Climate Connections

Scottish Wildlife Trust

towards low carbon high biodiversity economies

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About the Scottish Wildlife Trust

THE SCOTTISH WILDLIFE TRUST, established in 1964, has the charitable purpose to advance the conservation of Scotland's biodiversity for the benefit of present and future generations. With more than 36,000 members, over 120 reserves and a network of volunteers the length and breadth of the country, we are proud to say we are now the largest voluntary body working for all the wildlife of Scotland.

Our vision is of a network of healthy and resilient ecosystems supporting expanding communities of native species across large areas of Scotland's land, water and seas. This is the 'Ecosystem Approach', which is the basis of The Wildlife Trusts' UK Living Landscapes and Living Seas initiatives.

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Contents

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Above left image © Niall Benvie.

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Any opinions, conclusions or errors in this report are the sole responsibility of the authors.

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Executive summary

This report explains how the maintenance and restoration of **ecosystem health** can play a key role in helping balance Scotland's carbon budget and create a **low carbon, high biodiversity economy**.

Prerequisites to the restoration of ecosystem health include the recovery of species populations, the improvement of habitat quality and the building of functional connections between fragmented patches of habitat. By focusing effort on the restoration of ecosystem health, Scotland will make significant progress towards achieving ambitious greenhouse gas emissions reduction targets (42% by 2020) and at the same time hit targets to halt the loss of biodiversity by 2020.

The **peatlands** of Scotland alone store a stock of carbon 3 times that of all forests and other vegetation: nearly 200 times the carbon contained within the nation's total annual greenhouse gas emissions. A loss of just 1.6% of this peatland carbon is equivalent to the total annual human carbon emissions in Scotland. Active peatlands, growing **forests** and sustainably managed **uplands** will all sequester and lock up carbon in soils and biomass. Using this 'natural fix' will help reduce the estimated 1.5Gt of global carbon emissions arising from land use change every year (Trumper *et al*, 2009).

The cost of implementing a system of land use which delivers **carbon sequestering landscapes** is at least as cost effective (in terms of £ per tonne of CO_2 saved) when compared with technological fixes. Such a land use system will also deliver other vital **ecosystem services** including biodiversity, clean water, flood amelioration, soil protection, cleaner cities and recreational benefits. Provision of these public benefits on private land may lead to small reductions in productivity and income. Such changes from the de-intensification of land use will need to be compensated for through well designed agri-environment payments schemes.

The key messages contained within this report, listed below, are focused on Scotland, but are applicable to countries across Europe:

- The restoration of ecosystem health could make a major contribution to achieving Scotland's 42% greenhouse gas emissions reduction target by 2020.
- Through focusing on relatively cheap 'natural fixes' such as peatland maintenance and restoration, woodland creation and management, de-intensification of agricultural systems and the greening of settlements, Scotland could also achieve its targets to halt biodiversity loss by 2020.
- Restoring ecosystem health will make habitats more resilient in the face of climatic and environmental change, helping us adapt to the worst effects of global warming.
- In towns and cities, the greening of the urban ecosystem could create more liveable settlements, adapted to the challenges of higher temperatures and changing weather patterns such as more intensive rainfall.
- We already understand how to restore degraded ecosystems and what the key threats to ecosystem health are (Hughes and Brooks, 2009). We simply need to ensure policy, regulation and incentives are designed to allow this work to happen.
- The development of ecosystem health indicators is urgently required to help monitor change and to target action towards key systemic threats to ecosystem health. This report outlines what such indicators might look like for Scotland.

The most important section of this report is Part 3, which details '**20 policies for 2020**' based on evidence gathered during the writing of this report. These have been developed to be both affordable and deliverable within 10 years, although some fundamental changes to incentives and regulation will be required if many of them are to happen.

Introduction

Action to tackle climate change and efforts to prevent biodiversity loss are two sides of the same coin. This report makes the case that maintaining and restoring **ecosystem health** is a prerequisite to **mitigating** the impacts of, and **adapting** to, **climate change**. The creation of carbon **sequestering landscapes** and 'climate change ready' cityscapes offers new opportunities to re-balance our carbon budget whilst creating environments that provide for the needs of both the human population and for biodiversity.

This report highlights the steps necessary to restore **ecosystem health** through maintenance and improvement of **ecosystem services**: those essential processes that we obtain from the environment including clean air, clean water, pollination, biodiversity assets, flood protection and soil for food production. It considers also how maintaining ecosystem health is essential in the fight against climate change and in maintaining our **economy**, **prosperity** and **well-being** (EASAC, 2009). These approaches echo some of the key issues raised in *The Economics of Climate Change: the Stern Review* (Stern, 2007), which analysed the overall financial costs of climate change. Ensuring ecosystem health is potentially a triple win, helping climate change **adaptation**, **mitigation** and assisting **biodiversity conservation** (World Bank, 2008). This report will begin to reveal the true value of a **natural fix** (Trumper *et al*, 2009) to these problems, working with the grain of nature rather than against it.

Box 1: converging agendas

- 1990s – biodiversity conservation
- Late 1990s – biodiversity and people
- Early 2000s – biodiversity, people and ecosystem services
- The future – biodiversity, people, ecosystem health and climate change

How we plan our towns and cities for a sustainable future, what transport systems we should have, how we manage our countryside and how we look after our peatlands are all key issues that require decisions now to inform future management. Recent years have seen a number of legislative and policy changes from government in Scotland that provide a framework and clear targets for action. The Climate Change (Scotland) Act 2009 sets challenging targets for emissions reduction and is a key part of this new legislative framework, as is the Marine (Scotland) Act 2010. In addition, major policy initiatives have been launched including the Scottish Land Use Strategy (Scottish Government, 2011a). Clearly, this is a period of real opportunity for the development of actions and new ideas that will simultaneously help recover biodiversity, improve the health of ecosystems and foster a **low carbon economy**.

Of course, this new approach will not happen spontaneously, and this report makes a series of interlinked recommendations for policy development and for action to help in the creation of resilient, biologically diverse and carbon sequestering landscapes. This report is aimed at the policy community, decision makers, parliamentarians and officials, as well as third sector organisations. It is written with a focus on Scotland, but many of the issues highlighted are common across much of Europe.

Some of the issues covered in this report have been considered at a global level by a range of bodies. For example, the Intergovernmental Panel on Climate Change (IPCC, 2000, 2007) is addressing issues related to climate, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2011) will perform a similar role in relation to biodiversity and ecosystems. The UK National Ecosystem Assessment (Watson and Albon, 2010) has also drawn attention to the considerable economic value of the services we obtain from the environment.

The clear message emerging from these initiatives is that a healthy and resilient natural environment depends on the effective conservation of biodiversity.

So how does Scotland's biodiversity contribute to the services we get from the wider ecosystems around us? Soil formation, effective nutrient cycling, regulation of the climate, carbon sequestration, and the supply and storage of clean water are just some of the hidden services which depend on biodiversity. Others, such as the pollination of crops by bees and other insects (Goulson, 2003), are now perhaps better recognised and their value quantified. Given these relationships, it is important that the wider value of biodiversity in the provision of ecosystem services is given greater recognition and profile in the future.

This report is in three parts:

- **Part 1 – What we know**
  Reviews what is known about biodiversity, ecosystems and climate change, and considers the impacts of climate change.

- **Part 2 – What we can do**
  Considers the actions that need to be taken to maintain biodiversity, ecosystems and the services that we obtain from them in light of the impact of climate change. Importantly, this section reviews the role that the effective management of biodiversity can play in climate change mitigation and adaptation.

- **Part 3 – Looking to the future**
  Lays out some key policy recommendations that will help maintain biodiversity and increase the overall health of ecosystems and their resilience to climate change.

Right: Incinerator chimney. Image © Niall Benvie.

Part 1
What we know

Part 1 What we know

The impact of climate change on biodiversity in Scotland

It is estimated that Scotland's marine and terrestrial environment supports around 90,000 native species (Usher, 1997). It is this diversity of habitats and species that characterises the overall appearance of our countryside and landscapes, with sea lochs, open coasts and estuaries, rivers and farmland, as well as the unique assemblage of species and habitats in the uplands.

The close link between our history, culture and the environment is important and goes to the heart of many values and attitudes in conservation practice. It may be a generalisation to state that we like the landscapes and scenery that we grew up with; however, this is perhaps a key aspect in the minds of many when making judgements about how the land and the sea should be managed.

How do these – often strongly held – cultural traditions square with the need to adapt our land use systems to the inevitable changes that climate change will bring? There is an urgent need to inform people about the likely changes to biodiversity and to consider what can be done to manage it in the face of climate change.

Impacts of climate change on bluebell woods might include timing of natural events, a rise of invasive species and soil changes. Image © Scottish Wildlife Trust.

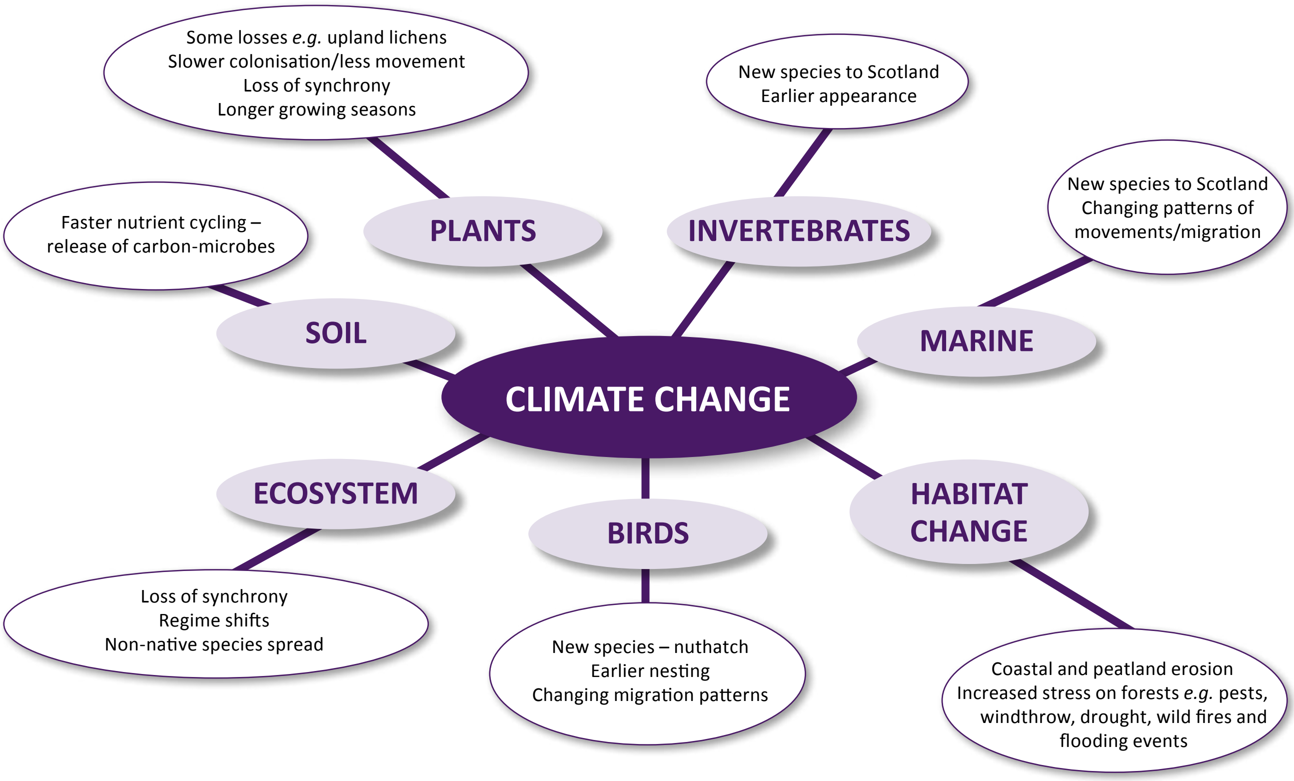
Figure 1 highlights some of the changes already occurring to habitats and species in Scotland. Whilst changes are occurring to some high profile and important species and habitats (Mackey and Mudge, 2010), perhaps the more profound changes are as yet unseen by most people. For example, climate change can alter the underlying processes that occur in soil as a consequence of variations in the patterns of temperature or rainfall, affecting the nature and timing of many other events. The soil provides a dynamic and vital underpinning for many habitats and agricultural systems, so anything that changes the way that it behaves has to be examined carefully.

Our native biodiversity is tuned to an annual rhythm of events with, historically, a degree of synchrony and predictability each year (Amano *et al*, 2010). The timing of birds' nesting, for example, coincides with the availability of food for their young; the hatching of many insects is timed to coincide with the availability of a food supply; and plants flower at times when insects are present to pollinate them. It is increasingly apparent that this natural order of events is becoming de-synchronised (Sparks *et al*, 2006).

This is a concern in relation to biodiversity and in relation to the economics of many of our land- and sea-based industries. Crops depend on pollination by insects that have hitherto occurred in sufficient numbers and distribution to undertake this role at the right time of the year. What happens, however, if the timing of insects' hatching varies due to temperature changes and their effectiveness as pollinators consequently reduces?

Changes in species distribution, breeding season, migration routes and timings are all beginning to be seen across Europe (Huntly *et al*, 2007) and have the potential to lead to large-scale changes in distribution and even extinction in some cases (Thomas *et al*, 2004). Changes in the distribution of some important habitats are likely over time, with those fragile and sensitive habitats being particularly

Figure 1: some effects of climate change on Scotland's biodiversity



vulnerable. Peatlands and some coastal habitats, for example, are particularly at risk as these have proved to be sensitive to changes in rainfall and to rising sea levels.

Changes have been recorded over recent years to some of our typical plants, with earlier flowering being seen in a number of species. New species of fauna have also started to appear in Scotland for the first time, including the Holly Blue butterfly *Celastrina argiolus*, whilst others – such as the Comma butterfly *Polygonia c-album* – have extended their range northwards (Fox *et al*, 2007). In addition, there has been a spread north by some breeding bird species such as the nuthatch *Sitta europaea,* moving into the Borders and other parts of southern Scotland (Forester *et al*, 2007).

In the marine environment, changes are being seen (Mieszkowska *et al*, 2005) in the distribution of plankton species (SNH, 2010), with a related movement north of fish species to cooler areas of sea (MCCIP, 2011).

Given this level of change, it is important that support tools are developed to assess the priorities for action when making policy decisions (Thomas *et al*, 2004). Each of the examples shown in Figure 1 may seem to be relatively small-scale when considered in isolation. However, when you consider these collectively, the effect on Scotland's biodiversity may well be profound.

The comma butterfly – a climate change winner – is expanding its range northward. Image © Oliver Smart.

Invasive non-native species

The impact of climate change on the numbers and distribution of invasive non-native species – in other words, those plants and animals that have reached Scotland only through the actions of man – is a major cause for concern (SNH, 2007). Invasive non-native species are already impacting on native species and habitats. It seems highly likely that the distribution and abundance of a number of alien species is limited due to climatic factors; however, as the climate changes these non-native species may well find conditions becoming increasingly suitable (National Botanic Gardens, Ireland, 2005).

There are many examples that can be cited from both the terrestrial and the marine environment that are of particular concern. For example, the Pacific oyster *Crassostria gigas* is presently farmed at a large number of locations around the Scottish coast and plays an important role in the economy of the Scottish shellfish industry. It is also found in other more southerly parts of the UK where it has begun to spawn naturally, leading to 'wild' Pacific oyster beds becoming established (Syvret *et al*, 2008). The colonisation of Scottish waters may simply be a matter of time. It is important to consider what the implications for the native oyster *Ostrea edulis* might be and what effects there could be on other habitats and wildlife. It will also be necessary to consider the impact such colonisation could have on the Scottish shellfish industry, and how the present quality standard of 'Scottish oysters' will be maintained in years to come if sub-standard 'wild' Pacific oysters are available. This is one of many dozens of examples highlighting the ecological and economic impacts of invasives, which are only likely to increase with climate change.


Will blue tits synchronise the hatching of their broods with the caterpillar season in decades to come? Image © Kim Taylor.

Making choices

The pace of environmental change is likely to increase over the coming decades and this will present society with some tough decisions on how best to safeguard ecosystem health. The pattern of species change is also likely to continue, as are more subtle changes affecting habitats.

But how do we deal with these changes? There are essentially three choices for habitats and species management in the face of climate change. These choices are akin to a medical triage: used in emergency situations where the level of intervention is determined by the health of the patient and by what action is possible (Mitchell, 1986). They are as follows:

1. If the patient is OK – leave them alone
2. If the patient is dead or beyond help – leave them alone
3. If the patient is injured or ill but action is possible that can help – take action

Clearly, in relation to the conservation of habitats and species, the first category of assessment is easy. If they are doing OK then no further action is needed.

The third category is also easy in terms of deciding to take action. People like trying to help, but the obvious challenge is to make sure that their actions are appropriate. Conservation effort over the last couple of decades has shown that focused action can be extremely effective, leading to positive changes for biodiversity. Examples include the reintroduction of the sea eagle *Haliaeetus albicilla* and red kite *Milvus milvus* to Scotland (Galbraith *et al*, 1995), and the recovery of the otter *Lutra lutra* right across the UK (Crawford, 2011).

The real challenge will be how we deal with the second category in the triage above, where no action is realistically practicable. The reality is that some species will disappear from Scotland in the coming decades and that a decision to take no action is likely to be the only realistic option. This is difficult territory, especially for conservationists who take pride in action and in success.

It is important to make a distinction in such circumstances between a particular species disappearing from Scotland and one becoming extinct overall. If, for example, Scotland has a high percentage of the global population of a species or extent of a habitat, then we should take action and try to maintain that population. The much trickier situation is where the Scottish population is only a small part of the global number or extent. Here, the discussions could be emotive and decisions very difficult, depending on the species or habitat involved.

Developing an overall assessment of the risk to species and habitats from climate change (Thomas *et al*, 2004), and making a judgement on their ability to adapt, is therefore urgently required to underpin any future adaptation plan for Scotland's biodiversity. Without this knowledge, resources could be wrongly deployed on species well able to adapt by themselves, or spent on species that could – in all probability – disappear from Scotland anyway in the near future.

Ecosystem-based assessment and management

The Scottish Wildlife Trust called for a fundamental shift in the way we plan and manage land in our first Policy Futures report, *Living Landscapes: towards ecosystem based conservation in Scotland* (Hughes and Brookes, 2009). The report recognised that the key to managing landscapes for carbon sequestration is through a system-level approach to the management of biodiversity.

The Millennium Ecosystem Assessment (MA) reported on the state of the world's ecosystems in 2005 (MEA, 2005). The MA was the most comprehensive stock-take of habitats and species at a global level for decades, and whilst the findings make very worrying reading, it also stresses the benefits that sustainable and equitable use of resources has brought over recent years.

A glimpse of a dystopian future? Hand pollination in China after the invertebrate population collapses. Image © Imagechina.

As well as presenting the situation at a global level, the MA lays out a range of possible options for the future management of resources. It suggests that we need to make decisions now that will improve the well-being of people around the world, in the context of climate change. It presents a framework for the management of resources, demonstrating the interdependence of the environment and human well-being. It also shows that healthy environments are essential for maintaining healthy human populations. Taking a holistic approach is seen to be important, encompassing some of the less tangible benefits that we receive from the world around us. It emphasises also the importance of internal links and processes within ecosystems, with biodiversity performing a key role in delivering the goods and services that we rely on for our quality of life.

Subsequent to the production of the MA in 2005, the United Nations Environment Programme published GEO4, a further report on the links between climate change, biodiversity and human wellbeing (UNEP, 2007). A number of countries are now undertaking ecosystem-level analyses to evaluate in more detail what their economy and culture receives from the environment and what the key dependencies are between parts of the ecosystem. In the UK, the National Ecosystem Assessment involved a large number of scientists from a wide range of disciplines (Watson and Albon, 2010). These assessments are important baselines, but we now need to move beyond assessment to real action on the ground.

Searching for ways to deal with climate change is leading to new ideas about the scale and nature of planning required (Reed *et al*, 2009). For example, we now recognise the interdependencies between land management in the uplands and lowlands: if the uplands are overgrazed, with degraded soils and sparse vegetation cover, then water run-off and flooding down-stream can be severe. We see also the connections between the land and the sea: polluted rivers impact on estuaries and coasts. Equally, we are beginning to realise that the geographical scale at which we view problems can have a bearing on how we then address those problems, as can consideration of the timescales that might be

Box 2: the key findings from the Millennium Ecosystem Assessment, 2005

Improve policy, planning and management

- Integrate decision-making between different departments and sectors, as well as international institutions, to ensure that policies are focused on protection of ecosystems.
- Include sound management of ecosystem services in all regional planning decisions and in the poverty reduction strategies being prepared by many developing countries.
- Empower marginalised groups to influence decisions affecting ecosystem services and recognise in law local communities' ownership of natural resources.
- Establish additional protected areas, particularly in marine systems, and provide greater financial and management support to those that already exist.
- Use all relevant forms of knowledge and information about ecosystems in decision-making, including the knowledge of local and indigenous groups.

Influence individual behaviour

- Provide public education on why and how to reduce consumption of threatened ecosystem services.
- Establish reliable certification systems to give people the choice to buy sustainably harvested products.
- Give people access to information about ecosystems and decisions affecting their services.

Develop and use environmentally-friendly technology

- Invest in agricultural science and technology aimed at increasing food production with minimal harmful trade-offs.
- Restore degraded ecosystems.
- Promote technologies to increase energy efficiency and reduce greenhouse gas emissions.
- Measures to conserve natural resources are more likely to succeed if local communities are given ownership of them, share the benefits, and are involved in decisions.
- Today's technology and knowledge can reduce considerably the human impact on ecosystems. They are unlikely to be deployed fully, however, until ecosystem services cease to be perceived as free and limitless, and their full value is taken into account.
- Better protection of natural assets will require coordinated efforts across all sections of governments, businesses and international institutions. The productivity of ecosystems depends on policy choices including investment, trade, subsidy, taxation and regulation, amongst others.
- We are spending the Earth's natural capital, putting such a strain on it natural functions that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted.

At the same time, the assessment shows that the future really is in our hands. We can reverse the degradation of many ecosystem services over the next 50 years, but the changes in policy and practice required are substantial and not currently underway.

involved in resolving these issues. All this has led to the development of the Ecosystem Approach, which encourages holistic management of ecosystems over long timescales and, crucially, recommends involving local people in decision-making.

This holistic approach is important in considering how climate change might impact on ecosystems, and it also indicates how ecosystem restoration might reduce many of the impacts of climate change.

The effects of climate change on ecosystems

So far, this report has looked at the impacts of climate change, including changes relating to the functioning of ecosystems and to the timing of natural events. This raises questions in the longer term about the overall stability of ecosystems in light of climate change and serves to highlight the importance of ecosystem health as a matter of urgency.

What changes could prove particularly damaging to biodiversity and to the country's economy? How will changes in one country affect the global picture, given that they will only represent a small part of the overall equation? Perhaps some of the most comprehensive analysis of ecosystems and climate change has been undertaken as part of the Intergovernmental Panel on Climate Change (IPCC) reporting processes. The contribution of Working Group II to the Fourth Assessment Report (IPCC, 2007) examined the possible impacts, adaptation and vulnerability of ecosystems to climate change at the global level (See Box 3).

Whilst many of these conclusions are, as yet, untested, the overall picture is one of rapid change in terms of species composition and the processes within ecosystems. This is worrying on two counts: first, in terms of the effect this might have on ecosystem services; and second, the changes this may cause in biodiversity at a global level. It is hard to judge exactly how many of these changes will occur locally, and how rapid and severe they might be. In truth, they may be far worse than we currently realise, damaging economies more than is presently predicted.

Restoring ecosystem health

The overall 'health' of an ecosystem depends on several characteristics relating to its structure and functioning. Whilst there is currently no standard definition of ecosystem health, one vital element is species diversity. Underlying ecological processes, such as natural successions and nutrient recycling, are another critical factor in maintaining ecosystem function. Traditionally, we have tended to look at the **state** of the system, rather than consider the **processes** which are, by their very nature, more difficult to measure and understand.

For the health of the system to be maintained, the pressures acting on it need to be reduced to a level where natural processes are able to function effectively. Gaining a better understanding of how these pressures and processes work is important.

Box 9 of this report considers the factors that would need to be measured to track the overall health of an ecosystem. These include habitat quality and condition, extent of semi-natural habitat, presence of keystone species and an effective structure. Factors such as fragmentation, presence of non-native species, degree of land-use change or pollution also help indicate the various pressures acting on the system. For example, pollutants such as reactive nitrogen from sources including ammonia emissions from agricultural fertilisers and livestock, and nitrogen oxides from fossil fuel combustion, are having a widespread and profound effect on the health of ecosystems across the UK (Sutton *et al*, 2011; Sutton and Van Grinsven, 2011).

Assessing and monitoring the health of ecosystems is an essential first step in delivering restoration, as effective management tends to follow effective assessments. The development of Ecosystem Health Indicators is therefore fundamental in driving a more sustainable and balanced approach to land use.

Box 3: key conclusions from Working Group II (IPCC, 2007)

1. During the course of this century, the resilience of many ecosystems (*i.e.* their ability to adapt naturally) is likely to be exceeded by an unprecedented combination of changes in climate, associated disturbances (*e.g.* flooding, drought, wildfire, insects and ocean acidification) and other global change drivers (especially land-use change, pollution and over-exploitation of resources), if greenhouse gas emissions and other changes continue at or above current rates.
2. By 2100, ecosystems will be exposed to atmospheric CO_2 levels substantially higher than in the past 650,000 years and global temperatures amongst the highest of those experienced in the past 740,000 years.
3. This will reduce biodiversity, perturb functioning and alter the structure of most ecosystems, compromising their resilience overall. Importantly, the working group considered that present and future land-use change and associated landscape fragmentation are very likely to impede species' migration and thus impair natural adaptation via geographical range shifts.
4. Several major carbon stocks in terrestrial ecosystems are vulnerable to current climate change and/or land-use impacts, and are at a high degree of risk from projected unmitigated climate and land-use changes.
5. Approximately 20 to 30% of plant and animal species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels.
6. Projected impacts on biodiversity are significant and of key relevance, since global losses in biodiversity tend to be irreversible.
7. With global average temperature increases of 2°C above pre-industrial levels, many terrestrial, freshwater and marine species (particularly endemics across the globe) are at a far greater risk of extinction than in the recent geological past.
8. The Working Group concluded that current conservation practices are generally poorly prepared to adapt to this level of change and effective adaptation responses are likely to be costly to implement.
9. Substantial changes in structure and functioning of terrestrial ecosystems are very likely to occur with a global warming of more than 2 to 3°C above pre-industrial levels.
10. Between around 25 and 40% of ecosystems will reveal appreciable changes by 2100.
11. Substantial changes in structure and functioning of marine and other aquatic ecosystems are very likely to occur with a mean global warming of more than 2 to 3°C above pre-industrial levels and the associated increased atmospheric CO_2.
12. Climate change and ocean acidification will impair a wide range of planktonic and shallow benthic marine organisms that have shells or skeletons, such as corals and marine snails.
13. Ecosystems and species are very likely to show a wide range of vulnerabilities to climate change, depending on imminence of exposure to ecosystem-specific, critical thresholds.

Right: Oak sapling. Image © Laurie Campbell.

Part 2
What we can do

Part 2 What we can do

Biodiversity and the low carbon economy

Biodiversity will play a major role in moving Scotland towards a low carbon economy in the coming decades. Quick wins include retaining carbon within peatlands (House *et al*, 2010) rather than letting it escape into the wider environment through erosion and oxidation, and managing woodlands in a way that enhances their ability to sequester carbon from the atmosphere (Read *et al*, 2009). Moving towards 'sequestering landscapes' will require some changes in the way we manage our ecosystems in Scotland, yet it is a challenge we must overcome – and soon – if we are to protect the carbon already locked away in the soil and in vegetation, not to mention dramatically increase the rate it is sequestered from the atmosphere.

It is obviously essential that people continue to make a living from productive areas of land and sea, but priorities for management – and in particular the financial support from government providing incentives for certain activities and lifestyles – are changing. Twenty or thirty years ago, land was used for food or timber production as a priority. We are now seeing a welcome shift – in political rhetoric, at least – towards management for multiple objectives and away from the intensively-managed monocultures which have so often failed to deliver wider benefits. Increasing consideration is being given to carbon management at a landscape scale, with support from European funding streams for practices that enhance carbon storage or sequestration becoming a real possibility for the future. This is good news for our transition to a low carbon economy, and potentially good news for biodiversity.

But looking ahead, will it really be possible to manage areas economically whilst maintaining biodiversity and assisting in the sequestration and storage of carbon? The answer to these questions is undoubtedly complex, but history tells us that expensive, hard engineering solutions to problems of this kind have, at best, yielded variable results. Can cheaper, greener solutions be achieved through utilising nature's capacity to heal itself if given the opportunity?

The key challenge for the future is to achieve a **low carbon, high biodiversity economy** that sustains the prosperity and well-being of future generations. Putting nature at the heart of land use management is seen by many as a moral obligation, but – being more hard-nosed about this for a second – it will also pay real dividends over the coming decades, positioning Scotland as a leading advocate of low cost, natural fixes to the problem of climate change and **resource efficiency**.

The following section looks at some of the priorities for action, and shows how biodiversity could be managed to help Scotland mitigate and adapt to climate change.

Developing a 'natural fix' approach to adaptation

We are faced with important choices in how we adapt to climate change (Scottish Government, 2009, 2011c). We could simply allow anthropogenic damage to the natural world and its processes to continue without further intervention, or we could take action – where possible – to assist in maintaining biodiversity and ecosystem health. As part of this approach, the Intergovernmental Panel on Climate Change looked at the types of adaptation to climate change, classifying these as 'anticipatory' or 'reactive' (see Figure 2). Whilst this classification is useful in providing examples of action, it is also important to develop actions that are anticipatory and assist natural systems to recover. We have to consider what actions are needed when managing the natural world that might anticipate some of the potential impacts from climate change. This section looks at what is possible and how to go about it.

Figure 2: types of adaptation to climate change (Adapted from IPCC, 2001)

		ANTICIPATORY	REACTIVE
NATURAL SYSTEMS			• Changes in length of growing season • Changes in ecosystem composition • Wetland migration
HUMAN SYSTEMS	Private	• Purchase of insurance • Construction of houses on stilts • Redesign of oil rigs	• Changes in farm practices • Changes in insurance premiums • Purchase of air-conditioning
	Public	• Early-warning systems • New building codes, design standards • Incentives for relocation	• Compensatory payments, subsidies • Enforcement of building codes • Beach nourishment

Taking action

What measures can be put in place to help enhance biodiversity and improve nature's ability to withstand the stresses that climate change introduces? Whilst some species and habitats will be able to adapt, it is equally clear that others will not. What can be done to ensure resilience, the continuation of ecosystem services and overall ecosystem health?

The meeting of the Convention on Biological Diversity (CBD) held in Nagoya, Japan in October 2010 agreed a set of important targets that should help guide our actions (CBD, 2010).

The agreement to tackle adaptation (see Box 4) by the 193 parties to the CBD is a major step forward and could see the development of a common approach to action in many countries. This builds on existing conservation practices and enhances the importance of taking action in the wider countryside and in marine areas, as well as in protected areas (Tyldesley, 2009; Secretariat of the Convention on Biodiversity, 2007). It stresses also the importance of restoring degraded ecosystems and thereby improving carbon management and reversing biodiversity loss. This is highly relevant to many areas across Europe – especially in the urban environment and to habitats such as peatlands and some woodland – where further recovery from past losses in extent and quality is needed.

In translating these high level aspirations from CBD into action on the ground, there are some general principles that can be applied to the conservation of species and habitats, as shown in Box 5.

So what would applying these principles mean in practice? Firstly, it would help ensure that species and habitats are more resilient, thereby improving the overall health of the ecosystem. It would also mean a renewed focus on conservation management beyond protected areas – areas where most people live, work and experience nature first hand. Getting the management right here would compliment protected area designation. Species would be able to exist throughout their natural ranges, helping to maintain viable populations and patterns of genetic variability.

Finally, it will be important to maintain flexibility both in response to changes and in managing adaptation. This is easier said than done, as once particular management is put in place certain activities can tend to become fixed. Being flexible, taking risks, learning on the job and recognising that not all techniques will be successful all seem to be important aspects of how to develop an effective approach. This is new territory for many; hence it is important to recognise that innovation, imagination and real effort will be required if we are to be successful.

Ecological coherence: joining it all up

Maintaining a high quality assemblage of native habitats and species and establishing ecological coherence are of primary importance to ecosystem health. Repairing the environmental damage of the past and creating connected networks of habitat across the country – especially close to towns and cities – is an urgent requirement (Greenspace Scotland, 2009), not to mention an exciting prospect. Such a development could prove to be economically attractive, creating jobs and adding value through increased ecosystem services over the longer term, whilst creating better places for people to live.

Improving connectivity now has considerable legislative relevance, with several EU Directives and International Conventions requiring an underpinning of ecological coherence. It is important that public bodies and others are aware of this and play their part in conserving threatened populations. Coherence will only be achieved if proactive action is put in place.

Two broad areas of policy will be required to achieve coherence.

1. Proactive initiatives, including:

- Regional spatial land use mapping to identify areas where connectivity can be enhanced.
- Development of a National Ecological Network. This is essentially an opportunity map on a national scale, with a long-term vision to create connections across regions on micro and macro scales.
- Renewed targeting of rural development and other public funds to incentivise connectivity at farm, landholding, landscape and regional scales.
- Providing support for multi-landowner partnership projects which seek to restore ecological condition and connectivity across contiguous areas of land.

Box 4: Nagoya call for action – reducing the impacts of climate change on biodiversity and biodiversity-based livelihoods

Reduce the negative impacts from climate change as far as ecologically feasible, through conservation and sustainable management strategies that maintain and restore biodiversity. Implement activities to increase the adaptive capacity of species and the resilience of ecosystems in the face of climate change, including:

1. Reducing non-climatic stresses, such as pollution, over-exploitation, habitat loss and fragmentation and invasive alien species.
2. Reducing climate related stresses where possible, *e.g.* through enhanced adaptive and integrated water resource and marine and coastal management.
3. Strengthening protected area networks including the use of connectivity measures *e.g.* the development of ecological networks, ecological corridors and the restoration of degraded habitats and landscapes.
4. Integrating biodiversity into wider seascape and landscape management.
5. Restoring degraded ecosystems and ecosystem functions.
6. Facilitating adaptive management by strengthening monitoring and evaluation systems.

2. Enabling measures, including:

- Using land-use opportunity maps to help guide the location of new developments and formulation of Local Development Plans.
- Ensuring green networks are 'designed in' to new developments where environmental impact assessments show a risk of fragmentation of existing ecological networks.

Practical examples: managing biodiversity to adapt to climate change and reduce carbon emissions

This section examines some of the major uses of the land and sea in Scotland and suggests ways that management could achieve the triple win of helping biodiversity and the mitigation and adaptation to climate change.

Protected areas

Areas designated for nature conservation purposes cover around 11% of the Scottish land surface area (SNH, 2011), whilst the designation of Marine Protected Areas are presently under consideration by the Scottish Government. Improving the

Network corridor. Image © P MacDonald.

ecological condition of these areas continues to be a cornerstone of conservation effort.

Developing the ecological coherence of these fragmented sites, however, has been less successful. This should involve the assessment of connectivity between sites, moving towards the concept of a coherent 'network' of sites, with individual protected areas linked and functioning as part of a larger

Box 5: focusing action

Aim big
The larger an area under sympathetic management the better. Larger populations of species are less prone to localised extinction.

Protect the jewels
It is important to protect areas known to be of importance for particular species and habitats, as these can act as 'foundation sites' from which to re-build ecosystem health.

Build connections
Well-connected habitats allow movement of some species and increase overall resilience to environmental change.

Be flexible
Changes to the climate are not static and the consequent impacts are likely to vary over time. Flexibility in response – while striving to limit pressures – may well enhance the chances of success.

Maintain geographical range and variation
It may help adaptability if the range and variation of a species population or habitat is conserved.

whole. Developing this network is a major challenge, but is vital for the longer-term viability of the biodiversity contained within these areas.

Climate change is already bringing about significant change to features in protected areas and, whilst the detailed composition of species and habitats will vary over time in any particular area, most sites will retain features of interest, at least over the medium term. Monitoring key biological features on these sites to detect changes and to ensure that management can be adapted is essential.

Protected areas provide vital breathing space in which the resilience of features to the changing climate can be maximised. Viewing these areas as high quality 'hotspots' for biodiversity provides a context for their role in carbon sequestration and storage.

For many protected areas, especially Natura sites, the law and implementation practice relating to the setting of boundaries is fixed. Whilst this is desirable from a legal standpoint of establishing clearly defined areas, it may in future prove difficult for the legally recognised boundary to mirror the movement or spread of the protected habitats and species in response to climate change. The development of a more flexible, expansive system of boundary management may become necessary to accommodate local shifts in the distribution of habitats and species. For conservation actions to be fully effective it will, in addition, be necessary for protected areas to sit within a wider landscape that is more sympathetically managed than at present.

The climate-adapted city – Viikki, Helsinki.
Image © Scottish Wildlife Trust.

Creating better connectivity between key habitats, and having larger areas of semi-natural habitats in the wider countryside, would help develop ecological coherence and ultimately secure greater carbon and biodiversity gains.

With the rapid development of carbon accounting, it is now time to evaluate the role of protected areas in carbon sequestration and long-term carbon storage.

Settlements

Most people in Europe live in an urban environment, spending the majority of their time in towns and cities. It is where people live and work, but it is also a place where they see and experience nature first hand. Green space in and around towns and cities is important for a variety of reasons (see Box 6), not least because they keep urban dwellers at least tenuously connected to the natural world. Urban areas are also dependent on their hinterlands for a wide range of ecosystem services, such as a supply of water and areas for recreation.

Adapting our urban environment to the impacts of climate change to ensure towns and cities remain 'liveable' will be a key challenge in the coming decades. To do this we will need to develop higher quality green space and enhance the connections between these areas. Other measures will include increasing the extent of permeable surfaces to help manage surface water, and 'micro greening' in and around buildings *e.g.* through the creation of green walls and roofs.

There is also scope for improving the sequestration potential of urban areas through the establishment of urban forests made up of networks of street trees and forested parkland.

The 2009 Climate Change (Scotland) Act set binding targets for a reduction in greenhouse gas emissions of 42% by 2020 and 80% by 2050. One of the most important tools available to the Scottish Government for delivering these targets is the planning system, not least because it is a wholly devolved competency. With good planning, we could begin to create the low carbon, ecologically sustainable, highly vibrant neighbourhoods we will need to drive down emissions and adapt to the uncertainties of climate change.

If we are to achieve these ambitious targets, it will demand nothing short of a quiet revolution in the way we live in towns and cities across Scotland. We will need a fairer 'contract with the environment', one which recognises and costs the – currently externalised – value of ecosystem services such as pollution filtration, heat regulation and the provision of pleasant, healthy environments where people want to be. We will also need to make good use of our centuries-old experience in the art of place-making, creating world-leading 'living cities'.

We urgently need to change our approach to place-making as the alternative of increasingly car-dependent, ecologically damaging, energy-hungry and people-hostile places is no longer an option.

We need to start planning now for the climate change city – indeed the climate change era – if we are to safeguard our quality of life and the health of the urban ecosystems we depend on.

This review recommends that, in addition to the use of engineered Sustainable Urban Drainage Systems (SUDS), the wider impact of sealing urban surfaces in the more flood-prone parts of Scotland needs to be considered. There is real potential here for new and innovative ways to create wetland areas in urban environments. Flood control, water management and human recreation could all benefit if new wetlands were created in and around our settlements.

One exciting challenge for the future would be to create a protected area of National Nature Reserve quality within the boundaries of one of the cities in Scotland, demonstrating that biodiversity and people can co-exist even within a very urban context. Creating such an area would have enormous educational and social benefits.

Action is possible to improve areas of green space at various levels, from individual citizens to national governments. Individuals could plant a tree, local authorities could manage local woodland and the national government could continue to promote forest planting and management policies to maximise carbon retention and sequestration near towns and cities. If parks and woodlands are the 'green lungs' of our towns and cities, we must allow them to breath in the years ahead.

Improving the state of our green space forms a key part of the Land Use Strategy for Scotland (Scottish Government, 2011a), which seeks to encourage access and use of green space and the wider countryside. The strategy rightly stresses the importance of experiencing the outdoors near where people live, and encourages the development of multifunctional land that is capable of delivering a range of economic, social and environmental benefits.

We are clearly in a period of real opportunity as far as restoring biodiversity and countering the impacts of climate change in urban areas. We now need to put these ideas into practice and secure the investment to make it happen.

Box 6: benefits of green space (Greenspace Scotland, 2008)

What are the real benefits of green space? 'Greenspace Scotland' has undertaken a review of the various benefits for the environment of having open green spaces in and around towns and cities. Greening urban areas:

- Improves overall air quality
- Improves the climate and reduces the heat island effect, especially in warmer climes
- Reduces noise pollution and the visual intrusion from traffic
- Reduces the risk of flooding where there is plenty of urban vegetation to intercept and absorb storm water

Box 7: a vision for the climate change adapted city

Characteristic	Future vision
Compact	High-density, traditional urban forms are creating vibrant, attractive and multifunctional places where people live, work and play.
Walkable	Travel distances between work and home are shorter, so more people walk and cycle. Urban streetscapes are more accessible and attractive on foot. This is encouraging people to spend more time in their own neighbourhoods, adding to the 'life' of those neighbourhoods.
Carbon neutral	Buildings are generating energy through decentralised energy systems and regulating their own temperature. Green roofs and street trees are helping insulate buildings in winter and keeping them cool in summer.
Energy efficient	High-density neighbourhoods are becoming more energy efficient due to closer proximity and the smarter, greener design of buildings.
Water smart	Permeable surfaces and more over-ground drainage is ameliorating against flash-flooding and creating attractive water environments, enhancing the urban aesthetic.
Multifunctional at a neighbourhood level	People work, live and play more within their neighbourhoods. This is increase the 'cultural capital' of place and attracting inward investment and talented in-migrants.
Networked	Public transport networks are properly joined up with effortless interchanges at key locations. These interchanges link into active travel networks which follow strategically planned green networks. Such networks also help nature adapt to climate change and enable species to move through the urban fabric.
Liveable	Heat island effects, wind tunnels, air pollution and noise are minimised through the strategic deployment of quality green armature. This is measurably improving the health and well-being of city dwellers year on year.
Recreational	People are spending more days out in the city. Larger green spaces are increasingly providing activity-based recreation, but also areas for quiet recreation.
Proactive	City authorities recognise that investment in quality places and green armature is reaping rewards and is actively improving city form and function.
Partly self-sufficient	Food is being grown in surprising places – from road verges to roofs. Organic allotments and private gardens are becoming more productive.
Planned and flexible	The city is planned with a light touch. Spaces morph from living to working to recreational spaces and back again without facing unnecessary bureaucracy.
Complex and multilayered	Ecological, social, economic and cultural networks overlay each other in a way which leads to a complex and fascinating urban living environment.
Clean and healthy	Air quality, active lifestyles and quality local food are improving life expectancy and life quality. Ground-level ozone and carbon pollution levels are falling year on year as the 'tipping point' for the shift to public transport and active travel is surpassed.
Part of sustainable hinterlands	Sustainable hinterlands are producing much of the city's food for both neighbourhood shops and larger supermarkets. It is possible to walk from the city centre to the hinterland along green networks linked with long-distance footpaths.
Desirable	Inward investment is increasing and new talent is moving in, attracted to the clean, green and sociable credentials of the climate change city.
Biologically diverse	Green spaces at all scales contain mostly native plants which are attracting a rich array of birds, mammals and invertebrates.
Inclusive and democratic	Decisions about new developments and how to manage the urban environment involve a range of local stakeholders and communities of interest.
Educational	School classes spend at least a fifth of their week out of school 'real world learning'. Green spaces have become tools for teaching children about the natural world and allowing them to explore nature at first hand.

Farmland

Farmland in Scotland ranges from the fertile lowlands to the more extensive hill farming systems of the uplands. It is estimated that emissions of greenhouse gases from farmland make up around 13% of Scotland's annual emissions (Scottish Government, 2010; CCC, 2010). Given the large area of the country that is given over to agriculture, there is a real need to ensure that farmland is managed in a way that improves overall ecosystem health *e.g.* through reducing chemical inputs and enhancing on-farm biodiversity. These are big challenges for farmers, more so as they need to be delivered whilst they cope with the impact of the changing climate on their operations.

The publication of the Scottish Land Use Strategy (Scottish Government, 2011a) provides a major opportunity to introduce measures encouraging farmers to enhance the retention and sequestration of carbon in new, innovative ways whilst simultaneously conserving biodiversity. The strategy signals a commitment from government to protect carbon-rich soils from disturbance or drying, which can cause significant declines in soil carbon stocks. It also suggests the potential for re-wetting habitats such as peatlands to protect soil carbon. The strategy also promotes 'multi-functional' land-use and promotes the Ecosystem Approach as a framework for achieving truly sustainable land management.

So, what practical measures can farmers take to reduce emissions and improve ecosystem health and resilience? Adaptation in agricultural areas is of course a global issue, and the Food and Agricultural Organisation has considered the priorities at that level as part of a wider global effort (FAO, 2007). Within Scotland, clear advice has come from the Scottish Government via their 'Farming for a Better Climate' initiative run with the Scottish Agriculture College (SAC, 2010). This identified five key action areas to help Scottish farmers reduce emissions, adapt to climate change and improve their businesses. These are:

- Using energy and fuels more efficiently
- Developing renewable energy
- Locking carbon into the soil and vegetation
- Optimising livestock management and storage of waste
- Optimising application of fertiliser and manures

In adopting these measures, farmers can make a real contribution to reducing emissions whilst simultaneously reducing input costs and potentially developing new income streams. In terms of land management and biodiversity, the last three bullet points above are the most relevant.

Carbon in farmland soils and vegetation
One of the most important ways that the effective management of biodiversity can contribute to the reduction of carbon emissions is through the management of the existing carbon content in soils. Scotland holds vast reserves of carbon in its soils, including peatlands (Smith *et al*, 2010). Whilst farmers have, in effect, being doing this for decades, it remains a priority for action. It is important to consider if there are new techniques that can be deployed to maintain and enhance the amount of carbon stored in the soil. Again, 'Farming for a Better Climate' has suggested some key actions for farmers to consider in achieving this aim (see Box 8).

Crofting can, at its best, deliver multiple benefits to communities, carbon management, biodiversity, landscapes and secure local food supply. Image © Chris Gomersall.

Managing livestock
Much of the Scottish farming industry is based on rearing livestock such as sheep, cattle, pigs and hens. The livestock sector is of key importance to the overall structure and composition of Scottish farming and makes an important financial, cultural and landscape contribution to the rural economy. The livestock sector also produces significant emissions from the by-products of the animals' digestive systems and other parts of the production process. This is also a major problem at a European and worldwide level, and solutions need to be found to reduce emissions as a matter of urgency.

Although the level and nature of these emissions relates in part to the animals involved and to the food supply they receive, achieving significant reductions whilst maintaining the overall economic viability of farms will prove challenging. Mixed farm, extensive approaches, previously used in Scotland with lower input-lower output, have something to offer here in helping the design of future farming systems. Continuing to consider quality as well as quantity products should be part of this overall change in focus.

In addition to emissions from livestock, the storage and disposal of slurry is a particularly important issue in avoiding pollution which can impact on biodiversity (especially plant communities) and the release of greenhouse gases. The efficient management of livestock and poultry and their waste can significantly reduce greenhouse gas emissions (SAC, 2010).

Practical measures
- Where possible, cover and aerate slurry and manure while stored
- Draw up and regularly review animal health plans for all your livestock. Consider on-farm anaerobic digestion of manures and slurries from livestock
- Promote genetic improvements and management systems to improve efficiency of food conversion
- Begin to take a 'whole production cycle' view of animal rearing to consider where carbon savings could be made

Fertilisers and manure
How farmers manage fertilisers and the use of manure on their farms can have a significant impact on biodiversity. Optimising the application of fertilisers and manures can reduce greenhouse gas emissions and can have real benefits for the environment (Sutton *et al*, 2011a, 2011b). 'Farming for the Future' has made some very practical suggestions for farmers to consider, including:

- Applying nitrogen at optimum rates for the crop
- Improving the timing of nitrogen applications in line with best practice
- Making sure you know the nutrient value of manure and slurry and use this first rather than fertiliser
- Ensuring slurry and fertiliser applications are separated
- Choosing plant varieties which use less nitrogen or fix nitrogen more efficiently

Box 8: locking carbon into the soil and vegetation of farmland

Aim
To reduce greenhouse gas emissions from soils by maintaining and developing activities that help to lock carbon into the soil and vegetation. This process is known as creating carbon sinks.

Practical measures
- Protect peatlands and moorland from damage by avoiding ploughing, drainage and over grazing
- Take action to control soil erosion
- Create wildlife corridors along water margins, field margins and headlands
- Retain and conserve semi-natural grasslands
- Protect and – where necessary – restore wetlands, including floodplain management
- Manage existing woodlands on farms and create new ones
- Consider reduced tillage on suitable land and ploughing in stubble and other crop residues

- Where practical, using composts and straw-based manures in preference to slurry

These measures are an indication of what can be done as part of everyday farming operations. The key is for farmers to want to put them into action, and for them to be supported in doing so.

Developing new, innovative sustainable farming systems is crucially important to the future of rural Scotland, the future of biodiversity and the future levels of greenhouse gas emissions from land use.

Forests and woodland

Forests play a significant role in the sequestration and storage of carbon (Read *et al*, 2009; FCS, 2006). At a global level, the management of forests is key to helping mitigate climate change. For example, how countries manage rainforest or 'old growth' forest in the Americas is an issue of international interest and concern.

Historically, Scotland had a considerably greater forest cover than at present (FCS, 2008). It is important to increase the extent of our forests, and to do so in a way that does not cause damage to biodiversity, enhances the resilience of ecosystems, and helps carbon sequestration and storage (FCS, 2010). Carbon-rich peatlands must be avoided when considering new areas to be planted. National targets for Scotland to increase the area under woodland from 17 to 25% by 2050 (FCS, 2006) offer a real opportunity to join up existing woodlands and create larger and more robust functional units of woodland.

As well as increasing the extent of forests, enhancing the quality of existing forest areas has real potential to bring benefits for biodiversity and to increase carbon sequestration and storage over the medium term. Expansion of Continuous Cover Forestry and long-term retention stands, for example – where a reasonable proportion of the woodland is allowed to mature and develop well beyond the normal felling rotation – would be valuable (Stokes and Kerr, 2009; Ray *et al*, 2008), particularly for saproxylic invertebrates and carbon storage.

Making full use of woodlands to assist ecosystems in adapting to climate change will require forests to be designed and managed with climate change in mind from the outset. Planning new, larger and much more diverse areas of native woodland needs to start now.

Unproven non-native commercial species such as eucalyptus are likely to cause profound changes in plant and invertebrate communities and soil biodiversity. These, we would argue, should be avoided. Instead, native species adapted to the Scottish ecosystem should be planted (possibly using more southern genetic provenances).

Soils and peatlands

Scotland holds some of the most extensive and important peatland ecosystems in the world (Smith *et al*, 2010; Reed *et al*, 2010). Globally, peatlands hold critically important carbon stores (Joosten, 2010; Limpens *et al*, 2008), with peatlands in Scotland holding huge reserves of carbon (Chapman *et al*, 2009; Billet *et al*, 2010). These areas are characterised by a unique assemblage of species and habitats, making them a key part of the Scottish landscape. In addition, these areas can – when not degraded – provide a range of ecosystem

'Old growth' areas such as the Black Wood of Rannoch are largely restricted to the best designated sites. In the future, they could be common features in forests across Scotland. Image © Scottish Wildlife Trust.


Soil biodiversity and organic matter thrive under native tree canopies and in low input or organic agricultural systems.
Image © Laurie Campbell.

services such as clean water, flood mitigation (by retaining water and only slowly releasing it), and climate regulation. In an increasingly crowded European landscape, peatlands represent some of the last remaining wild places where it is possible to experience remoteness and to feel truly part of a bigger landscape. They are, however, particularly fragile and sensitive habitats (Clark *et al*, 2010).

The management and conservation of peatlands has had a chequered history in recent decades, with their value being linked historically more to their capacity as a fuel source – or as an area on which to plant trees – than as a major carbon store or as a key biodiversity asset. The past twenty years or so has, however, seen a remarkable transformation in how we regard them. It is now imperative that they are managed effectively to retain the store of carbon they hold and to ensure that the fragile biodiversity they contain is maintained and enhanced (Worral *et al*, 2010). Indeed, taking action now could prevent the release of large amounts of carbon into the atmosphere or into associated water courses, and could avoid considerable remedial management costs down the line.

It has been estimated that deep peat habitat covers around three million hectares, which is about 12% of the UK's land surface (IUCN, 2009). Most of this is still in a largely active state and capable of forming peat, but much of it has been damaged over the years by activities such as peat extraction, burning, over grazing, drainage and forestry planting.

Action is needed, firstly to retain existing peatlands, and secondly to restore damaged areas so that they recover their ability to sequester carbon and store it effectively. A programme of re-wetting peatlands could effectively restore much of the ecosystem functioning in these areas with all the benefits that would bring.

Without restoration, damaged peatlands will continue to deteriorate, sometimes at an alarming rate, with dramatic bog bursts and severe erosion causing costly damage to infrastructure such as water supplies. The consequences for carbon management can also be high, with estimates of up to 10 million tonnes of carbon dioxide being lost each year from the UK's damaged peatlands (IUCN, 2009).

A range of policy and other actions would benefit the conservation of peatlands, as summarised in Reed *et al* as part of their draft report on policy options for the sustainable management of UK peatlands to the IUCN Commission of Enquiry into peatlands (Reed *et al*, 2010). These include:

- The national coordination of peatland policy and knowledge exchange
- Pursuing a range of options to restore damaged peatlands
- Accessing private finance for peatland restoration via carbon markets
- Improving the links between agricultural payments and provision of ecosystem services
- Encouraging cross-boundary collaboration between peatland stakeholders to facilitate the management of ecosystem services
- Improving the planning system to benefit peatlands

The uplands

The uplands of Scotland contain a complex mix of habitats including peatlands and extensive areas of farmland reviewed earlier. Scotland is renowned for its upland landscapes, and the hills, moors and mountains are an increasingly important area for recreation and tourism (Thompson *et al*, 2005). As with other areas of land, the key challenge is how to develop management that will deliver multiple outcomes from the same area (Scottish Government, 2011; Galbraith and Price, 2005).

In future, managing for livestock, or timber production, will need to be achieved alongside the maintenance of biodiversity and the sequestration and storage of carbon (House *et al*, 2010). At present, financial support mechanisms do not always encourage the delivery of such multiple benefits. Ongoing reforms of the Common Agricultural Policy and domestic agricultural policy need to be designed in such a way that livestock keeping, carbon sequestration, hardwood timber production and nature can all be produced from the same hillside, not in large mono-cultural compartments as is often the case at present.

Coastal and marine

An EU working paper on 'Climate Change and Water, Coasts and Marine Issues' (EU 2009b, 147) lists a number of key impacts due to climate change. These include warmer temperatures and acidification, with changes in species reproduction cycles and distribution as a result, as well as more frequent algal blooms and shifts in the plankton community. It suggests that rising sea levels, glacier melting, ocean acidification and changes in precipitation and river flows will affect estuaries significantly as well as offshore waters and a range of sensitive habitats.

Scotland has distinctive and characteristic marine biodiversity spread throughout open coastal areas, sea lochs, estuaries and areas of open sea (Baxter *et al*, 2011; Scottish Government, 2011b). It also has around 10% of the EU's coastline, with clean, relatively warm and productive estuarine and coastal seas surrounding our coast. They provide a range of ecosystem services valued at £11 billion per annum (Marine Scotland, 2011).

The seas are important for the provision of a range of food and other materials and play a critical role in the regulation of Scotland's climate, with the Gulf Stream in particular having a vital warming effect. The emission and absorption of carbon dioxide within ocean systems is one of the key determining factors in limiting the extent and severity of climate change, hence managing the sea to maximise its ability to sequester and store carbon will be one of the main challenges for the future.

Change is already happening in the marine environment, with a range of studies revealing just how significant this has been (Baxter *et al*, 2011). For example, the Marine Climate Change Impacts Partnership Annual Report Card (MCCIP, 2011) reports that marine air and sea temperature has risen in the north-east Atlantic and UK waters in the last 25 years. In addition, global sea level has risen at an average of 1.88 mm per year since 1955 and the ocean is becoming more acidic as a result of increased amounts of atmospheric carbon dioxide being absorbed at the surface. Areas around the coast are subject to ongoing erosion, with around 12% of the Scottish coast suffering in this way. The Report Card also indicates that a wide range of marine species are changing their distribution, with species that had a historically southerly distribution moving northwards and those with a historically northern distribution moving further north and progressively away from the UK .

Maintaining the health of our marine ecosystem at this time of relatively rapid change poses a particular challenge given the size, complexity and connectivity of the areas involved (MCCIP, 2009). The legislative framework relating to the management of the marine environment is, however, presently undergoing a major overhaul with the implementation of the Marine (Scotland) Act 2010. Developing a coherent series of Marine Protected Areas in which ecosystems are managed sympathetically is a prerequisite for the wider sustainable management of the coast and seas.

Iconic and economically important species like our Atlantic salmon depend on healthy freshwater ecosystems. Image © Laurie Campbell.

Creating a more productive and 'natural' marine ecosystem will pay real ecological and financial dividends in the medium term. For example, achieving the sustainable management of fish stocks has to be a key part of ensuring the resilience of the system, as these populations have a pivotal role in the wider moderation of the system. Ensuring the resilience of the system in this way should make it better able to withstand other climate-related stresses. Equally, the development of a range of natural measures to counter coastal erosion, such as 'managed retreat' (allowing some low-lying areas of land to flood thereby alleviating pressure elsewhere), offers real potential for a better and more environmentally sustainable form of management.

Importantly, effort needs to be coordinated at an international level to be effective. For example, the EU white paper, 'Adapting to climate changes: towards a European framework for action' (EU, 2009a, 2009b), suggested that in order to increase the resilience of coastal and marine areas, 'consideration of climate change should to be properly integrated in the implementation of the Marine Strategy Framework Directive which requires the achievement of good environmental status of the EU's marine waters by 2020'.

Freshwater

Scotland is fortunate in holding significant freshwater resources (Maitland, Boon and McLusky, 1994). Our rivers and lochs are among the finest in the world and provide an important source of freshwater for domestic and other purposes. Many other freshwater ecosystems around the world are under real threat and are already impacted by climate change (Doll and Zhang, 2010).

The management of these wetlands and the management of water for use by the population has become even more challenging in the face of climate change. Whilst many of Scotland's wetland ecosystems are in good condition, there is still work to do to ensure that those areas in need of improvement are managed to enhance their condition. SEPA (2009) have assessed the ecological condition of Scotland's surface and coastal waters (see Fig 3), indicating that whilst the overall picture is good, significant improvements are needed in some areas. These improvements are essential to enhance the overall resilience of these lochs and rivers to the changes from climate change, as well as from pollution and the other pressures they face. The work of SEPA and others over recent years indicates that improvements are achievable when appropriate techniques are applied.

Management at the catchment scale – where a holistic, ecosystem-scale approach has been used – is to be encouraged (WWF, 2007), but must be underpinned by an effective monitoring strategy to provide reliable data and information on the impacts of any management.

Flooding has, over recent decades, caused widespread damage to both urban and rural areas across Europe. Many floods are made worse by rapid, or flashy, run-off of water after heavy rainfall. This, coupled with the increasing canalisation of rivers and the limited natural storage of water in lochs and pools, means that some parts of lowland Scotland are vulnerable. Moving to a more natural flood management system – limiting rapid run-off, using natural storage in the uplands (*e.g.* peatlands, woodlands and scrub) and natural flood plains in the lowlands – seems an obvious and potentially cost-effective step.

In order to make best use of this natural ability, we need to better understand catchment-scale hydrological water flow and quantify the full extent of the potential for natural flood management so that land management can be tailored to manage flows.

Helping to understand the nature and impact of climate change

Indicators and monitoring

Changes in climate and their effects on biodiversity have been monitored around the world to reveal the nature and scale of the impacts being seen. This work has tended to focus on the 'state' of these features, recording how many individuals there are in a population or how well they are breeding in any particular year. For habitats, the measurements have focused on the extent of the habitat or on the ecological condition of the area concerned. With the development of the Ecosystem Approach and consideration of the complex relationship between climate change, ecosystem functioning and ecosystem services, it is timely to consider how best to put in place a system of monitoring to record these underlying processes and relationships in the ecosystem, whilst still monitoring some of the key species and habitats.

Scotland has data sets recording trends in the state of biodiversity over many years (Mackey and Mudge, 2010; Parsons *et al*, 2006). It is important to stress the enormous value of long-running data sets and to emphasise the need for ongoing funding of these programmes to ensure the continuation of monitoring. Put simply, without the ongoing collection of information we have no way to be sure what the impact of climate change will be. Distinguishing between short-term variations and long-term, underlying trends can reveal what is really happening to the natural world. Having long runs of data can provide the context for recent changes, giving rise to more balanced decisions and potentially to a better use of funds to address real changes rather than simply react (or overreact) to short-term variations. Developing a clear and agreed set of biodiversity trend reports for Scotland is therefore a key priority for the future. Producing detailed 'State of Scotland's Ecosystems' reports every five years (or perhaps every six years to fit with periods of reporting required under the EU Environmental Directives) is also vital.

The development and use of a series of biodiversity state indicators by governments and others over recent years has been valuable. The integration of

Figure 3: the ecological status of surface and coastal water in 2008 (Source: SEPA, 2009)

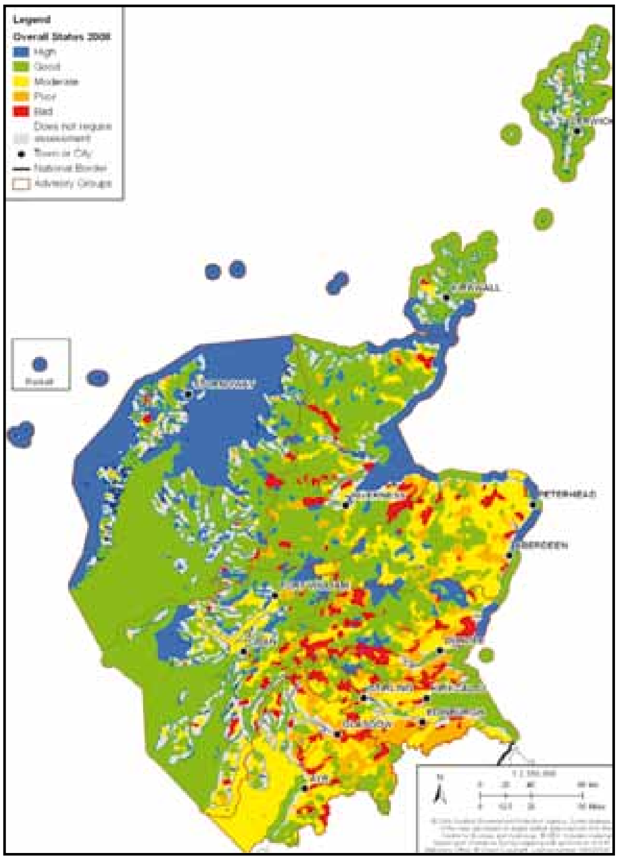


Figure 4: an overview of biodiversity from SNH (Mackey and Mudge, 2010)

Key

Increased	↑
Divergent	⇳
Fluctuated	⇔
No change	●
Earlier	←
Later	→
Baseline	□

State	S
Engagement	E
Broader Natural Heritage	N
National Performance Framework	NP

	Scotland's biodiversity	Status	Date from	Date to	Trend
S1	BAP priority species	37% increasing / stable	2008	2008	□
S2	BAP priority habitats	43% increasing / stable	2008	2008	□
S3	Terrestrial breeding birds	31% increase	1994	2008	↑
S4	Wintering waterbirds	7% increase	1975	2007	↑
S5	Breeding seabirds	28% decline	1986	2009	↓
S6	Vascular plant diversity	10% decline	1998	2007	↓
S7	Woodland diversity	17% shrub cover	1995	1999	□
S8	Terrestrial insect abundance – butterflies	Divergent	1979	2007	⇳
S9	Terrestrial insect abundance – moths	Fluctuating	1975	2004	⇔
S10	Notified species in favourable condition	71% favourable	2009	2009	●
S11	Notified habitats in favourable condition	62% favourable	2009	2009	↑
S12	Otter	92% occupancy	1979	2004	↑
S13	Freshwater macroinvertebrates	27 families average	1981	2008	↑
S14	Marine plankton	Divergent	1958	2007	⇳
S15	Estuarine fish diversity	Status being restored	1977	2005	↑
S16	Marine fish at full reproductive capacity	55% at capacity	1998	2008	⇔
S17	Invasive non-native species	14% increased	1950s	2001	↑
E1	Attitudes to biodiversity	> 70% interested & care	2006	2009	↓
E2	Green space	25% green space	2007	2009	⇳
E3	Visits to the outdoors	78% in the last year	2005	2008	●
E4	Involvement in biodiversity conservation	Increase	2005	2008	↑
E5	Membership of biodiversity NGOs	Increase	2007	2009	↑
N1	Information provision	4.7 million records	2000	2007	↑
N2	Built development	66% of 1 km squares contain development	2005	2008	↑
N3	Visual influence of built development	Increased to 69% area	2002	2008	↑
N4	Timing of seasonal events	Earlier by differing rates	1958	2006	←
N5	River quality	Excellent increased to 31%	1999	2006	↑
N6	Tourism	92% for scenery	2006	2007	↑
N7	Land under conservation management	64% of land area covered	2008	2010	⇳
NP	Biodiversity: increase the index of abundance of terrestrial breeding birds				↑
NP	Increase the proportion of adults making one or more visits to the outdoors per week				●
NP	Increase to 95% the proportion of protected nature sites in favourable condition				●

indicators used at the Scottish level with that used across the whole European Union has helped draw attention to the changes in biodiversity more widely. The challenge now is to develop this approach along with the production of trend reports, to create a system that has the ability to report on the overall health of ecosystems and on the services that we receive from them.

Developing monitoring at the ecosystem level
Amongst the variety of issues explored in this report, the concept of ecosystem health is the most important. Managing our environment so that it can support us is fundamental to our future well-being. Measuring the success or otherwise of this management effort is equally important: 'what you can't measure, you can't manage', as the old adage goes.

Box 9: Ecosystem Health Indicators (Source: Scottish Government's Biodiversity Action Coordination Group, under development)

State components
Targets need to address both the structure (condition and extent) and the functional processes that determine the capacity to deliver key services for people.
Monitor:
- Habitat quality and condition
- Extent of semi-natural habitat – heath, bog, woodland, grassland *etc.*
- Keystone species or indicator species, including wild birds and butterflies
- Soil structure and quality – Soil Survey of Scotland, Macaulay transect lines

Pressure components
Targets should aim to reduce the direct pressures on biodiversity and promote sustainable use. Different combinations of pressure act on each ecosystem.
Monitor:
- Fragmentation – index of connectivity to cover key habitat types
- Land use changes
- Degree of invasive species penetration and extent
- Diffuse pollution and water quality
- Climate change and the degree of change

Response components
Have the right policies and actions been put in place to alleviate the pressures?
Monitor:
- Climate change adaptation plan
- Targeted agricultural support mechanisms to support biodiversity in the wider countryside
- Effective network of protected areas
- Sustainable management of marine areas – habitats and species
- Effective control of pollution in both aquatic and terrestrial systems

Benefit components
Targets should highlight the key services from biodiversity and ecosystems that are of value to people, making them relevant to a wide range of stakeholders and reinforcing the links to key government priorities.
Monitor:
- Carbon balance – are landscapes sequestering or emitting carbon?
- Levels of natural water purification
- Food supply – levels of the sustainable harvesting of marine fish stocks
- Maintaining biodiversity
- Providing attractive and uplifting landscapes
- Providing clean and stimulating urban environments

Developing a system that integrates the monitoring of species, habitats and ecosystem processes is achievable, but will require the development of a standard set of Ecosystem Health Indicators which can be combined into 'scorecards' which at a glance show the overall health of the ecosystem (be it by broad habitat type or geographical area).

Along with this more integrated approach to data collation and reporting, there will also be the need to use the evidence base to change policy and action on the ground, ensuring that threats and pressures are tackled effectively.

The mountain hare faces an uncertain future as climate changes start to impact on the uplands. Image © Steve Gardner.

Part 3
Looking to the future

Part 3 Looking to the future

Climate change will fundamentally alter the economy, society and environment of Scotland. Our collective well-being is dependent on the state of our environment and the essential services that environment provides. Supporting the health and sustainable management of ecosystems through the development of a **low carbon, high biodiversity economy** in Scotland is therefore a prerequisite to our future prosperity.

The list of '20 policies for 2020' below have been carefully selected as public funding is likely to remain tight in the coming decade but, we believe, if delivered together they will move Scotland towards a system of land use management which by 2020 will have contributed hugely to both reversing biodiversity loss and reducing greenhouse emissions.

The 20 policy recommendations are followed by a list of seven practical initiatives which civil society, including environmental NGOs, could take forward to contribute to improving ecosystem health.

Future policy directions

1. Produce a comprehensive series of at least five-yearly **State of Scotland's Ecosystems** assessments, including an analysis of the benefits and services we obtain from our ecosystems and an action plan designed to tackle the **key systemic threats** to ecosystem health.

2. Develop national, regional and settlement level **Ecosystem Health Indicators** (EHIs) and report these annually using an easy to understand 'report card' format.

3. Redesign agricultural support payments so they reward farmers and other land managers for implementing **low carbon, high biodiversity food production systems** on their holdings, especially in relation to the conservation of the soil and sensitive management of livestock.

4. **Integrate programmes** and strategies for the conservation of biodiversity, the management of water quantity and quality, the protection of soil and adaptation to climate change, to progressively develop a holistic, **catchment management** approach to Scotland's ecosystems.

5. Develop a long-term vision and opportunity map for a **National Ecological Network** that will help facilitate the resilience and movement of nature in the face of climate change.

6. Prioritise actions in relation to the management of ecosystems to tackle the **key systemic threats** of climate change, habitat fragmentation, unsustainable grazing, diffuse pollution, poorly located and designed developments, invasive non-native species, unsustainably managed marine resources and unsustainable land management practices.

7. Increase the support available for the restoration of **planted ancient woodlands** (PAWS) and degraded **peatlands** as these areas are particularly important for both carbon capture and biodiversity.

8. Develop achievable targets for the restoration of **Scotland's wetlands** to assist in adaptation to climate change. Restoring natural wetland functions will pay for itself in terms of flood control and biodiversity gains.

9. Manage Scotland's **protected areas** and other conservation sites in the context of the wider landscapes in which they sit so they contribute to an ecologically coherent network of semi-natural habitats across Scotland (part of the National Ecological Network).

10. In line with emissions reductions targets in other sectors, **reduce emissions** of both carbon and reactive nitrogen from agricultural and other land-use practices, and take active measure to conserve the carbon content of the soil.

11. Implement **low-impact silvicultural systems** across half of the national forest estate, focusing on areas of ancient and native woodland and areas of biodiversity importance *e.g.* red squirrel habitat.

12. Incentivise the restoration of **Scotland's deep peat soils**, including all blanket bogs and lowland raised bogs.

13. Implement pilot restoration schemes on two substantial **floodplains**, allowing them to flood naturally.

14. Increase the extent of **woodland cover** to 30% by 2050 without adversely affecting biodiversity overall. At least 90% of the expansion should be Scottish native species.

15. Re-introduce the **Eurasian beaver** *Castor fiber* – a natural ecosystem engineer – to Scotland.

16. Continue to evaluate the financial value of **ecosystem services** to reveal what we get from the environment and what it is worth in cash terms. This will provide context for policy formulation and show true values of those services not given a monetary value at present.

17. Invest in the creation of nature-rich urban landscapes, with **high quality green infrastructure** embedded at multiple scales linked to settlement hinterlands by contiguous green networks.

18. Produce a high-level policy on **sustainable design** (or refresh the existing 'Designing Places' policy) which sets out how design and place-making can help tackle climate change, biodiversity loss, resource efficiency, unsustainable transport and waste issues.

19. Designate a network of ecologically coherent **Marine Protected Areas** covering the full range of types of site, from representative habitats to critical sites for mobile species by 2012 and, within the MPA network, include some **highly protected marine reserves** where nature conservation is the primary objective.

20. **Communicate** the concept and the value of ecosystem health and resilience in the face of climate change to both the policy community and the wider public.

As ecosystem engineers, Eurasian beavers could play a 'keystone' role in restoring wetland and woodland health. Image © Duncan Halley.

Initiatives for civil society

The following set of practical actions would help deliver the policy recommendations made above. They are designed to be real-world examples of what could be delivered by civil society with some help from government.

1. Plant a native Scottish tree for each person in Scotland *i.e.* 5.5 million trees by 2020.

2. Demonstrate the Ecosystem Approach on the ground in at least two large-scale pilot studies on-land by 2015.

3. Create a National Nature Reserve-quality conservation area within a major city to demonstrate that quality habitats can be created within urban areas.

4. Support and improve the Central Scotland Green Network through locally-led initiatives which cumulatively contribute to the ecological coherence of the Central Belt (including measurable and continuous improvements in the functional connectivity of key habitat types).

5. Foster regeneration of trees and scrub in upland areas through working with neighbouring landowners to lower deer numbers to sustainable levels, helping 'decompartmentalise' the landscape and creating a better mix and structure of habitats.

6. Re-naturalise the rivers and streams on NGO-owned land across Scotland by re-establishing natural flow patterns and routes for rivers as far as possible and progressively allow the free movement of fish along rivers that are presently dammed or that have other barriers to movement in place.

7. Prioritise the control and eradication of those invasive alien species that have the potential to cause significant imbalances to ecosystems using risk analysis.

Simple solutions – planting trees is perhaps the easiest way to restore ecosystem health. Image © Niall Benvie.

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Annex 1

Key facts from UKCIP 2009

Recent climate trends
Average global temperature and sea level have risen since the late 19th century and at an increased rate over the past few decades.

- Warming of the global climate system is unequivocal, with global average temperatures having risen by nearly 0.8°C since the late 19th century and rising at about 0.2°C per decade over the past 25 years.
- It is very likely that man-made greenhouse gas emissions caused most of the observed temperature rise since the mid-20th century (IPCC Fourth Assessment Report, 2007).
- Global sea-level rise has accelerated between the mid-19th century and mid-20th century, and is now about 3 mm per year. Human activities are likely to have contributed between a quarter and a half of the rise in the last half of the 20th century (IPCC Fourth Assessment Report, 2007).

Observed trends for the UK
Average UK temperature has risen since the mid-20th century, as have average sea level and sea surface temperature around the UK coast. Over the same time period, trends in precipitation are harder to identify.

- Central England Temperature has risen by about 1°C since the 1970s, with 2006 being the warmest on record. All regions of the UK have experienced an increase in average temperatures between 1961 and 2006 annually, and for all seasons. Increases in annual average temperature are typically between 1.0 and 1.7°C, tending to be largest in the south and east of England and smallest in Scotland.
- All regions of the UK have experienced an increase over the past 45 years in the contribution to winter rainfall from heavy precipitation events. In summer, all regions except north east England and north Scotland show decreases.
- Severe windstorms around the UK have become more frequent in the past few decades, though not above that seen in the 1920s.
- There has been considerable variability in the North Atlantic Oscillation, but with no significant trend over the past few decades.
- Sea-surface temperatures around the UK coast have risen over the past three decades by about 0.7°C.
- Sea level around the UK rose by about 1 mm per year in the 20th century, corrected for land movement. The rate for the 1990s and 2000s has been higher than this.
- The annual number of days with air frost has reduced in all regions of the UK between 1961 and 2006. There are now typically between 20 and 30 fewer days of air frost per year, compared to the 1960s, with the largest reductions in northern England and Scotland.
- There has been a decrease in the average number of Heating Degree Days (HDD), and an increase in the average number of Cooling Degree Days (CDD) in all administrative regions of the UK as a whole, between 1961 and 2006.
- There has been a slight increase in average annual precipitation in all regions of the UK between 1961 and 2006; however this trend is only statistically significant above background natural variation in Scotland, where an increase of around 20% has been observed. Likewise for an increase in average winter, only statistically significant in Northern England and Scotland where increases of 30 to 65% have been experienced.
- Average annual and seasonal relative humidity has decreased in all regions of the UK (except Northern Ireland) between 1961 and 2006 by up to 5%.

Climate change: what is happening?

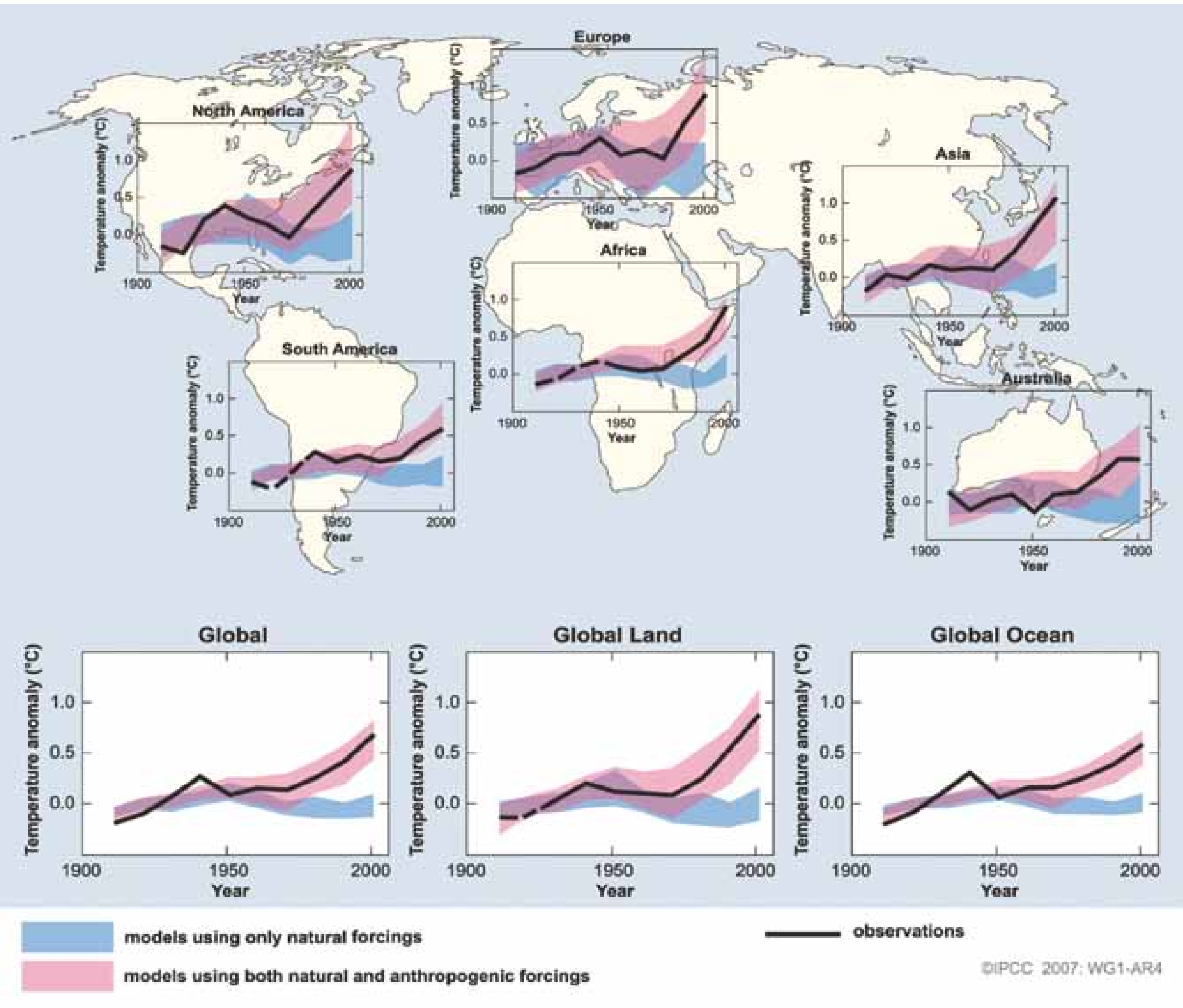
The global situation

The work of the Intergovernmental Panel on Climate Change has revealed a rise in air and ocean temperatures, widespread melting of snow and icecaps, rising average global sea level and changing patterns of extreme climatic events (IPCC, 2007). There is, of course, still debate in some quarters around the exact cause of the increases in temperature and the other changes observed and, in particular, over the contribution to these increases that is 'man-made'.

However, the evidence is now overwhelming that emissions from human activities are playing an important part in the changes seen in the world's climate. Global average temperatures increased by 0.79°C from 1906-2005 (IPCC, 2007), and for the coming two decades a temperature increase of around 0.2°C or even greater is predicted (IPCC Special Report on Emissions Scenarios, 2000).

It has been estimated that even if greenhouse gas emissions remained at present levels, a threshold has been reached whereby a consequent rise in global temperature of 2.4°C and the associated loss of biodiversity (and other adverse consequences) becomes much more likely, and may be unavoidable. It is anticipated also that the rise in temperature is likely to be higher than average on land, particularly at high altitudes in the northern hemisphere. With

Figure 5: global temperature change (IPCC, 2007)



such changes possible, the key challenge is to maintain biodiversity and to develop the resilience of species and habitats so that they have the ability to respond and adapt to change.

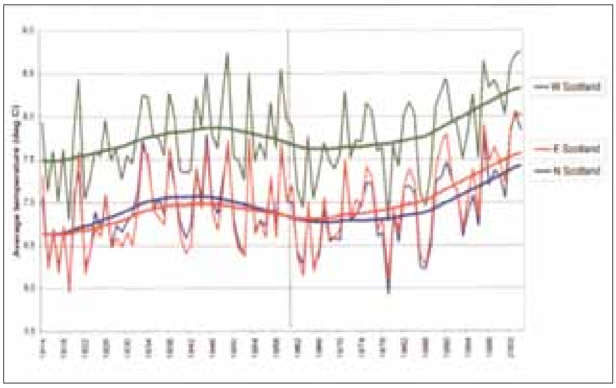
The global picture of climate change is complex, with significant changes likely to the average temperatures and rainfall and to the overall patterns of weather, with move "events" such as droughts, heavy rainfall or snowfall.

Scotland's climate

Whilst our understanding of the global pattern of climate change is improving, there is still considerable uncertainty over what the climate will be like in the future (Jenkins *et al*, 2010). We are fortunate, however, in having excellent weather recording systems in Scotland, and an examination of recent trends (Barnett *et al*, 2006) shows that on average our climate has become warmer (Figure 6) and generally wetter, although there have been considerable local and seasonal variations.

For example, the number of weather events (such as heavy rainfall) seems to be increasing in Scotland and the overall pattern of weather seems to be changing, reinforcing the need to consider both the impact of this change and how best to adapt to these different circumstances. It is important that this is updated on a regular basis so that the most up-to-date information is available on these trends.

Figure 6: average temperature for each region in Scotland from 1914-2004 (Source: Barnett *et al*, 2006)

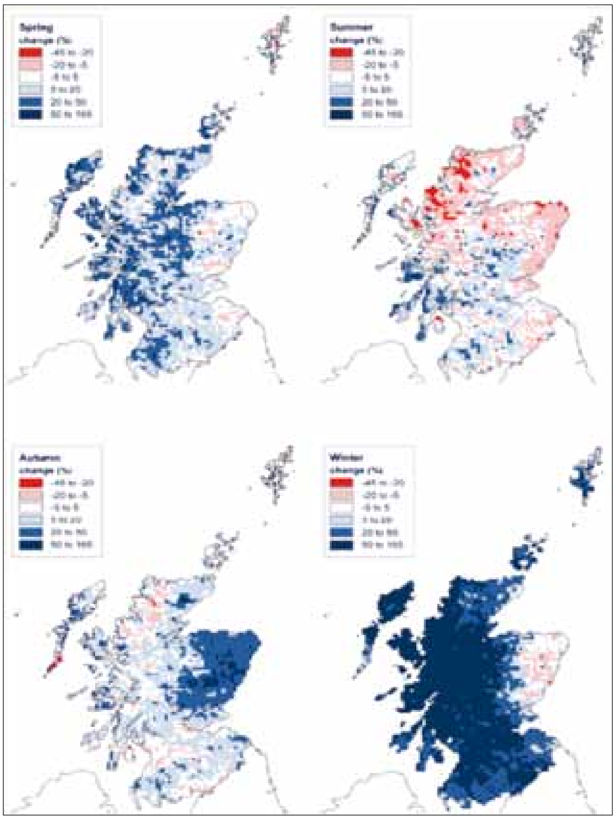


Average temperature has increased over recent decades, with a consequent increase in the overall length of the growing season. This has the potential to lead to profound changes in the overall timing and synchrony of events for a wide range of species and habitats.

Trends in precipitation

Trends in the level of precipitation have been recorded over the period 1961-2004. These show considerable change with important regional variation. Many areas in the West of Scotland are becoming wetter – especially in the winter – with some areas in the east becoming drier – especially in the summer – but appearing to have wetter periods in autumn. These changes and regional variations emphasise that this is complex information to interpret with uncertainties remaining about possible future changes.

Figure 7: patterns of change in precipitation totals between 1961 and 2004 (Source: Barnett *et al*, 2006)



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