerals are all used for ornamental purposes. Small areas of land are used for commercial production of ornamental plants. For example, in 2007 470 ha were used for growing bulbs, 236 ha for ornamental trees, 12 ha for roses, 7 ha for bedding and pot plants, and 4 ha for other flowers (Rural and Environment Research and Analysis Directorate 2008). There are very limited data for most other uses of ecosystems for ornamental resources.

19.5.3.10 Genetic resources

Very little information is available on the use of genetic resources in Scotland (or the UK). However considerable opportunities exist for use of genetic material, especially from plants. The book *Flora Celtica* (Milliken & Bridgewater 2006) describes the many and varied ways in which plants in Scotland have been and are being used. The role of plant genetic material in relation to medicinal, and diet and nutritional, uses needs further investigation.

19.5.3.11 Water

Population growth in cities and increased connectivity to mains water supplies has increased demands for water, although private water supplies are still used in many rural areas. In Scotland between 1971 and 2001 there was an increase in use of unmetered water supply from about 1.39 mega litres per day (Ml/day) to about 1.88 Ml/day in 2001 (Moran *et al.* 2004). The amount of metered and non-potable water declined from about 0.58 Ml/day to about 0.47 Ml/day over the same period (Moran *et al.* 2004). Average per capita consumption of water in 2001 is about 143 litres per day (l/day); this is forecast to increase to over 149 l/day by 2015 (Moran *et al.* 2004).

The quality of potable water is managed by extensive treatment and quality at consumers' taps has been reported by the Scottish Government Drinking Water Quality Division (Scottish Government Drinking Water Quality Division 2008). Water quality is very high. In 2007, only 577 tests out of 1,600,601 failed to comply with requirements under water quality regulations (Scottish Government Drinking Water Quality Division 2008).

Water resources in Scotland are managed by Scottish Water and SEPA under the Water Resource Planning and River Basin Management Processes. Leakage is a significant component of total consumption in Scotland at about 41% in 2007–2008 (Chapter 15).

19.5.3.12 Renewable energy

Many of Scotland's land, freshwater and marine environments provide the most suitable conditions in the UK for provision of renewable energy. Topographically, Scotland is better suited to low- and medium-head hydropower, and deep valleys in impervious rocks offer good, watertight reservoir sites (Johnson 1994). Hydroelectric power has been generated for over a century, the first significant schemes: Foyers on Loch Ness (1896), Kinlochleven (1909), and Lochaber (1928) being for local use in the production of aluminium (Johnson

1994). The main growth of hydroelectric generation has occurred since the 1940s, following the construction of the high voltage electric transmission grid in the 1930s. Reviews reporting in 1942 (Cooper Committee 1942) and 1962 (MacKenzie Committee 1962), and establishment of the North of Scotland Hydro-Electric Board in 1943 (Anon 1943; North of Scotland Hydro-Electric Board 1944) provided direction and momentum to the development of hydroelectric power. By the end of 1959 the Board had completed 41 separate schemes with a total installed capacity of 866,000 kilowatts (Brown & Hunter 1961). Johnson (Johnson 1994) summarises the contribution of hydropower to electricity generation in Scotland until the early 1990s. Rapid development in the 1960s resulted in about two-thirds of all generation by the North of Scotland Hydro-Electric Board being from hydro, the remainder from coal and oil, by the end of the decade (Johnson 1994). This fell to 25% by 1991–1992 (with 36% from oil and gas, 24% nuclear, 15% coal and other sources). In 2007 hydroelectric generation (other than from pumped storage systems) was 4,697 gigawatt hours (GWh) (11.5% of gross consumption) (Department for Business 2007), virtually identical to the 4,665 GWh (11.4% of gross consumption) generated in 2000.

Hydroelectric power is valuable because it is flexible and rapid in response to demand, and the infrastructure is reliable and readily available. By the 1990s hydropower schemes were being used to meet fluctuations in daytime demands for electricity, nuclear and thermal power plants, delivering a high and constant output (Johnson 1994).

The potential for wind, wave and tidal energy from Scotland's ecosystems has been recognised for many years, as have the technical and economic challenges of generating electricity from these sources (Brown & Hunter 1961). Wind, in particular, has long been recognised as a potential and technically accessible source of electric power (Golding 1955, 1961) although it is only relatively recently that it has begun to be developed and used to a significant extent. Taken together, wind and wave power generated 217 GWh (0.5% of gross consumption) in 2000 compared with 2,644 GWh (6.5% of gross consumption) in 2007 (Department for Business 2007).

Figure 19.49 shows the modelled mean wind speed for Scotland and 2010 distribution of wind farms. Generally the coastal areas have greater potential for wind power generation (Golding 1961) and the coastal and marine environment has been increasingly identified as having possibilities for the generation of wind power in the future.

Wind is, however, relatively unpredictable and this limits the utility of wind as a source of electric power. Wind power is also controversial, often related to public attitudes and landscape aesthetics (Warren & Birnie 2009). Wave and tidal power are more predictable and reliable than wind but have their own technical challenges. The potential of coastal and marine areas around Scotland for wave and tidal power generation have been identified (see **Figure 19.21** for areas of high tidal capacity). Efforts are currently underway to exploit this capacity, partly driven by challenges such as the Saltire Prize that aims to accelerate commercial development of marine renewable energy. The impacts of wave and tidal energy devices on the marine and coastal environment are unknown, particularly the effect of arrays of turbines on seabed and coastal sediments and habitats.

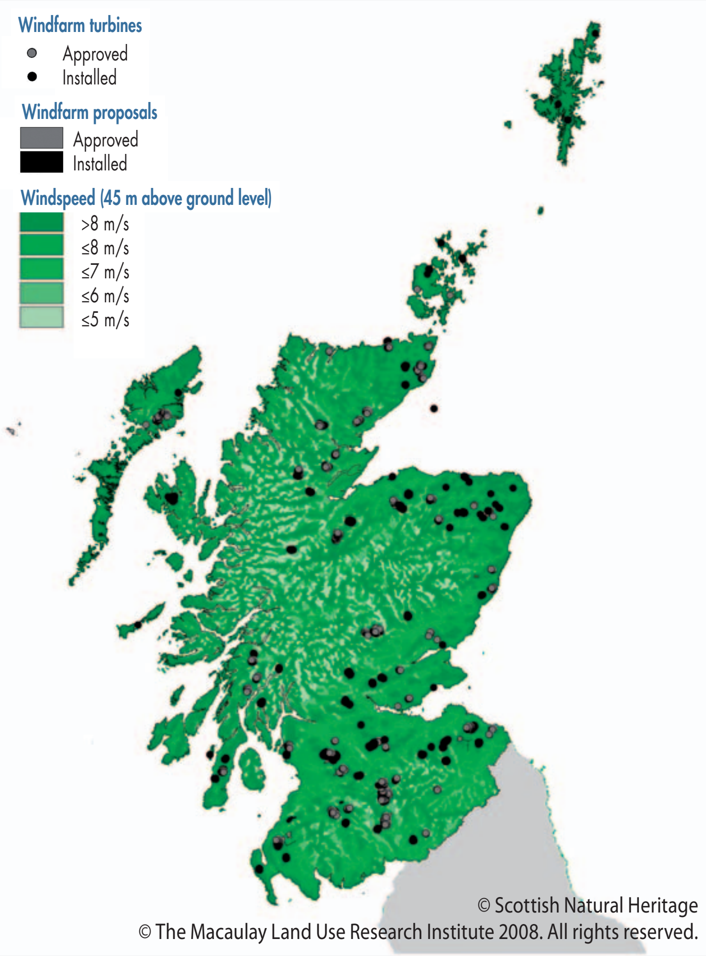


Figure 19.49 Mean wind speeds and windfarms in Scotland, 2010. Source: mean wind speed is that calculated by ETSU Ltd, on behalf of the Department of Trade and Industry, using the NOABL model (Brocklehurst 1997). The outputs were calculated for a resolution of 1 km x 1 km at 45 m above ground level. Windfarms and wind turbine data are from Scottish Natural Heritage.

In 2008 Scotland had 2,665 megawatts (MW) of installed renewables capacity. There was also a total of 3,336 MW in schemes not yet constructed but with planning consent (SNH 2008); onshore wind accounted for 3,023 MW of the total. Research for Scottish Enterprise has estimated that the £498 million 623 MW Airtricity Clyde Valley wind farm led to increases of £12 million and £110 million in local and national gross domestic product (GDP) respectively, and creation of 849 jobs throughout the economy (direct, indirect and induced), 246 of these jobs being in the local economy (O'Herlihy & Co. Ltd 2006).

19.5.4 Cultural Services

The UK NEA recognises that cultural services are associated with a variety of environmental settings (geographical and social places) and intimately related to their variety of meanings for people and society. Cultural services and the places to which they are attached are individually established by people and groups.

The assessment of cultural services for Scotland is developed here in relation to two major scales of interest within environmental settings: local places and landscapes/seascapes. These can have geographic and social definitions.

19.5.4.1 Environmental settings: local places

Local places are defined with meaning according to the needs and experiences of individuals. Homes, and local streets and neighbourhoods, define the geographical territories that people experience in their daily activities. At this scale the local environment provides the setting for the cultural services experienced and valued by individuals. There is substantial work in environmental social sciences and in studies of the built environment, health and the humanities that demonstrates the benefits delivered by local places and spaces such as parks, woods, rivers and street trees (Chiesura & de Groot 2003; Chiesura 2004; Andersson 2006; Croucher *et al.* 2007; van Leeuwen *et al.* 2010). These elements of the urban system are important in helping individuals to achieve a good quality of life and well-being (Koren & Butler 2006; Fuller *et al.* 2007). A Scotland-wide study in 2004 revealed that those living in areas with the highest levels of perceived street-level incivilities (such as litter and graffiti) were almost twice as likely to report feelings of anxiety and depression as those who perceived the lowest levels of street-level incivilities (Ellaway *et al.* 2009). Perceived absence of environmental goods (e.g. safe play areas for children) was associated with anxiety (2.5 times more likely) and depression (90% more likely, Ellaway *et al.* 2009). Other studies have investigated neighbourhood conditions that influence health and well-being (Braubach 2007) and in a study in Glasgow cleanliness, peacefulness and facilities that encourage exercise and social interaction in urban physical environments were shown to support the health of older people (Day 2008).

19.5.4.2 Environmental settings: landscapes and seascapes

Landscape is formally defined as *'an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors'* (Council of Europe 2003). Human perception is critical to this definition and illustrates and identifies the changing social context by which landscapes are defined and valued; individuals in Scotland and elsewhere have their own individual appreciation of landscapes. The combined influence of natural and cultural components of landscape has also been applied to the understanding of Scotland's coastal landscapes (Hughes & Macdonald 1999).

Whatever individual agreements or differences there may be over Scotland's landscapes, there are a variety of popular and widely advertised images and meanings of Scottish landscapes that have been developed and used, particularly in the second half of the 20th Century (McCrone *et al.* 1995). These shape not only the wider perceptions of landscape but also the way landscapes are valued and managed, and the way Scotland is marketed and advertised economically, socially, politically and for trade and visitors. Frequently the images of Scotland's heritage and landscapes are based on scenery, history (especially Celtic history), geography, monuments (notably castles), language and culture, the heritage of Highland clans, and political relations (McCrone *et al.* 1995) as well as its role in advancing the arts, science and economic and social thinking. These qualities have all been presented as defining a set of distinctively Scottish environmental and social landscapes for decades, as can be seen, for example, in almost any guide to Scotland over the past 70 years (e.g. Meikle 1947; Harvey 1949). All the qualities, individually and collectively, may also provide a sense of place. Archaeological sites, widely and densely distributed throughout Scotland, also provide a sense of place as well as inspiring aesthetically, artistically and in other ways.

There are several designations of landscape character for Scotland. There are 40 National Scenic Areas covering over 1.4 million ha (12.7%) of the land area (**Table 19.1**). National Parks also address the issue of landscape character and the two National Parks in Scotland together include 639,200 ha, about 8% of Scotland. In order to develop understanding of the character of Scotland's landscapes to complement the understanding and knowledge of other aspects of the natural heritage such as conservation of biodiversity, SNH developed Landscape Character Assessment (Hughes & Macdonald 1999; Hughes & Buchan 1999; Bennett *et al.* 1999). Landscape Character Assessment is combined with Natural Heritage Zones to develop a framework for assessment of the natural heritage that includes landscape (Thin 1999). Similarly the European Environment Agency has developed a Net Landscape Ecological Potential Index[12] (NLEPI) to document the relative quality of natural habitats at a landscape-scale, taking the connectivity and fragmentation of habitat into account (Weber *et al.* 2008). This is a culturally-determined assessment using both designated areas for both nature and landscape character as evidence of landscape value. **Figure 19.50** shows the distribution of National Parks, National Nature Reserves, Sites of Special Scientific Interest, Special Areas of Conservation, Special Protection Areas and RAMSAR sites in Scotland. These are combined with Broad Habitat types and road data to estimate habitat fragmentation and create a map of net landscape ecological potential. The high potential of the Cairngorm and other mountain and remote upland areas of Scotland is shown in this analysis.

Each of the Broad Habitats, combined with Scotland's geodiversity, contribute to landscape appearance in Scotland. Open habitats such as moorlands and grasslands combine with the topography and geology of Scotland to offer broad views. Coastal Margin habitats are also important and seascapes provide an immediate and important component of Scotland's large-scale and local relationships between people and environment.

12 The Net Landscape Ecological Potential is an index that indicates habitat quality at landscape scales including its social component. The index is based on nature conservation and landscape designations. The net landscape ecological potential of a landscape is not the same as its heritage and cultural value of landscape, although high values would often be expected to coincide.

19.5.4.3 Health: physical activity and green exercise

Much of the research on benefits of greenspace and high quality environments has taken place in cities and other urban areas. This is not surprising, since these are the areas in which the majority of the population lives and where green environments are most frequently experienced.

A recent review of international literature for greenspace scotland (Bell *et al.* 2008) provides examples of the health benefits of greenspaces in Urban areas, as do a number of other studies conducted in Scotland, that have already been described (Braubach 2007; Day 2008; Ellaway *et al.* 2009). Elsewhere, studies have been conducted in Scandinavia, the USA and Japan (Kaplan & Kaplan 1989; Frumkin 2001), as well as for the UK as a whole (Mitchell & Popham 2007; Mitchell *et al.* 2009).

Both physical and mental health benefit from engaging with nature in a variety of ways, including simply viewing it, as well as more active pursuits. Exercise (e.g. walking, fishing, and sports such as golf) helps with cardiovascular and respiratory health as well as increasing muscle endurance and improving HDL cholesterol levels. A Finnish study of golfers who walked while playing, rather than using carts, showed health benefits compared to sedentary men (Parkkari *et al.* 2000).

Exercise, especially for children, is more frequent in Urban areas with proximity and access to parks and recreational areas as this increases the opportunity to exercise (Giles-Corti & Donovan 2002; Giles-Corti *et al.* 2005). There is evidence that stress is reduced by both exercise in and views of green environments and that behaviour and cognitive function are improved (Taylor *et al.* 2001).

Greenspaces contribute to social interaction and networking (Hitchings 2010) and have been associated with reduced levels of crime, aggression and violence (Kuo & Sullivan 2001). The aesthetic value of urban areas is improved by greenspaces (Sheets & Manzer 1991). Safety and design of greenspace requires more research.

A number of hedonic valuation studies have shown that greenspace can have a direct effect on property prices and on other public good (e.g. recreation) and social and economic (reduced absenteeism) benefits that are not valued and recognised by markets. For example, proximity to an urban park not only increases property values, but the size of urban parks also substitutes for living space with amenity benefits to residents (Poudyal *et al.* 2009). In Glasgow house prices were shown to be depressed in relation to increasing road noise (Lake *et al.* 2000).

As described Section 19.4.6 Scotland has considerable greenspace in urban areas (Birnie *et al.* 2002; greenspace scotland 2009), and the possible specific benefits of these environments to health and well-being, as well as social and economic aspects of living in Scotland's towns and cities, merit considerable further attention.

19.5.4.4 Leisure, outdoor recreation and tourism

All the Scottish ecosystems provide opportunities for recreation and tourism, including hiking, cycling, skiing and nature viewing. Geoparks and Scotland's geodiversity also offer opportunities for enjoyment of Scotland's landscapes

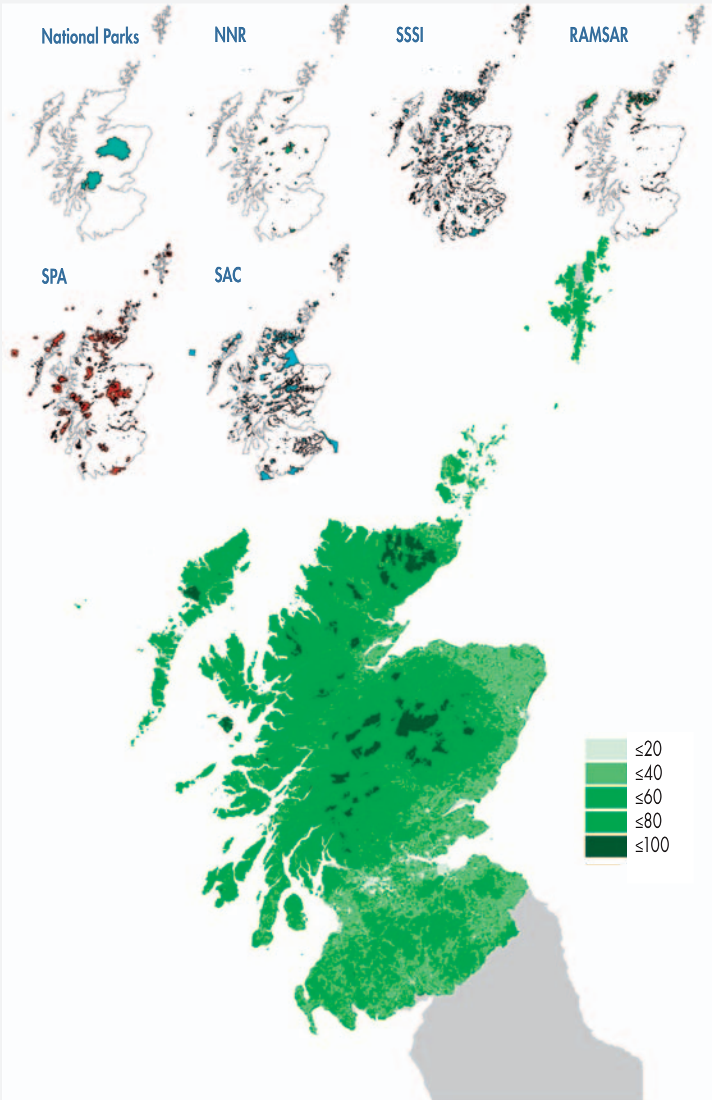


Figure 19.50 Nature conservation designations and Net Landscape Ecological Potential Index (NLEPI) for Scotland. NNR: National Nature Reseve; SSSI: Sites of Special Scientific Interest; SPA: Special Protection Areas; SAC: Special Areas of Conservation. Source: Scottish Natural Heritage. NLEPI calculated for this report.

(Gordon *et al.* 2004; Gordon 2008). Wetlands and water-rich landscapes are an integral part of the character of Scotland's landscapes and provide a sense of place, notably evident in the world famous character and reputation of Scotland's leading salmon and trout fishing rivers (e.g. Tweed, Tay, Spey and others) and lochs. Water-based recreation includes fishing, canoeing, kayaking, nature viewing, jet skiing, water skiing, wind surfing and swimming. Many of these recreational opportunities, but especially fishing salmon and trout, are a major contribution to local economies and communities. Almost all active recreation has benefits for health and well-being, the added benefit of exercise in green environments being found in several studies (Hansmann *et al.* 2007).

As cultural services, recreation and tourism have a high value (measured, for example, as % GVA or by number of jobs). Tourism was worth about 4% GVA to the Scottish economy in 2002 and £4.2 billion in 2006. A recent review of the economic impacts of nature-based tourism in Scotland concluded that overall total visitor spending attributable to nature-based tourism each year is about £1.4 billion with about 39,000 FTE jobs (Bryden *et al.* 2010).

There are between 37 million and 64 million annual recreational and tourism visits to Scottish forests and woodland, respectively. In 2006 this provided some £209 million GVA and sustained approximately 18,000 jobs (Edwards *et al.* 2009). Coastal tourism is also significant in Scotland. In 2002 there were 42 million day visits to the Scottish seaside, spending some £300 million (GB Leisure Day Visits 2004). In 2005 there were 9.2 million overnight visits to the Scottish seaside valued at £481 million (UKTS 2006). The combined value of day and overnight visits in Scotland is likely to be considerable.

Almost half of the adult population in Scotland made at least one visit per week to the outdoors for leisure and recreation purposes in 2007, the same level as was recorded during 2006 (TNS 2009). Additionally, 80% of the adult population claimed to have made at least one trip to the outdoors in the previous 12 months; this is approximately 340 million visits to the outdoors in Scotland during 2007, a 3% increase on the estimate for 2006. In 2004 the average distance travelled for these visits was 26 km; in 2007 it was 18 km. The proportion of visits on foot increased from 50% to 61% and by car decreased from 43% to 31% over the same time interval.

Specific recreational activities also generate considerable use of Scotland's environment as well as jobs and economic income. In 2002–2003 expenditure on recreation in the Highlands and Islands area was estimated to be in excess of £400 million (walkers and mountaineers: £246 million, water sports participants: £90 million, snow sports: £29 million, cyclists: £24 million, equestrianism: £15 million) (George Street Research and Jones Economics 2004). In 2006 it was estimated that sport shooting in Scotland directly employs 5,300 FTEs (about 58,000 paid workers) with 11,000 total FTEs through direct, indirect and induced impacts (Public and Corporate Economic Consultants 2006b). Deer management (for sporting and other purposes) supports 2,520 FTEs and has a GVA of £70 million (Public and Corporate Economic Consultants 2006a). Coarse and game angling supports about 2,800 jobs (salmon and sea trout-related employment is some 65% of the total) and is worth about £113 million per annum (Glasgow Caledonian University & Cogentsi Research International Ltd. 2004). Recreational sea angling supports over 3,100 FTEs and income of over £69 million (Glasgow Caledonian University *et al.* 2009). Golf supports 4,400 jobs and is valued at about £120 million GVA. Scotland regularly hosts the British Open Championship; the Open in Carnoustie in 2007 brought about £15 million to the local community and some £26 million to the Scottish economy (Angus Council 2008). The 2007 Mountain Bike and Trials World Championship at Aonach Mor attracted 30,000 spectators, of which two-thirds were from outside Scotland, and generated £6 million net expenditure in Lochaber and £1.5 million expenditure in Scotland (MLURI *et al.* 2009).

There have been estimates of the economic value of marine wildlife tourism in Scotland. In 1996 about 2,670 full time jobs were supported and revenues of £57 million generated. Tourism expenditure related solely to the east of Scotland bottlenose dolphin population was estimated to be at least £4 million, providing 202 FTE posts (Davies *et al.* 2010). Whale watching and sea fishing also create employment and income in coastal and marine areas.

19.5.4.5 Heritage: aesthetics and inspiration

The aesthetic and inspirational values of Scotland's land- and seascapes are well known. Their values arise from habitats, topography, geodiversity (Gordon *et al.* 2004; Gordon 2008), expectations of iconic wildlife, and rapidly changing skyscapes associated with Scotland's dynamic weather. There are also clear and obvious links between Scotland's contemporary landscapes and their history that further add to the aesthetic and inspirational services. Together these create a wealth of recognisable local, regional and national identities, many with strong cultural and historical roots, that are regularly exploited in advertising for tourism, recreation, and as part of Scotland's international and domestic brand (McCrone *et al.* 1995). Often these local features are packaged together to create national qualities, for example heritage trees (Rodger *et al.* 2006). Scotland's landscapes are part of an individual and national sense of place, and link the local and landscape-level cultural services. Natural beauty provides inspiration, harmony, peace and feelings of security; land- and seascapes have long been associated with all of these characteristics that contribute to individual and community well-being.

19.5.4.6 Religion and spirituality

Relatively little is known about religious and spiritual values attached to Scotland's ecosystems. Religion and spirituality are two separate but related themes that have strong relevance to human experiences and relations with nature. Religious experience may be linked to specific places, typically churches and cathedrals (Winter & Gasson 1996) but also through their historical status, the stories attached to them and their reputation combined with physical remains or monuments. In Scotland this will include places in cities and towns, but also notable sites such as Iona, Callanish, Maes Howe and others. The attachment this has to ecosystems is limited however, although the landscape setting of these monuments often supports and enhances individual perception of their significance.

More frequently, spirituality as a cultural ecosystem service is associated with local places and landscapes through human attachment to place (Brown & Raymond 2007), often related to notions of wilderness (Habron 1999). This view was pioneered by John Muir (Kocher-Marbaeuf 2008) and Victorian perceptions of the Scottish Highlands (Holl & Smith 2007), and spread through nature writing (e.g. Syse 2007).

19.5.4.7 Biodiversity

In addition to its other roles, biodiversity can also be considered a cultural service. People place considerable value directly on biodiversity itself, through support for different species and groups, and through concern for the existence and health of Scotland's biodiversity. Involvement in biodiversity conservation, membership of biodiversity non-governmental organisations (NGOs) and public attitudes to biodiversity in Scotland are used as biodiversity indicators by SNH (Mackey & Mudge 2010). The total number of conservation volunteers in Scotland increased by 43% between 2005 and 2008 and membership of NGOs increased by 15% between 2007 and 2009 (Mackey & Mudge 2010). More than 70% of adults in Scotland responded positively regarding interest, relevance and concern about Scotland's biodiversity in surveys in 2006 and 2009 (Mackey & Mudge 2010). Two of the 45 National Indicators of the Scottish Government are concerned with biodiversity: i) increase to 95% the proportion of protected nature sites in favourable condition, and ii) biodiversity: increase the index of abundance of terrestrial breeding birds. Progress on these two indicators is indicative of the state of other aspects of Scotland's biodiversity and ecosystems.

19.6 Scotland's Dependence on External Ecosystem Services

Scotland both uses and exports products derived from the services gained from ecosystems, notably, but not solely, from provisioning services. Scotland's landscapes and history are an important part of its brand (McCrone *et al.* 1995). Scotland also imports goods derived from ecosystems outside Scotland's borders, not only elsewhere in the UK and Europe but also from international markets.

Figure 19.51 shows the imports and exports of food and live animals for Scotland for 2009 (HM Revenue and Customs 2010). This gives an indication of the extent to which Scotland is dependent on provisioning services from ecosystems outside Scotland's borders. Value of food and live animals for export was about £937 million while imports were £914 million. Food and live animals are about 8.5% of the total value of imports and 6.2% of the total value of exports for Scotland. Import of beverages was about £155 million while export of beverages was valued at £2.8 billion in 2009. Beverages are 1.4% of the total value of imports and 19.2% of the total value of exports for Scotland. The high export value of beverages is due to Scotch whisky. A higher value of imports than exports occurs for meat and meat preparations, dairy products and eggs, vegetables and fruit, sugar and honey, and feeding stuffs for animals, not including unmilled cereals (see **Figure 19.51**). Fish, crustaceans, molluscs, and aquatic invertebrates make up 60% of Scotland's exports of food and live animals.

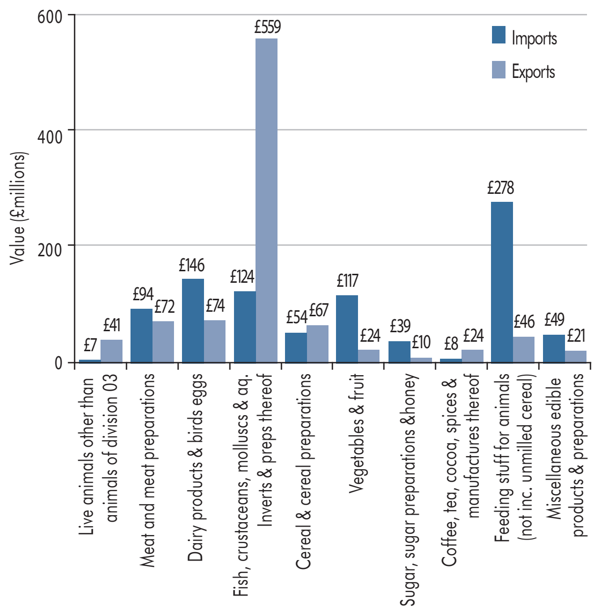


Figure 19.51 Imports and exports of food and live animals for Scotland for 2009. Source: HM Revenue and Customs (2010).

19.7 Drivers of Change

A wide range of drivers of change influence the present and future status and condition of habitats and ecosystem services. Drivers operate at a range of organisational scales from local to international. Drivers of change can be considered under five major headings: policy and institutional, economic, demographic, social and cultural, technological, and environmental (Birnie *et al.* 2002; Miller *et al.* 2009). Taken together, these represent a complex suite of interacting forces. Their influence is played out in the way that social and economic systems (individuals, groups, communities, and institutions) respond through decisions and planning (Miller *et al.* 2009), and environmental systems respond via physical, chemical and biological processes. Critically, ways in which social and environmental systems interact also need to be recognised and understood to achieve preferred social, economic and environmental goals (Harris 2002; Hooper *et al.* 2005; Lawton 2007; Slee *et al.* 2009).

Given the importance of agriculture, both crop production and livestock, in terms of both the area of Scotland on which it is carried out and the range of habitats used, the drivers of change in agriculture over the last 70 years have had a major influence on Scotland's ecosystems. Since 1945 the Government has had a strong influence on agriculture through policies and economic drivers. The 1947 Agricultural Act was passed after the end of WWII and was implemented through guaranteed prices for agricultural products and through production grants and subsidies. Subsidies included hill sheep and hill cattle subsidies, calf and beef subsidies, subsidies for lime and fertilisers, and long-term improvement to agricultural infrastructure such as under the Farm Improvement Scheme. All of this support encouraged maximisation of production and, with increased mechanisation and use of artificial fertilisers, pesticides and herbicides developed during the war, led to major structural changes in agriculture as well as extreme impacts on habitats and biodiversity. There was unrestricted entry for agricultural produce to Britain from

1947 and payments made under price guarantees were thus related to the difference between market prices and the guaranteed prices. During the 1950s the emphasis changed from maximisation of production to economic efficiency of production (Coppock 1971), price guarantees applying to standard quantities of produce. The environmental, economic and structural effects of these changes were similar to those following the 1947 Act. The entry of Britain into the European Economic Community (EEC) in 1973 entrenched the principle of support for farming (Grant 1997). The EEC protected against imports and the vagaries of the world market while inflating prices through buying surplus production into Intervention storage. This provided an impetus for further increasing production. Quotas were introduced from 1984 to reduce over-production. The MacSharry reforms to the CAP in 1991 included set-aside to remove land from cereal production in an attempt to manage production. Set-aside and other agri-environment schemes also improved the environmental impacts of agriculture and help to maintain environmental quality. The wildlife benefits of set-aside have been well studied, especially for birds (Sotherton 1998; Donald *et al.* 2001; Watson *et al.* 2009; Whittingham *et al.* 2009). Ongoing reform of the EU CAP is of critical importance for ecosystem health and provision of ecosystem services.

Policy and economic drivers operate through regulations and incentives and the drivers are apparent in Acts, policies and in designation. Numerous Acts apply directly or indirectly to activities in the ecosystems of Scotland. The National Parks (Scotland) Act 2000 established National Parks in Scotland to conserve and enhance the natural and cultural heritage of the area, promote sustainable use of the natural resources of the area, promote understanding and enjoyment (including enjoyment in the form of recreation) of the special qualities of the area by the public, and promote sustainable economic and social development of the area's communities. As such, this Act provides a legal requirement for management of areas of Scotland that are directly focused on the goals that are informed by ecosystem assessment and that can be implemented using an ecosystem approach (Defra 2007). The Salmon Conservation (Scotland) Act 2001 is directed at conservation of salmon and sea trout, while the Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003 consolidated a variety of Acts related to salmon and freshwater fisheries in Scotland. The Water Environment and Water Services (Scotland) Act 2003 and the Water Services (Scotland) Act 2005 protect the water environment in Scotland, while the Water Industry (Scotland) Act 2002 provides regulations about the quality of drinking water in Scotland. The Nature Conservation (Scotland) Act 2004 addresses conservation of biodiversity, conservation and enhancement of Scotland's natural features, and protection of birds, animals and plants. The Environmental Assessment (Scotland) Act 2005 requires environmental assessment of the impacts of plans and programmes. The Animal Health and Welfare (Scotland) Act 2006 makes provisions for prevention of the spread of disease and for the welfare of animals. The Aquaculture and Fisheries (Scotland) Act 2007 provides regulations related to fish farms. The Flood Risk Management (Scotland) Act 2009 directs the assessment and sustainable management of flood risks related to European Parliament and Council Directive 2007/60/EC. The Marine (Scotland) Act 2010 provides a mechanism for regulating functions and activities in the Scottish marine area, including the protection of the area and its wildlife. Policies and strategies also directly and indirectly address integrated ecosystem management, including the Scottish Biodiversity Strategy (Scottish Executive 2004), Scottish Forestry Strategy (Forestry Commission Scotland 2006) and Food and Drink Policy (Scottish Government 2009c).

Environmental change, including sea level rise (Richards & Phipps 2007; Rennie & Hansom 2011), climate change (SNIFFER 2006), habitat loss and destruction, and land use changes (Foley *et al.* 2005), is recognised as a major threat to Scotland's economy (Conway 1998) and ecosystems (Macdonald *et al.* 1994; Pakeman & Marrs 1996; Conway 1998; Kerr 2000; Milne & Hartley 2001; MacLeod *et al.* 2005; Wolf & Woolf 2005; SNIFFER 2006; Orr *et al.* 2008). The Climate Change (Scotland) Act 2009 sets targets for reduction of greenhouse gas emissions, imposes duties related to climate change on public bodies, and requires waste reduction and recycling, and increased energy efficiency. This Act also requires a Land Use Strategy that addresses sustainable land use to be presented to the Scottish Parliament by 31 March 2011.

Designation of habitats as, for example, SSSIs, NNRs and more recently National Parks, as well as under European legislation, also provides a mechanism for management of change in ecosystems.

In Scotland, there are several key contexts and goals/targets that shape the management of environmental systems through their influence on drivers of change. Several of these are enacted in the Scottish Parliament Acts described above. However, contexts and goals are not only internal to Scotland, being developed as a matter of national choice and preference, but are also external, related to international, European or UK objectives and obligations. (Currie 2002) estimates that over 80% of the environmental regulation that affects Scotland is applied through the European Union. Some Acts, for example the Flood Risk Management (Scotland) Act 2009 are a direct response to a European Parliament and Council Directive. Others refer to international conventions. For example, the Nature Conservation (Scotland) Act 2004 refers to the Convention on Biological Diversity (CBD). The Scottish Biodiversity Strategy, as well as ecosystem assessment (as in the UK NEA) and the ecosystem approach are all directly linked to the UN Convention on Biological Diversity, which is a significant international driver.

The Scottish Government National Performance Framework provides a set of specific targets for promoting sustainable economic development for the nation. Many other policies relate to the National Performance Framework and are directly relevant to environmental management and ecosystem goods and services. Some of the current policies and strategies applicable to environmental issues and management in Scotland are listed in **Table 19.15**.

These policies and strategies arise from a variety of imperatives, many of which have been described above. The Climate Change (Scotland) Act addresses Scotland's response to international issues of greenhouse gas reduction

Table 19.15 Current EU, UK and Scottish Government policies and strategies applicable to Scotland.

Agriculture Common Agricultural Policy Reform (2014) Animal Health and Welfare Strategy for Great Britain (2005) Community Action Plan on the Protection and Welfare of Animals 2006–2010 EU Animal Health Law Farming for a Better Climate Initiative (2009) Implementation Plan for the Animal Health and Welfare Strategy in Scotland (2003) Scotland Rural Development Programme 2007–2013 (2008)	**Economic development** Government Economic Strategy (2007) National Planning Framework for Scotland OECD Rural Policy Review. Scotland, UK (2008) Scottish Government Rural Framework (2010–2011) Reducing our ecological footprint (Scottish Government Performance Framework Indicator)
Air quality EU Air Quality Directive	**Energy** Biomass Action Plan for Scotland 2007 Renewables Action Plan (2009)
Biodiversity Scottish Biodiversity Strategy Review of 2010 Biodiversity Targets The Economics of Ecosystems and Biodiversity (2010) Nature Conservation (Scotland) Act 2004 Scottish Soil Framework	**Food, diet and health** Healthy Eating, Active Living (2008) Recipe for Success—The Scottish Food and Drink Policy (2009) **Forestry** Scottish Forestry Strategy (2006)
Climate Change Climate Change (Scotland) Act (2009) Climate Change Adaptation Framework (2009) Climate Change Delivery Plan (2009) Land Use Strategy (2011)	**Marine** The Marine (Scotland) Act 2010 UK Marine Policy Statement: Habitats Regulations Assessment **Waters** Bathing Water Directive EU Water Framework Directive (2000) European Nitrates Directive & Nitrate Vulnerable Zone Action Programmes Flood Risk Management (Scotland) Act (2009) Scottish Government Vision for Water Industry in Scotland (2010)

and both establishes and requires the Land Use Strategy due to be published in 2011. National Food and Drink Policy, Soil Framework Strategy, Scottish and local BAPs, and others, provide specific contexts and policies developed within Scotland to meet its own national objectives. Policies and strategies are also related to EU policies and Directives, such as the Water Framework Directive, Habitats Directive, River Basin Management Planning, that have importance within Scotland.

The suite of drivers listed in **Table 19.16** is common to many of the different issues. A major aspiration among policy-makers is for coordination between these different strategies. This is preferable to addressing each issue singly and in isolation from other issues through a self-standing and independent strategy. It will require systems-based integrative research and new approaches to governance (O'Riordan 2002, 2009). It will also require a commitment to reorient some strategic and policy approaches in order to deliver across a range of concerns in an integrated way. This is needed both to manage Scotland's resources and ecosystems and to tune the various policy instruments to deliver multiple social, economic and environmental benefits. Scotland is well positioned to accomplish this with commitment and motivation among a wide variety of institutions, established social networks on which to develop collaborations and partnerships, and established expertise in public engagement. Successful examples include Catchment Management Plans (e.g. Dee Catchment Management Plan), Coastal and other partnerships, two National Parks focused on economic, social and environmental development aligned with communities, and many other examples at local, regional and national scales.

In parallel with recent development of policies there have been significant developments in protocols and approaches for getting people more involved in environmental management (Kenyon & Nevin 2001; Quine *et al.* 2002; Varjopuro *et al.* 2008; Irvine *et al.* 2009). These parallel the increasing recognition of the social and economic importance and contribution of healthy and functioning environments. The CBD has developed the ecosystem approach (Defra 2007) as a strategy for integrated management of land, water and living resources to promote conservation, sustainable use, and the fair and equitable sharing of the benefits arising out of the utilisation of resources (United Nations 2000). The Scottish Government and SNH have built on the ecosystem approach for use in Scotland (Mudge & Christie 2009; Aspinall *et al.* 2010) as a mechanism for developing partnerships and collaborations to foster sound environmental management at local, regional and national scales. The ecosystem approach takes a whole systems view of environment and the different drivers of change, and links this understanding of how environmental systems work with the activities and goals of society.

Table 19.16 Drivers of change influencing Scotland's ecosystems and land systems. Source: Miller *et al*. 2009.

	Driver of change	Examples
Policy and Institutional	Institutions	• Governance arrangements • Designations—approximately 20% Scotland designated with local, national or international conservation designation
	Frameworks	• Planning system, Ecosystem Approach, Environmental Impact Assessment, Strategic Environmental Assessment, Integrated Catchment Management, Coastal Partnerships, River Basin Management, etc.
	Legislation	• Legally binding agreements, for example climate change reduction
	Regulation	• Climate Change (Scotland) Act
	Collaboration	• Coastal Partnerships, Catchment Management Groups, etc
Economic	Grants and payments	• Common Agricultural Policy (CAP) • Common Fisheries Policy (CFP) • Less Favoured Area Support Scheme • Single Farm Payment (SFP) • Scottish Rural Development Programme (SRDP)
	Prices and exchange rates	• Market prices
	Provision of infrastructure (housing and transport)	• Pressures for increasing housing stock • Rural transport (remoteness/accessibility)
Demographic	Demographic change	• Increasing age of population, motivation and behaviours
	Counter drift migration	• Urban to rural; second homes
	Land manager profiles	• i.e. Increasing age, lack of new entrants to many areas of employment in rural economy
Social and Cultural	Changes in decision-maker's motivations	
	Consumer preferences and marketing	
	Heritage	• Approximately 7,500 Scheduled Ancient Monuments, about 46,000 listed buildings, 293 Historic Gardens and Designed Landscapes, occupying 62,000 ha or approximately 0.8% of Scotland
Technological	Reducing costs and economies of scale	
	New products	
	Renewable energy (and landscape impacts)	• Windfarms
Environmental change	Climate change	• Temperature and precipitation • Uncertainty in changes in windiness and exposure • Changes in agroclimate: o Lengthened growing season o Changed seasonal access to land for machine-based operations o Reduced mountain snowpack o Decline in montane plant communities • Rivers: o Rising temperatures of river waters, decrease in baseflow and increase in increase in flash flooding (with consequences for freshwater life - salmonids) • Sea-level rise • Extreme events: storms, droughts and floods
	Habitat loss, direct physical loss (land conversion)	• Land abandonment, changes in management regime (over grazing and burning), nitrogen deposition (in the uplands), runoff, estuaries , chemical use (pesticides, herbicides, molluscicides, fungicides, fertilizers)
	Invasive non-native species	• Changing geographical distributions of pests and diseases
	Eutrophication of freshwaters and estuaries	• Algal mats • Anoxic zones
	Air quality	
	Wild harvesting	• Marine fish stocks and economics of coastal and fishing communities • Hunting (sporting estates)
	Soil erosion and compaction	• Loss of productivity • Land degradation
	Fate of organic soils and organic matter in soils	• 54% UK soil carbon in Scotland's soils; large areas of organic (peat) soils; inorganic soils of Scotland are carbon-rich

19.8 Consequences of Change for Biodiversity and Human Well-being

There has been considerable change in Scotland's ecosystems and the services they provide over the last 70 years. The delivery of provisioning services, about which more is known than other services, has increased considerably. However, this has not been without significant impacts and consequences for biodiversity and other ecosystem services, although the full impacts and linkages are not well documented. Most of the habitats and ecosystems considered 'natural' and semi-natural have declined in both area and condition. Biodiversity, measured in numbers and abundance of individuals of species, as well as by variety of species, communities and genetic diversity, has shown both declines and increases, although the general long-term trend over the last 70 years is one of decline. There are fundamentally important taxonomic groups for which very little is known (e.g. microflora and microfauna, bryophytes, lichens, invertebrates other than butterflies), including groups for which Scotland has internationally important species (Usher 2002a).

It is apparent that the ecosystems and landscapes of Scotland provide significant ecosystem goods and services and considerable economic benefit to the nation. Provisioning services have a particularly high economic value. Between 2004 and 2008 the average annual total direct value of agriculture, forestry and marine fisheries was about £2.5 billion. In 2008 agriculture was valued at approximately £792 million (Rural and Environment Research and Analysis Directorate 2009a). Forestry (wood production, processing and manufacture) was worth £460 million GVA at 2007–2008 prices. Fisheries also provide high economic value. The pelagic, demersal and shellfish industry in Scotland landed fish valued at around £350 million in 2008 (Scottish Government 2009a).

In addition to the direct value of GDP and GVA in agriculture and forestry, they also provide raw materials for production of many other goods with high value. Revenue from sales and value added in the food and drink industry and other products adds considerably to the total economic value of Scotland's production services. For example, food and drink are worth about an additional £3 billion to GVA. Whisky distillers purchase about £90 million worth of cereals from Scottish suppliers each year, providing an income of about £148 million per year while supporting approximately 7,000 jobs (DTZ Pieda Consulting 2002). Overall, revenue generated from agricultural produce increases the direct value to about £2.3 billion (about 1–2% of GDP and 1.2% of GVA).

A study by the Rural Payments Agency and Cambridge Econometrics and commissioned by SNH assessed the economic output from activities that depend on the natural environment in 2003 at £17.2 billion per annum (11% of total Scottish output). This output supported 242,000 jobs, about 14% of all FTEs in Scotland (RPA and Cambridge Econometrics 2008). About £3.9 billion and 154,000 jobs of these totals were assessed to be from direct impact, maintaining the trend for high quality employment opportunities related to the natural heritage of Scotland (RSK Era Ltd 2001; Environmental Resources Management Limited 2004).

The role of agriculture and forestry in shaping landscapes and ecosystems in Scotland is perhaps even more important than the economic values. The complexity of the economic and social dependencies of Scotland's society on supporting regulating, provisioning and cultural ecosystem services is revealed in the magnitude and scope of benefits obtained from Scotland's ecosystems and landscapes. The extent of agriculture and forestry land uses in Scotland is about 92% of the land area, and the direct impacts of land management for agricultural and forestry production make the functioning and health of Scotland's ecosystems highly dependent on management for delivery of provisioning services. The impacts on supporting and regulating services are of fundamental importance. Continued loss of habitat, changes in nutrient storage and cycling, climate change and impacts on biological function within habitats have significant consequences for human well-being. In particular, the supporting, regulating and provisioning services that are documented in this report all depend on the continued physical, chemical and biological operation of Scotland's land and marine ecosystems. One of the dominant drivers of change in these ecosystems is resource management.

The value of marine ecosystems includes the direct value from fisheries, sea fisheries almost matching crop production for value and being about half the value of livestock production in Scotland (**Tables 19.12** and **19.13**). Exports add considerably to this value (Section 19.6). The available evidence of the poor status of marine ecosystems (Defra 2010; Baxter *et al.* 2011) is of concern however, and appropriate management is required to ensure the health and long-term sustainable use of Scotland's marine ecosystems and environments.

Only certain cultural services are capable of being valued. However, the economic benefits from nature-based tourism alone, at about £1.4 billion with about 39,000 FTE jobs (Bryden *et al.* 2010), represents a significant value for Scotland.

19.9 Sustainable Management to Enhance Ecosystem Services, Biodiversity and Human Well-being

The diversity of services and their interdependence on ecosystem condition and management suggest that management approaches that focus on achieving multiple objectives are necessary. There are many examples of multiple uses of land and marine areas, and of conflict and apparent incompatibility of uses.

The variety and value of ecosystem services, and delivery of many services from the same ecosystem, management unit or land parcel, indicate that greater attention needs to be paid to multifunctional use of land and water (both fresh and marine). To achieve multiple objectives and to manage for multifunctional land and water uses requires understanding of the integrated nature of ecosystems, and the delivery of services, biodiversity and human well-being. Ecosystem assessment is one first step in this process.

There are already many approaches for the evaluation and management of multiple uses. These include environmental impact assessment and strategic environmental assessment that are used for planning, management and decision making. Both incorporate elements of an integrated understanding of ecosystems. Complementing these systems approaches, there are also approaches that are place-based. Catchment or river basin management develops local approaches to the management of river basins (Gardiner 1994; Ferrier & Jenkins 2010). Examples and guidance on catchment management are available from several sources (Dee Catchment Partnership 2007; Scottish Government 2009b, d). Forestry has adopted integrated approaches such as sustainable forest management (Wang 2004; Sturtevant *et al.* 2007) and ecosystem-based approaches (Schlaepfer 2005; Sayer & Maginnis 2007). Land use planning is also an integrative approach that incorporates linkages between communities and environments in particular places (Lloyd & McCarthy 2000; Lloyd & Peel 2007; Peel & Lloyd 2007). The governance and purposes of Scotland's National Parks makes them test beds and exemplars of community-based integrated planning to achieve multiple goals. Study of their operation and effectiveness would be informative for development of approaches to sustainable management in areas outside the National Park system.

The ecosystem approach, developed under the CBD, deliberately attempts to balance the need to conserve the healthy functioning of ecosystems with the demands placed on resources by society (Defra 2007; Mudge & Christie 2009). The ecosystem approach is set within the context of i) *decisions, plans and policies*, ii) the legal, political, social and economic *contexts* within which decisions are made, iii) the *scope* of an issue and iv) *management, consultative and participatory needs* of society (Aspinall *et al.* 2010). As a strategy for integrated management of land, water and living resources, the ecosystem approach recognises that people, with their diversity, are an integral component of ecosystems.

The ecosystem approach can be implemented through the application of a set of principles and actions (Mudge & Christie 2009; Aspinall *et al.* 2010). Key elements of the ecosystem approach include:

- Participation of people through public agencies, private land managers, voluntary groups, local residents and individuals;
- Understanding a range of management issues related to decision making, including that the ecosystem approach is itself a process that requires management;
- Understanding the scale and dynamics of ecosystems, the way they change, and impact of decisions; and
- Understanding ecosystem functions, goods and services. This includes understanding ecosystem goods and services from supply and demand perspectives, as well as knowledge of environmental quality and limits.

Independent of the approach used to develop policy-making and management strategies, there is a need to be aware of trade-offs and synergies between ecosystem services. For example, one globally recognised trade-off is between management of arable farming, with the intended and focused delivery of food production as a provisioning service, and an associated reduction in biodiversity and many other services including water quality, pollination and erosion regulation (Benayas *et al.* 2009). Reviewing and valuing all ecosystem services associated with specific land parcels or management activities provides a more comprehensive balance sheet for analysis of trade-offs and synergies. The understanding and evidence that such a balance sheet provides can contribute to achievement of multiple objective and multifunctional management with consequent improvements in social, economic and environmental sustainability.

19.10 Knowledge Gaps

Although a large amount is already known about ecosystem services in Scotland, particularly about provisioning services, there remain significant knowledge gaps. Addressing these gaps will contribute important content to the evidence base for both policy making and management of land and marine ecosystems in Scotland.

19.10.1 Biodiversity

There is a lack of information on status and trends in many important elements of Scotland's biodiversity. Biodiversity includes species, communities and genes, habitats and landscapes, and can be considered in a variety of ways, including by number or by functional relationships (Diaz *et al.* 2007). Work is needed to improve understanding of both the variety of elements and forms of biodiversity itself and the range of relationships between different elements of biodiversity with ecosystem services. For example, mammal and bird species diversity are important cultural services, plant species diversity influences carbon and nitrogen storage in grassland ecosystems (De Deyn *et al.* 2009), functional diversity of soil microorganisms is important for nutrient cycling (Brown 2002; Brussaard *et al.* 2007), and landscape-scale habitat diversity important for flood regulation. Measurement and monitoring of the functional links between biodiversity and supporting and regulating services are also needed to complement the efforts that currently apply to understanding relationships between biodiversity and provisioning and cultural services.

19.10.2 Trends in Ecosystem Services

There are a number of gaps in our knowledge of specific ecosystem services, most notably for supporting, regulating, and cultural services. In particular there is little historic data on the status and contribution of these services in Scotland and how they have changed over time. However, although of some historic and scientific interest, detailed understanding and knowledge of how *all* services have changed over the last 70 years, an aspirational objective of the UK NEA, is neither essential nor necessary for development of contemporary policy and management strategies. In contrast, an improved understanding and awareness of the connections and interdependencies between the many different services will provide a more solid evidence base for policy making and management in future. Further work to measure and monitor these connections and interdependencies, and how they change over time in future, for supporting, regulating and cultural services will be beneficial and informative.

19.10.3 Process-level Understanding

The ecosystem processes that are the basis for sustainable support and delivery of ecosystem services need further study, especially in the context of supporting multiple ecosystem services. The process-level biological, physical and chemical functions of ecosystems, and the roles of biodiversity as both a driver and product of ecosystem processes, require more study. This will improve understanding of the capacity of ecosystems to deliver services and inform analysis of trade-offs and synergies in delivery of ecosystem services. The functional behaviour and capacity of ecosystems to support the range of services documented in this report is currently unknown. Understanding of functional performance is closely linked to process-level understanding; this is a priority for scientific research as ecosystem function has links to ecosystem health, performance, resilience and sustainability. Improved understanding of the resilience and health of all Scotland's ecosystems would be beneficial, but is perhaps most critically needed for Enclosed Farmland and Marine habitats from which raw materials for food are derived. The long-term resilience of farmland ecosystems under high energy-input farming practices is, in particular, not known.

19.10.4 Monitoring and Measurement

Representative information is needed on the status, condition and trends of ecosystems and ecosystem services. There are two areas for development: the measurements made and the monitoring network used.

Considerable information on ecosystems and ecosystem services is already available, although there are a number of specific gaps. Land cover and habitat data are a foundational source of inventory for understanding the status and change in ecosystems. However, the sources of information on the area of ecosystems in Scotland over time have changed, which limits the ability to be confident of measured changes. The measurement of land cover in Scotland and its change from the 1940s to 1980s carried out by the National Countryside Monitoring Scheme (Mackey *et al.* 1998) has not been repeated to provide a recent update during the three decades since the 1980s. The Countryside Survey (Norton *et al.* 2009) does address the period since the 1980s but uses a different sampling strategy and set of data collection protocols and is not directly comparable with the National Countryside Monitoring Scheme. The Land Cover of Scotland (1988) (MLURI 1993) and the more recent Land Cover Maps of Great Britain for 2000 and 2007 were produced from different data sources (aerial photos and satellite imagery) with different scales, using different methods of interpretation (human visual versus automated digital) and with different classifications of land cover. National Forest Inventory and Native Woodlands Survey data are collected by the Forestry Commission; data on habitats are collected by Scottish Natural Heritage, and on water and other aspects of the environment by SEPA. Bringing these datasets, and others, together should support enhanced understanding of the status, condition and trends of Scotland's ecosystems.

In addition to information on ecosystems, ecosystem services need to be measured. Section 19.5 provides a list of candidate ecosystem services. Measures and indices of ecosystem status, condition and trends, and of ecosystem services should together provide an evidence base to monitor the status of uses and human benefits, including well-being, from Scotland's ecosystems, and to assess sustainability at national, regional and possibly also local scales. As part of the development of measures of ecosystem services it will also be necessary to address measurement of the interdependencies between services, as well as trade-offs and synergies.

Looking to the future, there are existing data sources that potentially offer an informative base for the monitoring and measurement of ecosystems and ecosystem services. Notably, the agricultural census collects data for agriculture that may be used as a base for assessment of ecosystem services, although this use would need to operate at a disaggregated level and conform to data protection regulations. Harmonised catchment monitoring schemes and river basin management plans and groups could provide a resource for integrated monitoring of certain ecosystem services and hydrological aspects of ecosystem process and function. The SSSI and other conservation designation networks are currently used as a monitoring system within the SNH Site Condition Monitoring programme. Analysis of the changes at these sites, considered as a whole distributed network, is providing insights into impacts of change across Scotland.

The monitoring of ecosystems and ecosystem services, especially at regional and local scales, needs to be based on a reliable, robust and statistically sound monitoring platform. The development of networks to monitor individual and groups of services is thus necessary for informed understanding of the sustainability of the state, condition and delivery of services into the future. The networks may be based on or link to one or more existing monitoring networks and programmes (e.g. the Environmental Change Network, Harmonised Catchment Monitoring Network, model and monitor farms, weather stations, river gauging stations, water and air quality monitoring sites, Countryside Survey, June Agricultural Census, or other long-term monitoring sites). Alternatively, a dedicated and fit-for-purpose monitoring system for ecosystem services might be designed, rather than basing knowledge on legacy networks of existing systems that have grown organically, with each component designed and site selected either opportunistically or for a particular, different and independent set of purposes.

19.10.5 Spatial and Temporal Scales

The evidence from the UK NEA is that a considerable amount of information is already collected and available for use. However, much of this information is at a national scale. Spatially disaggregated data that can be used regionally and locally would be beneficial. For a number of ecosystem services it would be possible and productive to conduct ecosystem service inventories at sub-national scales. For example, an inventory of ecosystem services could be applied for water catchments or for administrative regions. This would provide not only insights into the contributions of ecosystem services to regional and local economies and communities, but also evidence bases for regional and local decision making. Further, regional and local assessment would serve to raise public awareness of the contribution of ecosystems to economic and social sustainability at scales and for landscapes that are particularly important to residents and other relevant groups. The ecosystem approach provides mechanisms for managing issues that span multiple scales in space and time and for the generation and use of inventories of ecosystem services (Mudge & Christie 2009; Aspinall *et al.* 2010).

19.10.6 Linkages Between Ecosystems

Knowledge gaps also exist concerning the interrelations and interdependencies of ecosystems for delivery of ecosystem services. Ecosystems and habitats create a complex mosaic across Scotland's landscapes and the organisation of ecosystems in space has an influence on biodiversity and ecosystem services (Loreau *et al.* 2003; Pejchar *et al.* 2007; Opdam *et al.* 2009). Many of the issues and uncertainties associated with these landscape and ecological aspects of biodiversity and ecosystem services are allied to issues of scale in space and time. Analysis of the spatial pattern and organisation of ecosystems within landscapes in Scotland has not formed part of this national assessment. For regional and local scales, and for analysis of specific ecosystem services in catchments, administrative areas, or within urban or rural areas, understanding of the spatial organisation and interaction of ecosystems would be required. For management to increase or enhance particular ecosystem services in multifunctional landscapes at local and regional scales it might also be necessary for principles of landscape design to be linked to understanding of pattern and process (Nassauer & Opdam 2008; Lovell & Johnston 2009).

Given the dominantly urban base of the population of Scotland, the functional links between urban populations and communities and rural areas also requires more research, as do the links between land, coastal and marine ecosystems.

19.10.7 Links to Human Well-being

The linkages of ecosystem services to human well-being are only recently becoming recognised and considerable knowledge gaps are clear. The physical and psychological health benefits, and social and economic benefits, of greenspace in urban areas are now beginning to be understood, but the full range of benefits, and their specific values in Scotland, are largely unknown. There is scope for further research to identify the magnitude and impact of greenspace on many aspects of Scotland's population and communities. Medical, psychological and sociological research is needed to address physical and psychological health and well-being, as well as knowledge gaps related to use, access and public attitudes to greenspace. There is also potential for understanding the health benefits of food from locally produced raw materials (provisioning services) through studies of food, diet and health.

Other knowledge gaps include the use and value of natural environments for recreation, leisure and as part of the cultural identity of Scotland's communities, the roles of cultural services in enhancing human well-being in Scotland, and understanding public attitudes to the full range of ecosystem services (Warren & Birnie 2009).

19.10.8 Case Studies

Much of the available information on ecosystem services is at national or other coarse aggregate scale. To improve awareness of the connections between people and ecosystem services, and to develop understanding at landscape and local scales as proposed for cultural services, further work should identify and develop local exemplars of the contribution of biodiversity and ecosystems to ecosystem services and human well-being. This will address knowledge gaps related to societal awareness of dependence on healthy ecosystems.

19.11 Conclusions

Scotland's land, coastal and marine ecosystems sustain an extensive suite of ecosystem services and contribute significantly to human well-being and to the economic and social health of the nation. The environmental foundation (climate, geology, soil, vegetation and other biodiversity, topography/hydrography, management systems) of ecosystems in Scotland is well documented. There is considerable knowledge of the state, condition, trend and dynamics of Scotland's land, coastal and marine ecosystems, although further detailed information is needed, particularly for marine systems around Scotland.

Understanding of the supporting services provided by Scotland's ecosystems is well established, although the trends in these services over time are not well documented. Further work is also needed to establish the resilience of ecosystems to the range of pressures presented by possible environmental changes (e.g. climate change), and the consequences of societal choices and preferences (e.g. for food, landscape and energy). This means understanding ecosystems at the level of the supporting services which reflect fundamental biological and physical processes and underpin delivery of regulating, provisioning and cultural services.

Understanding the role of ecosystems in providing regulating services is similarly well established. Many of the ecosystem services provided by Scotland's ecosystems are well known at an aggregate national scale. Further investigation, and improved documentation, demonstration and awareness of the benefits of regulating services at local and regional scales and for specific communities is needed. The variety and extent of many provisioning services are very well established. Knowledge of some cultural services is well established, but for others, further attention is needed to establish specific examples of their extent and value in Scotland.

Figure 19.52 summarises the relative importance of different habitats and changes within them over the last 20 years in the delivery of final ecosystem services and indicates deterioration in service delivery for many services in all habitats other than Woodlands.

The importance of all habitats for the delivery of ecosystem services is apparent from the colours in the figure. This should not be surprising. All of the habitats and ecosystems of Scotland have been heavily influenced and shaped by human activity over periods of years to centuries. The wild and remote landscapes of Mountain, Moorland and Heathland habitats that dominate upland Scotland are a product of human activity as much as the built urban areas where over 80% of Scotland's population live. The resource management practices used in Scotland's habitats and ecosystems continue to support delivery of considerable levels of ecosystem services to Scotland's population and beyond, while influencing the state and condition of those ecosystems.

The arrows in the figure indicate the general trend of delivery of final ecosystem services from each habitat over the last 20 years. This aspect of the assessment gives cause

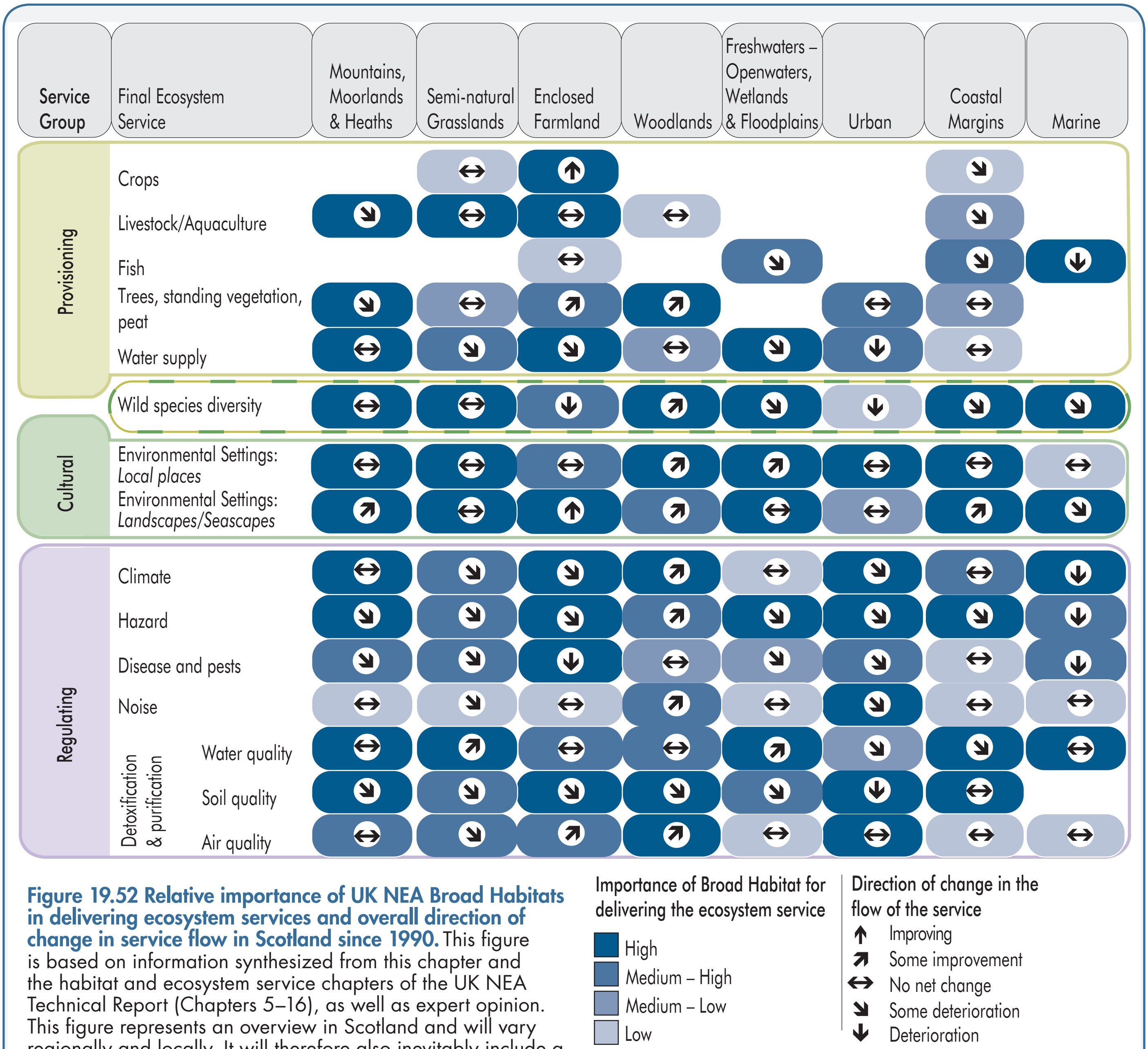


Figure 19.52 Relative importance of UK NEA Broad Habitats in delivering ecosystem services and overall direction of change in service flow in Scotland since 1990. This figure is based on information synthesized from this chapter and the habitat and ecosystem service chapters of the UK NEA Technical Report (Chapters 5–16), as well as expert opinion. This figure represents an overview in Scotland and will vary regionally and locally. It will therefore also inevitably include a level of uncertainty. Blank cells represent services that are not applicable to a particular Broad Habitat.

for concern. Of the 103 arrows indicating direction of change in the figure, 45 (43.7%) are towards some deterioration or deteriorating, 41 (39.8%) are showing equivocal changes, and only 17 (16.5%) are showing improvement or some improvement.

The Woodlands habitat shows improving/some improvement trends for eight ecosystem services, four trends that are equivocal, and one trend that shows as deteriorating/some deterioration. All the other habitats each have five to eight trends in service delivery that are deteriorating and/or show some deterioration. Marine and Urban habitats have no ecosystem services showing a trend of some improvement and/or improving; Coastal Margin, Semi-natural Grassland and Mountains, Moorlands and Heaths have a trend of some improvement/improving in only one service each. The assessment of delivery of ecosystem services, where possible over a period of the last 70 years, shows that Scotland's Broad Habitats provide significant levels of service and that there are important economic and other values that derive from this delivery. The assessment in **Figure 19.52** shows that delivery of these services is not without consequences for sustainable delivery, over 80% of the services showing deterioration or equivocal changes.

There is also good knowledge of the role of policies, legislation and regulation, societal preferences and economic drivers on management decisions that shape the future of Scotland's ecosystems. The UK NEA itself demonstrates impacts of policies and other drivers on ecosystem services. The relationships between Scottish national policy and UK and European policies as relative drivers of change in Scotland's land and marine ecosystems merit further attention.

The economic contribution of ecosystem services in Scotland over the past 70 years has been considerable. However, the growth in many of the provisioning services derived from agriculture and marine fisheries has not been without impact on biodiversity and the structure, function and processes of relevant ecosystems. In particular, the long-term resilience of farmland ecosystems under high energy input farming practices is not known.

Scotland has several flagship policies and a number of key Parliamentary Acts that will shape the state, condition and uses of Scotland's ecosystems over the next decades. Policies to address climate change, energy demand and provision, and food and health are all already in place. A land use strategy is to be published at about the same time as the UK NEA.

To contribute to development and delivery of policies related to Scotland's economy and environment, the Scottish Government Rural and Environment Research and Analysis Directorate (RERAD) research programme for 2011–2016 has a theme that directly addresses ecosystem assessment and the ecosystem approach. This will build on the work of the UK NEA, including the economic valuation and scenarios that explore future options for ecosystems and ecosystem services over the next 50 years. Many of the knowledge gaps identified here may be addressed in that programme.

The range, utility and value of ecosystem services obtained from Scotland's ecosystems are considerable. Although many of these services are traded and valued by markets and therefore subject to investment and development, many others are either valued less or not valued at all. Some of the cultural services are not capable of conventional valuation by markets. Many of the services provided by Scotland's ecosystems contribute to economic development; others are critical to health and quality of life. An inclusive and integrated approach to valuing and maintaining the full range of services and benefits enjoyed from Scotland's ecosystems and land- and seascapes can be obtained by attention to multiple services, understanding of trade-offs between services, and by wider awareness and participation in the governance of natural resource management.

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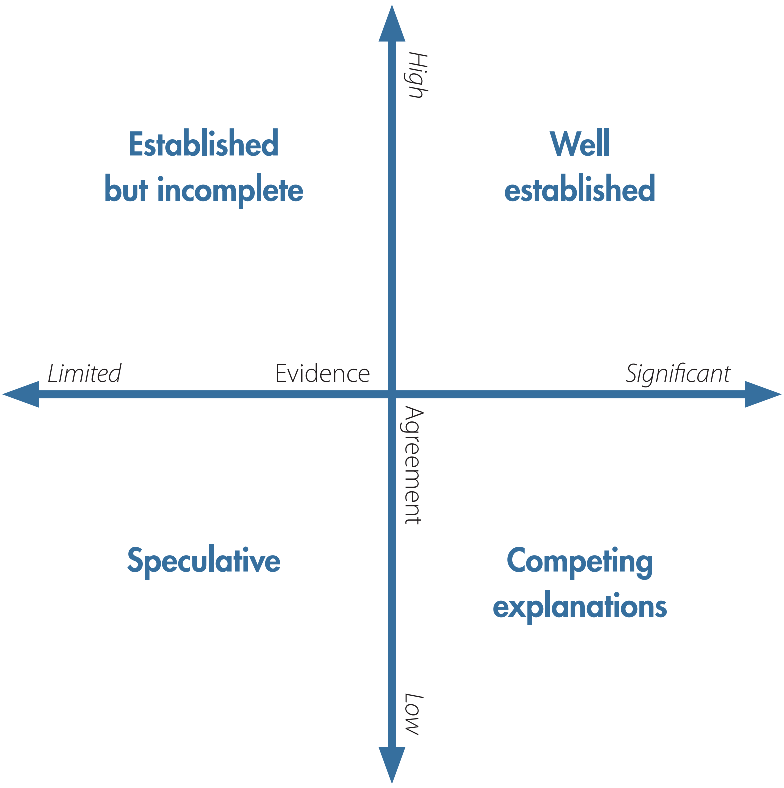
Appendix 19.1 Approach Used to Assign Certainty Terms to Chapter Key Findings

This chapter began with a set of Key Findings. Adopting the approach and terminology used by the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Assessment (MA), these Key Findings also include an indication of the level of scientific certainty. The 'uncertainty approach' of the UK NEA consists of a set of qualitative uncertainty terms derived from a 4-box model and complemented, where possible, with a likelihood scale (see below). Estimates of certainty are derived from the collective judgement of authors, observational evidence, modelling results and/or theory examined for this assessment.

Throughout the Key Findings presented at the start of this chapter, superscript numbers and letters indicate the estimated level of certainty for a particular key finding:

1. *Well established:* high agreement based on significant evidence
2. *Established but incomplete evidence:* high agreement based on limited evidence
3. *Competing explanations:* low agreement, albeit with significant evidence
4. *Speculative:* low agreement based on limited evidence



a. *Virtually certain:* >99% probability of occurrence
b. *Very likely:* >90% probability
c. *Likely:* >66% probability
d. *About as likely as not:* >33–66% probability
e. *Unlikely:* <33% probability
f. *Very unlikely:* <10% probability
g. *Exceptionally unlikely:* <1% probability

Certainty terms 1 to 4 constitute the 4-box model, while *a* to *g* constitute the likelihood scale.