

# Scotland's Nature on Red Alert

Climate change impacts on biodiversity



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## Summary

Photo Credit: Helen Todd

### Climate change is recognised by many as the most serious threat facing life on the planet today.

Governments have responded to that threat by agreeing to long-term goals of keeping global temperature rise this century, below 2°C and to pursue efforts to limit the temperature increase to 1.5°C. To achieve that goal will require unprecedented levels of action from governments, businesses and individuals.

This report sets out what has already happened to both the global and Scottish climate and how it might change in the future. It looks at the impacts of that change on Scottish biodiversity and brings together existing evidence on five habitats, their species, and the future impacts of climate change.

Scotland's landscapes and wildlife are diverse and beautiful. Our habitats and species are of value not just in their own right, but also for the ecosystem services they support and on which we all depend. And yet much of this biodiversity is seriously threatened by the challenge of climate change.

Species that could be affected in Scotland include some of our most well-known and iconic wildlife, ranging from Atlantic salmon to capercaillie to the freshwater pearl mussel. We have species such as the Arctic charr which are at their southern limit in Scotland and which may not be able to survive rising temperatures. Other species, such as the kittiwake and golden plover, may lose their main food sources. Plant communities will change as populations of upland and alpine specialists like Alpine lady's mantle are reduced and lowland generalist species increase. Our seas will also be affected, with cold water species like the white-beaked dolphin at risk of being lost from our waters. Increasing acidification of the oceans may also affect not just our wildlife, but our shellfish industries. And our world-renowned salmon rivers may lose more fish as water temperatures rise and summer water levels decline.

The ecosystem services on which society depends will also be affected. If our peatlands dry out, they can no longer store as much carbon for us and our rivers may no longer protect us from flooding if rainfall levels rise. Over time, there is also the potential for positive feedback within the carbon cycle to lead to an increase in carbon dioxide in the atmosphere and a worsening of the effects of climate change.

Even though the Paris Agreement calls for limiting temperature increase to 1.5°C, the current commitments submitted by governments as part of the Paris Agreement are estimated to result in a median increase in global temperature of 2.6 – 3.1°C by 2100. Temperature rise to this extent will cause catastrophic damage to our biodiversity.

Scotland's biodiversity is already experiencing a changed climate, affecting species abundance, distribution and impacting on species' ability to adapt. The State of Nature 2016 report indicates that almost one in ten Scottish species are at risk of extinction. The long-term trends (around 1970-2013) across three taxonomic groups (vascular plants, butterflies, birds) indicate that nearly 54% of vascular plant species (such as juniper) have shown decline, 39% of butterfly species have shown decline, and 44% of bird species (upland species such as dotterel and curlew, seabirds such as puffins and kittiwakes) have declined. Existing ambitions will therefore not curtail the impact of climate change on biodiversity in Scotland.

More needs to be done to combat this, as existing ambitions are not addressing the impact of climate change on Scotland's biodiversity. A net zero target by 2050 at the earliest is critical to safeguard our biodiversity. This needs to be accompanied by robust interim targets for 2030 to avoid a situation where temperatures peak and then drop, as this would have already had devastating and possibly irreversible effects for our biodiversity.

Our climate policies should also ensure that our ecosystems are resilient enough to continue to absorb greenhouse gases. A combined approach is needed to make sure we are using all the tools in our toolbox to combat climate change. Scotland has the potential to be a world leader in the fight against climate change – so that future generations may continue to enjoy, value and benefit from our biodiversity.

## Introduction

Climate change is acknowledged as the most serious threat facing the world today<sup>1</sup>.



Climate change is acknowledged as the most serious threat facing the world today. Global mean temperatures have already risen by approximately 1°C above pre-industrial levels. At this rate, the global mean temperatures can be expected to increase by 1.5°C, sometime between 2030 and 2052<sup>2</sup>. At the 2015 United Nations Climate Change Conference, delegates agreed to a long-term goal (often referred to as the Paris Agreement) to keep a global temperature rise this century to well below 2°C and to pursue efforts to limit the temperature increase to 1.5°C<sup>3</sup>. Achieving that goal will require substantial action from all countries.

A changing climate has the potential to impact biodiversity, both globally and locally. With an increase of 2°C in global mean temperature, 18% of insects, 16% of plants and 8% of vertebrates are projected to lose over half of their current climatic range (based on 105,000 studied species<sup>2</sup>). At 1.5°C, the impacts affect fewer species, with numbers declining to 6% of insects, 8% of plants and 4% of vertebrates<sup>2</sup>.

Globally, biodiversity is already declining at an alarming rate. WWF's Living Planet Index estimates that populations of all vertebrates across the globe (for which data are available) have declined by 60% since 1970<sup>4</sup>.

Biodiversity also has a key role to play in many of the ecosystem services that we depend on as humans, such as nutrient cycling and pollination. Any negative impacts on our biodiversity will also potentially affect the availability of those services for future generations<sup>5</sup>.

**Scotland's biodiversity is not exempt from this deterioration. The State of Nature Report for Scotland<sup>6</sup> findings indicate that more than half of our plant species and over a third of our butterfly species have already declined.**

A changing climate will bring yet another threat to Scotland's biodiversity. Some of our most iconic habitats, including our peatlands, uplands, coastal machair and oak woodlands have been identified as particularly vulnerable to climate change<sup>7</sup>. Habitats and species will be at risk of direct impacts from the changing physical conditions, as well as indirect impacts from changes in ecological processes<sup>8</sup>. Some species in Scotland will be at risk of extinction, whilst others may be challenged by the spread of new invasive species, pests and diseases<sup>9</sup>.

Recognising the importance of climate change as a global and local threat, the Scottish Government introduced the Climate Change (Scotland) Act in 2009. At the time, this set world-leading reduction targets for greenhouse gas emissions, including a target to reduce emissions by 80% by 2050. The Scottish Government has now introduced a second Climate Change Bill with new targets, to align Scotland's ambitions with the requirements of the Paris Agreement. In combination with actions from other governments, the extent of the new targets and the timescale for achieving them will directly influence the magnitude of climate change impacts in the future.

This report looks at the potential impacts of climate change on Scotland's biodiversity. It highlights the extent of the threats and demonstrates how those threats increase with increased global temperature rise. Case studies are provided which look at how key Scottish habitats, and the species within them, can be expected to respond to a changing climate.

## Climate change and biodiversity

Climate change has been identified as a major threat to biodiversity on a global scale.

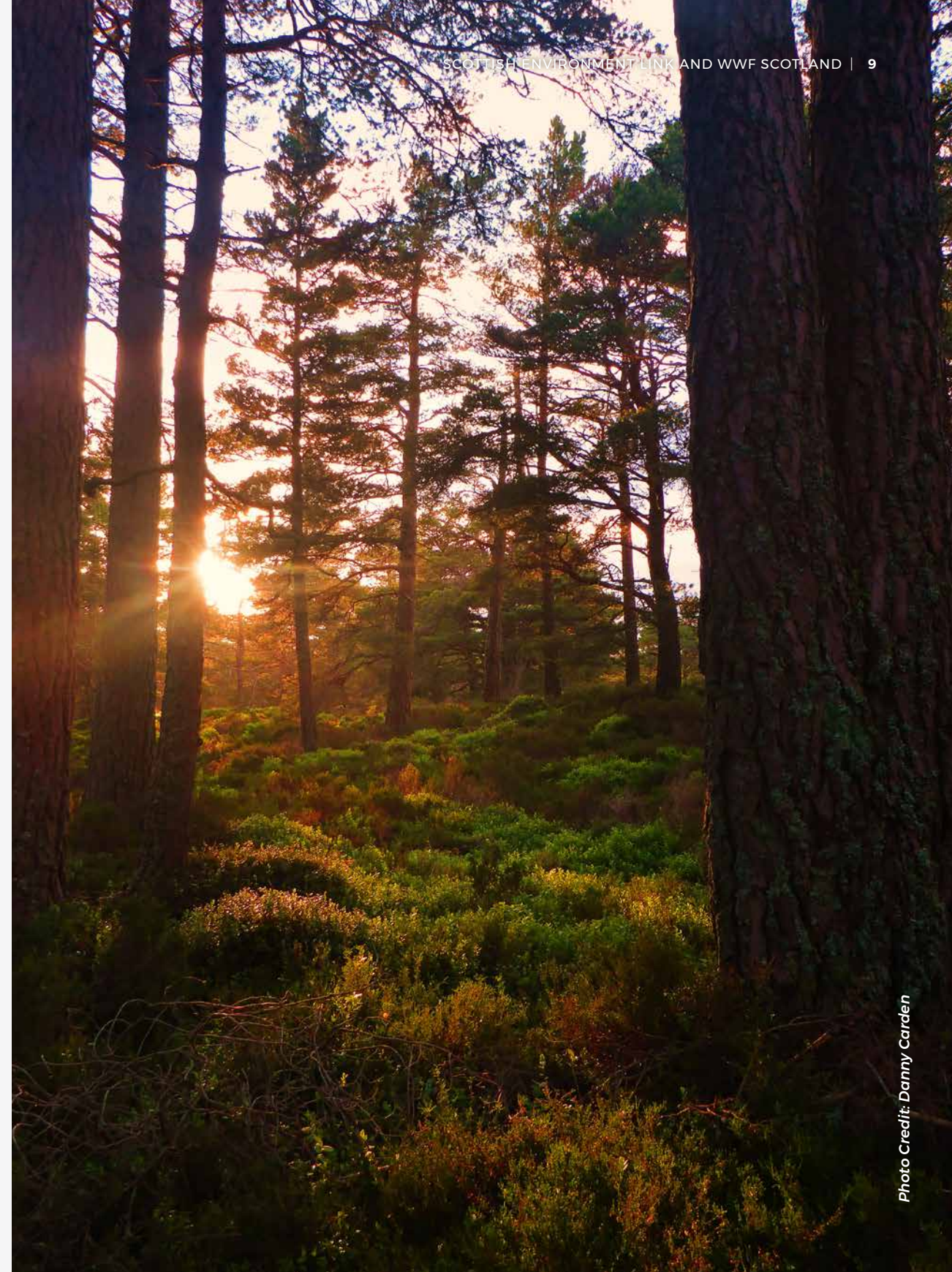
The Intergovernmental Panel on Climate Change (IPCC) has stated that it expects climate change to be a “powerful stressor on terrestrial and freshwater ecosystems in the second half of the 21<sup>st</sup> century, especially under high-warming scenarios<sup>10</sup>”.

Changes to climate have taken place in the past, and studies of the fossil record show that multiple species extinctions occurred during these periods<sup>10</sup>. A recent synthesis of scientific research into likely extinction rates under future climate change suggests that 5.2%, or 1 in 20 species, could face extinction under a global temperature rise of 2°C (extinction was assumed likely to take place if a species’ available range fell below a certain threshold)<sup>11</sup>. This study also highlighted that even for species not directly threatened with extinction, climate change may lead to substantial changes in their abundance and distribution, as well as in the interactions between different species.

All species have an identifiable climate space or range – an area where the climatic conditions are suitable and a population can be maintained. That climate space will move in response to climate change, causing range loss for some species and range expansion for others.

**A UK review which assessed over 3000 plant and animal species found that 21%, or 640 species, were at high risk of range loss under a low emissions climate change scenario<sup>12</sup>.**

The same review also found that many species may be able to expand their range through Britain, although it highlights that this dispersal could be limited by fragmented habitat. Those species associated with upland habitats, and cooler and wetter climatic conditions were more likely to be at risk of range loss than range expansion<sup>12</sup>. Inevitably, this will include many species found in Scotland, where cooler, wetter conditions and upland habitats predominate. This means that as species shift their ranges in response to climate change, the overall number of species present in Scotland may increase. However there is likely to be a decline in species that are associated with arctic, alpine and montane environments<sup>13</sup>. That could include some of our mountain birds, such as the snow bunting and the ptarmigan, as well as some of our specialist mountain plants, like the small mosses found beneath late-lying snow beds.



## Vulnerability of Scotland's biodiversity to climate change

Scotland's position at the western edge of the European continent will exacerbate the impacts of climate change as it limits the extent to which species can move in response to changed climatic conditions. For terrestrial species that need to move north to track suitable climate space, there is, quite literally, nowhere to go. This applies across northern Europe for species that need to move north, as the Arctic Ocean presents a natural barrier to movement<sup>14</sup>.

Climate change will place additional pressure on Scotland's biodiversity. But much of Scotland's biodiversity is already suffering from the impact of pressures such as over-grazing, habitat fragmentation and the spread of invasive non-native species<sup>6</sup>. The Biodiversity Intactness Index (BII) is one way to assess the extent of the loss of nature due to human activities. Index values below 90% indicate that ecosystems may have fallen below the point at which they can reliably meet society's needs<sup>15</sup>. The State of Nature report<sup>6</sup> calculated Scotland's Biodiversity Intactness Index value as 81.3% – suggesting that biodiversity is already under significant pressure in Scotland. For example, 44% of Scotland's blanket peat bog was lost between the 1940s and the 1980s<sup>6</sup>.

**80% of peatlands are now degraded in some way<sup>16</sup>.**

In the same time, areas of broadleaved and mixed woodland fell by 23% and 37% respectively<sup>6</sup>. Native woodland now only covers 4% of Scotland's land area and over half of those woodlands are in unsatisfactory condition for biodiversity<sup>17</sup>.

For species that need to alter their range to reflect changed climatic conditions, existing habitat fragmentation may impair their ability to move across landscapes. This could result in isolated populations which are unable to respond to shifting climate space, leading to localised extinctions and the loss of species from certain geographical areas. A recent scientific review paper found that 70% of the world's remaining forest areas are within 1km of a forest edge<sup>18</sup>. These edge areas can cause a barrier to species migration, if the adjacent land use is not suitable for the species to move across (for example, woodland species such as the dog's mercury plant may not be able to spread across intensively farmed arable land). When the researchers looked at fragmentation impacts across a variety of habitat types and on different continents, they found that fragmentation can lead to a decrease in biodiversity of between 13 – 75%.

Other pressures may combine with climate change to result in changes in the composition of ecosystems. For example, air pollution, over-grazing and climate change have all affected upland grassland communities, resulting in significant alterations in species compositions<sup>19</sup>.

## Climate change feedback

Biodiversity supports ecosystem services, which we rely on for the functioning of human societies. A key ecosystem service in relation to climate change is the sequestering or storage of carbon, which prevents it contributing to atmospheric carbon dioxide levels. Natural vegetation has the potential to absorb carbon, by locking it into the woody stems of plants and feeding it down into roots and the soil<sup>20</sup>.

As global temperatures and carbon dioxide levels rise, there is potential for natural vegetation to become more productive initially, enabling it to store more carbon<sup>21</sup>. However, this productivity is expected to peak around 2030, with ecosystem disruption (through for example, drought, disease and floods) leading to a reduction in vegetation production and a decrease in carbon storage<sup>21</sup>. Ultimately this may result in vegetation becoming a net carbon emitter by the end of the 21<sup>st</sup> century.

Recent evidence suggests that this peak may have already been reached in the northern hemisphere, with the amount of carbon stored each year by the biosphere over the summer (when vegetation is growing) decreasing slightly since 2006<sup>20</sup>. This would inevitably lead to a more rapid rise in atmospheric carbon dioxide and a worsening of the effects of climate change.

Thus far, the reduction in storage ability in the northern hemisphere each year is comparable to adding the human-induced annual greenhouse gas emissions from China to the atmosphere<sup>20</sup>. This demonstrates the potential for catastrophic positive feedback to further exacerbate climate change as a result of disruption to the ways in which ecosystems function.

## Scotland's changing climate

The UK Climate Projections were updated in November 2018<sup>22</sup> and have a number of revisions compared to the 2009<sup>23</sup> projections that have informed most climate change research to date.

At the time of writing, the full dataset was unavailable, but the main headline impacts can be derived from the published data. The new data come from revised climate models and enhanced cross-referencing with observations of climate.

The 2018 projections use different scenarios to the 2009 projections, based on future greenhouse gases called the representative concentration pathways (RCPs) covering a more up-to-date range of assumptions around future population, economic development and include the possibility of mitigation of greenhouse gas emissions because of international targets<sup>24</sup>. It is important to note that the low emission scenario (RCP 2.6) is a derived dataset, meaning that there is greater uncertainty than for the high emission scenario (RCP 8.5) as there may be interactions between different climate factors for which we cannot currently account.

As the updated 2018 projections are unavailable at a regional scale at the time of writing, the 2009 projection data has been used to provide an overview of the potential changes within Scotland by 2050. The 2018 projections have broadly similar median predicted changes compared to 2009 projections, so inclusion of these predictions remains relevant. However, the 2018 projections do show an increase in the possible ranges, so it is possible that the climate may be significantly more hostile than was previously thought by the end of the 21<sup>st</sup> century.

### North

+   
26mm

#### NORTHERN SCOTLAND

Northern Scotland is not expected to see quite such high summer temperatures with a maximum increase of 3.9°C projected. Winter precipitation could increase by up to 26mm in all emissions scenarios, whilst projections for summer precipitation are similar to the rest of Scotland.

+   
31mm

### West

#### WESTERN SCOTLAND

Changes in Western Scotland are like Eastern Scotland, but mean winter temperatures could rise by up to 3.3°C, whilst precipitation could increase by 31mm under all emissions scenarios.



+   
21mm  
East

#### EASTERN SCOTLAND

Under low and medium emissions scenarios, an increase in winter temperature is expected of between 0.6 – 3.1°C. An increase in mean summer temperature of between 1 – 4.5°C is predicted, raising the possibility of significantly hotter summers. Meanwhile, under a high emissions scenario, winter precipitation could rise by up to 21mm, whilst summer precipitation is most likely to decrease by up to 28mm.

### Lowlands

For most of lowland UK, heavy rain days (days with rainfall greater than 25mm) are expected to increase by a factor of between 2 and 3.5 in winter, and 1 to 2 in summer by the 2080s under the medium emissions scenario. This will be likely to lead to more flooding and river spate events.



Photo Credit: Adobe Stock

## Climate changes to date

Scotland's biodiversity is already experiencing a changed climate. From the global to the local scale, there is significant evidence that our climate is changing.

The IPCC's most recent report states that the world has experienced a long-term warming trend since pre-industrial times. Global mean surface temperature for the decade 2006–2015 was 0.87°C (calculated as between 0.75°C and 0.99°C) higher than the average over the 1850–1900 period. The report also highlights that warming greater than the global annual average is being experienced in many regions, including two to three times higher in the Arctic<sup>2</sup>.

In 2014, Scotland and Northern Ireland Forum for International Research (SNIFFER) looked at climate trends in Scotland<sup>25</sup>. Between 1961 and 2004, they found that annual average temperatures had increased by just over 1°C in Eastern and Western Scotland and by just under 1°C in Northern Scotland.

They also found a 58.3% increase in the mean precipitation total for winter in Scotland, and a 21.1% in the annual precipitation total for Scotland, suggesting a significantly wetter climate. However, there was no clear trend in summer precipitation changes.

As would be expected from warmer temperatures, days of snow cover in Scotland had decreased by 32.1%. Days of heavy rain (greater than 10mm in a day) had increased by a total of 8.3 days, suggesting an increased likelihood of floods and spate events.

## Climate change pathways

Both the global and the Scottish climate have already begun to exhibit signs of change. However, future patterns of climate change could develop in a number of ways.

The Paris Agreement signalled a clear intention by governments to limit global warming to below 2°C and to pursue efforts to move closer to limiting the increase to 1.5°C<sup>3</sup>. Therefore, depending on the actions taken by governments, global temperature increase could follow one of several potential pathways:

- ↑ A rise limited to 1.5°C
- ↑ A rise limited to 2°C
- ↑ A rise which exceeds 2°C
- ↑ A rise which exceeds 2°C temporarily, before returning to a lower level ('an overshoot scenario')

These different pathways will have different impacts on biodiversity. The IPCC report<sup>2</sup> highlights the likely impact of a 1.5°C rise versus a 2°C on a global scale. Unsurprisingly, the number of species which will lose over half their climate space is lower with a smaller temperature rise (18% of insects, 16% of plants and 8% of vertebrates at 2°C versus 6% of insects, 8% of plants and 4% of vertebrates at 1.5°C). At 1.5°C versus 2°C, an additional 5.5 – 14% of the globe becomes available to act as climate refugia for plant and animal species, which is an area roughly equivalent to the current global protected area network<sup>26</sup>. Other related risks, such as forest fires and the spread of invasive species are expected to be lower with a 1.5°C rise than 2°C<sup>2</sup>.

Ocean temperature rises are also expected to be lower if a 1.5°C pathway is followed. The IPCC report suggests that with 1.5°C of warming, one sea-ice free Arctic summer is projected per century. However, at 2°C, this increases to at least one per decade. Sea level rise could reach 50cm by 2100 with 2°C of warming but be limited to 40cm with a 1.5°C rise<sup>27</sup>. Ocean acidification is also expected to be more significant at 2°C<sup>2</sup>.

To date, there has been relatively little research undertaken on the differing impacts of a 1.5 versus a 2°C temperature rise on UK or Scottish biodiversity. Long term datasets are limited for many species, so it is not often possible to correlate changes in populations directly with changes in temperature. However, many studies have attempted to predict the impacts of climate change on Scottish biodiversity, both in terms of habitats and species.

## Case studies

The remainder of this report identifies some of the impacts of climate change on key habitats and species in Scotland. Each case study looks at a specific habitat and identifies the likely impacts on species within those habitats. This is not an exhaustive list of all impacts on all Scottish biodiversity, but it highlights some of the major threats to some of our species.





Photo credit: Adobe Stock

# Freshwater habitats

The rivers and burns of Scotland are an integral part of the landscape, famed the world over for their salmon stocks. And whilst it may seem that there is nothing more refreshing than dipping your toes in a cool burn on a hot day, our freshwater environment is also at risk from a changing climate.

## HABITAT CHANGES DUE TO CLIMATE CHANGE

A changing climate will have several significant impacts on Scottish rivers in terms of physical changes.

### Temperature

Mean air temperatures are predicted to rise in Scotland as a result of climate change. The extent of that rise varies with different emission scenarios, as discussed in the section on Scotland's changing climate. The relationship between air temperature and water temperature is complex and can be affected by a number of factors, including altitude, extent of shading and adjacent land use.

Researchers have modelled this relationship and predict that the maximum water temperature could rise between 0.4 – 0.7°C for every 1°C rise in maximum air temperature during the summer months<sup>28</sup>. So, we can expect our river waters to get warmer if air temperatures rise as predicted.

As water temperature rises, dissolved oxygen levels in the water decrease, reducing availability of oxygen for aquatic life. Warmer water temperatures can also combine with lower water levels to further reduce dissolved oxygen availability. In the lower sections of rivers and in still waters, algal growth may also increase in warmer weather, which places a further demand on any oxygen that is available, resulting in an increased risk of deoxygenation<sup>29</sup>.

### River levels

Increased rainfall, particularly during the winter months, is also expected with a changing climate. The extent of the increase varies across Scotland and with different emission scenarios. The intensity of that rainfall is also expected to increase, leading to both a greater number of flood events, and an increased severity of flooding.<sup>23</sup> Without careful land management, high intensity rainfall can also result in soil erosion, which can contribute to water pollution as silt is washed into burns.

Conversely, summer precipitation levels are predicted to decrease, leading to drier summers and an increased risk of drought. This will lead to lower river levels and in extreme cases could lead to sections of rivers drying up. When river levels are lower, there is less capacity to dilute any incoming pollution, so drier conditions could also lead to more heavily polluted freshwater systems<sup>30</sup>.

### HAVE PHYSICAL CHANGES ALREADY BEEN DOCUMENTED?

#### River temperature

High quality, long term datasets on river temperature are limited but the Girnock Burn in Aberdeenshire has been studied since 1968<sup>31,32</sup>. Between 1970 and 2000, an increase in monthly average temperature of 1.46°C was recorded for April, and an increase of 1.04°C was recorded for July<sup>32</sup>.

Similar increases have been recorded by researchers modelling long term water temperature changes from a combination of changes in air temperature and shorter runs of water temperature records. For example, an estimated increase of 1.4°C for water temperature in a forest stream and 1.7°C in a moorland stream has been modelled in Wales between 1981 and 2005<sup>33</sup>.



Photo Credit: Charlie Phillips

### Precipitation

There are more long-term datasets available for precipitation, and a 58.3% increase in average precipitation totals has been recorded for winter months between 1961 and 2004<sup>25</sup>. An increase of 8.3 extra days per year of heavy rain (rainfall equal or greater than 10mm in one day) was also recorded across Scotland<sup>25</sup>.

Data are also available for river levels over the longer term. For example, data from a gauging station on the River Spey was analysed by the Spey Foundation which found an upwards trend in river flows in winter, spring and autumn between 1953 and 2013<sup>34</sup>. When flow records were analysed for rivers across the UK, other researchers found that the northern and western parts of the country were experiencing a trend towards more extended periods of high-flow and more spate conditions<sup>35</sup>.

### IMPACTS ON BIODIVERSITY

#### Atlantic salmon, trout and Arctic charr

Scotland's rivers are famed for their fish stocks, with visitors coming from far and wide to fish our salmon. But climate change has the potential to impact on many of our freshwater fish species, including Atlantic salmon, trout and Arctic charr. Atlantic salmon is listed in Annex II of the EU Habitats Directive and the UK populations are of European importance<sup>42</sup>, whilst Arctic charr is a conservation feature in five Scottish Sites of Special Scientific Interest<sup>43</sup>.

Perhaps the most obvious impact is from rising water temperatures. Atlantic salmon, trout and Arctic charr are all cold-water adapted species and higher water temperatures can be lethal for them.

### ATLANTIC SALMON

#### WHAT SPECIES:

Atlantic salmon. Known as the 'King of the Fish', Atlantic salmon is Scotland's largest freshwater fish, growing up to 1.5 m in length. They breed in freshwater but spend most of their lives feeding at sea, returning at maturity to spawn in the river of their birth.

#### WHERE IS IT FOUND:

Throughout Scotland.

#### WHY IS IT IMPORTANT:

This is a keystone species, as it helps define the aquatic ecosystem, and as a species it is integral to aquatic biodiversity<sup>36</sup>. It is also an indicator of the state of health of the freshwater environment.

Atlantic salmon supports a globally recognised angling industry in Scotland. It is estimated that anglers spend a total of £113 million on angling in Scotland<sup>37</sup>, with salmon and sea trout anglers accounting for over 65% (£73 million) of this total. It is a UK Biodiversity Action Plan priority species, and has declined markedly in many rivers, particularly on the west coast of Scotland.

#### HOW WILL IT BE AFFECTED:

Increased water temperatures and increased flood events causing washout.

Depending on the speed at which the water temperature rises, and the duration of exposure to warmer water, rise in water temperatures between 27 and 33°C are lethal to Atlantic salmon<sup>44</sup>. Trout cannot survive water temperatures of more than 25 to 30°C, whilst young Arctic charr can only survive temperatures up to 22 to 27°C.

It is unlikely that we will experience water temperatures that high in Scotland in deep, fast-flowing water. However, with lower water levels in drought years, there is potential for temperatures to reach lethal levels in open water areas, with no shading. This could mean that open, unshaded, moorland locations experience changes in water temperatures, resulting in these locations becoming unsuitable for brown trout. Additionally, further temperature rise may make these locations unsuitable for Atlantic salmon<sup>45</sup>.

Even without reaching a lethal temperature, an increase in water temperature can reduce growth and egg survival rates for these fish species. For example, optimum hatching rates for eggs of Arctic charr occur at winter water temperatures of just 1-5°C. The viability of eggs of Arctic charr is therefore particularly vulnerable to increases in temperature<sup>46</sup>.

**Scotland is regarded as a stronghold for Arctic charr, but a recent study showed that 10 of the 11 UK populations of Arctic charr have declined in abundance since 1990.**

Those populations considered to be most vulnerable to climate change (due to their location, altitude or depth) were found to have declined the most<sup>47</sup>. The threat to Arctic charr is also exacerbated by their preference for loch locations, which isolates them in one location and makes it harder for them to shift their range in response to changing climatic conditions<sup>48</sup>.

The projected increases in winter rainfall, and the associated increase in spate occurrence also has the potential to impact on our freshwater fish.

High river flows can be damaging to fish stocks through the washout of eggs from gravels, an increase in habitat instability and even through fish stranding<sup>31</sup>. When the Spey Foundation reviewed rod catch data in comparison with high flows, it found a 15.5% decline in catches in the years after significant spate events<sup>31</sup>.

#### Freshwater pearl mussel

The presence of freshwater pearl mussel is reputed to have been one of the reasons for Julius Caesar's desire to invade Britain. But over the years, pearl mussel populations have declined significantly, due to a combination of poaching, water pollution and loss of habitat<sup>49</sup>. They are now listed

on Annex II of the EU Habitats Directive and are classified as vulnerable by the IUCN, with only a few viable populations surviving in mainland Europe<sup>50</sup>. Climate change has the potential to further contribute to the loss of populations.

The upper thermal limit for freshwater pearl mussel survival is not known, so although rising water temperatures may have a negative impact on the freshwater pearl mussel, this has not been quantified. However, significant rises or falls in water levels have been shown to result in mussel mortality. Slightly higher river flows could benefit the freshwater pearl mussel, as the increased water levels help to cleanse the riverbed gravels in which they live<sup>51</sup>. But significant spate events cause the mussels to be washed out of the river gravels, often dropping them in unsuitable river habitat, or sometimes even onto dry land.

## ARCTIC CHARR

### WHAT SPECIES:

Arctic charr. It is likely that this species was the first freshwater fish to colonise Scotland after the last Ice Age.

### WHERE IS IT FOUND:

In upland freshwater lochs.

### WHY IS IT IMPORTANT:

Arctic charr as a species is representative of complexity and functional diversity in an ecosystem. The understanding of its diversity and challenges associated in determining the significance of its diversity are very important features in developing protective measures against changes driven by climate change<sup>39</sup>. These species are identified as being the most threatened and requiring conservation action under the UK Biodiversity Action Plan.<sup>38</sup>

### HOW WILL IT BE AFFECTED:

Increased water temperatures exacerbated by its inability to move between lochs in response.



## FRESH WATER PEARL MUSSEL

### WHAT SPECIES:

Freshwater pearl mussel. Similar in shape to marine mussels but grows larger and can live more than 100 years making this species one of the longest-living invertebrates.

### WHERE IS IT FOUND:

In clean, fast flowing rivers.

### WHY IS IT IMPORTANT:

Freshwater pearl mussel is a keystone species in several freshwater ecosystems<sup>40</sup>. This species is an important indicator for measuring freshwater biodiversity. Scotland holds many of the world's most important freshwater pearl mussel's populations. Freshwater pearl mussel indirectly improves habitat quality for its hosts, important hosts in European and thereby Scottish waters are Atlantic salmon and brown trout<sup>41</sup>.

### HOW WILL IT BE AFFECTED:

It is currently classed as endangered by the IUCN and is one of the most critically endangered molluscs in the world. Over the last 100 years it has been lost from a third of the rivers that used to contain it. Its vulnerability will increase with rise in water temperatures, increase flood events, increased drought events. Additionally, the freshwater pearl mussel relies on the Atlantic salmon and brown trout (species which are likely to be threatened by climate pressures) for part of its life cycle, adding another layer of vulnerability.



Photo Credit: Joel Berglund

For example, a once in a 100-year flood on the River Kerry in Scotland in 1998 resulted in over 50,000 mussels being killed (estimated to be 5-10% of the population)<sup>52</sup>. In a recent survey of 126 pearl mussel rivers in Scotland, 26 were considered to have climate change / river bed instability threats<sup>53</sup>.

Conversely, increased periods of drought can have a significant negative impact on freshwater pearl mussel. Freshwater pearl mussels need to be permanently submerged in water, but in periods of very low flow, water levels can drop to such an extent that the mussels are out of the water. This has occurred in rivers in Portugal, where mussels died as they were stranded at the edges of rivers during drought periods in 2018<sup>54</sup> and also occurred in Scotland during the low river levels of 2018.

Freshwater pearl mussels are slow colonisers with a long-life span (often up to 100 years). This means they can only respond very slowly to a changing environment, and the current timescales of climate change may be too rapid for them, putting them at greater risk than more adaptable species.

In addition, freshwater pearl mussels rely on salmonid fish for part of their lifecycle. If Atlantic salmon and trout populations are impacted by climate change and their populations decline, this will have a knock-on effect on freshwater pearl mussels, further threatening their survival.

### Birds

Some of our freshwater birds are also at risk of a changing climate. For example, the RSPB estimate that populations of common scoter, which breed in small lochs in North and West Scotland, have declined by 43% between 1986-1990 and 2011-2015<sup>55</sup>. The birds are considered to have a high risk of extinction in the UK due to changing climatic conditions and the UK breeding population has declined substantially in recent years<sup>56</sup>.

Many of our wading bird species could also be affected by climate change. These birds have already declined significantly within Scotland, with combined numbers of 14 wader species reported as 21% lower in 2015/16 than they were in 1975/76<sup>57</sup>. As the name suggests, these birds are found in wet environments and so changes in precipitation levels will inevitably affect them.

For example, maturing lapwing chicks feed on earthworms in wet grassland. If summer rainfall decreases and the grassland becomes drier, the water table drops, and earthworms move lower in the soil profile. This makes it harder for lapwing chicks to reach them, and they may then struggle to obtain enough food to reach fledgling weight<sup>58</sup>.

### Invertebrates

Durance and Ormerod<sup>29</sup> looked at the impact of water temperature rises on invertebrates within headwater streams in Wales.

**They found that the abundance of spring macroinvertebrates was significantly affected by temperature and that abundance could decline by 21% for every 1°C rise in water temperature above current levels.**

With temperature gains of 3°C or more, local extinction of some species would be expected, reducing overall biodiversity.

Other studies have looked at the change of range for specific invertebrate species which are associated with colder water. For example, researchers investigated changes in range for the upland summer mayfly. They found that its range appeared to be contracting both northwards and upwards. In the Clunie Water, they found the mayfly to be present in north-facing burns, but absent in adjacent, warmer, south-facing burns, suggesting that water temperature plays an important role in the distribution of this species<sup>59</sup>.

An additional significance of any impacts on invertebrate species lies in their position in the food chain, and the consequential effects their loss could have on fish species such as Atlantic salmon, trout and Arctic charr, as well as on other insect feeding birds and mammals.

# Marine Habitats

As an island nation, Scotland's marine environment has always been important. Despite providing both economic and biodiversity resources, we know less about the marine environment than the terrestrial environment and these knowledge gaps also apply to the impacts of climate change.

## HABITAT CHANGES DUE TO CLIMATE CHANGE

The most obvious changes in the marine environment will be rises in water temperature and sea levels.

### Temperature

Mean sea temperatures are predicted to rise around Scotland as a result of climate change. The UK Climate Projections 2009 estimate a sea surface temperature that is 2 to 2.5°C warmer by 2080-90 under a medium emissions scenario. However, temperatures in the summer in the north and west of Scotland may be only 1°C warmer, with the warming most evident in autumn. On the continental shelf, where sea depths are shallower, the extent of warming at the sea bed is expected to be like the surface. But in the very deep waters beyond the continental shelf, temperatures at sea bed are not expected to change significantly<sup>60</sup>.

### Sea level

Sea levels are predicted to rise with climate change, and the UK Climate Projections 2009 estimate a rise of approximately 30cm in the Clyde to Skye coastal waters and the Moray Firth by 2095 (under a medium emissions scenario). Slightly larger rises of 35cm are predicted for the remainder of the mainland, with rises of 40cm for the Hebrides and Orkney and 50cm in Shetland.

### Acidification

The ocean absorbs carbon dioxide, which then dissolves in sea water to produce carbonic acid. As more carbon dioxide is emitted, the oceans absorb greater amounts and become more acidic. Since the Industrial Revolution, sea water acidity has increased by about 30% and could increase by 120% by 2060<sup>61</sup>.



## HAVE PHYSICAL CHANGES ALREADY BEEN DOCUMENTED?

### Temperature

Between 1985 and 2009, sea temperatures were found to have increased by 0.4°C in the coastal waters to the south east and south west of Scotland and by 0.3°C in the waters around the north of Scotland (data calculated from a combination of satellite and in-situ observations)<sup>62</sup>.

### Acidification

There are few long-term datasets on sea water acidity for UK waters, but more recent monitoring at Stonehaven has found a statistically significant decline in pH (i.e. an increase in acidity) between 2008 and 2015<sup>63</sup>.

### Sea level

The extent of sea level rise to date varies around the Scottish coast, partly due to the land moving upwards since the last ice-age (isostatic readjustment) at differing rates. One of the longest time-series records of sea level comes from Aberdeen, where sea levels showed no significant trends between 1920 and the mid-1980s. Since 1985, sea levels at Aberdeen have been more than 6cm higher than the 1920s baseline, and between 2006-08 sea levels were higher than the 1920s by more than 10cm<sup>64</sup>.

## IMPACTS ON BIODIVERSITY

### Whales, Dolphins and Porpoises

As sea water temperatures change, some cetacean (whales, dolphins and porpoises) species will shift their ranges to areas where water is at a more suitable temperature. For species that prefer colder water, their range is likely to move northwards and will reduce as the areas of warmer water expand<sup>67</sup>. Many cetacean species are also limited to certain depths of water, with some preferring the shallower waters of coastal shelves (less than 200m deep).

In north-western Europe, water of that depth is mostly limited to latitudes of less than 60° north, such as the area to the west of Scotland. If waters warm within these areas, this could potentially lead to dramatic reductions in populations of species such as white-beaked dolphins, which need both cool and relatively shallow water<sup>54</sup>. Often these areas of shallower water are separated by areas of deep ocean, which isolates populations in specific areas, making them more vulnerable to changing conditions.

**When the ranges of common cetaceans were compared with likely changes in conditions, it was found that the range of 88% of the studied species could be affected, with 47% of the species experiencing unfavourable range changes and 21% experiencing changes that could lead to localised extinctions<sup>68</sup>.**

Making assessments of marine mammal populations and any shifts in their range is difficult, but the records of mammal strandings can be used to establish which species are occurring in Scottish waters. When the strandings data from 1948 to 2003 was analysed, no new species were recorded between 1965 and 1981. From 1981 onwards, four new species were recorded in North-West Scotland, three of which (Striped dolphin, Fraser's dolphin and pygmy sperm whale) were associated with normal ranges in warmer waters<sup>54</sup>. An increase in the number of marine mammal species occurring in Scottish waters may sound like a good thing, but it should be noted that a sightings survey undertaken in the west of Scotland in 2002/03 found a decrease in sightings of species associated with colder water, such as the white-beaked dolphin<sup>54</sup>, so some species may disappear from Scottish waters.



Photo Credit: Mike Tetly

## WHITE BEAKED DOLPHIN

### WHAT SPECIES:

White beaked dolphin. They are quite large dolphins and often, but not always, have a short, thick, white beak.

### WHERE IS IT FOUND:

In cold temperate sub-polar waters of the north Atlantic Ocean. An estimated 80% of the European population is found around the UK and Scotland is an important habitat for the white-beaked dolphin, especially around the northern Minch, Outer Hebrides and the northern North Sea.

### WHY IS IT IMPORTANT:

White-beaked dolphin is listed on the Scottish Biodiversity List<sup>65</sup> and is considered an important species for conservation. It is a Priority Marine Feature and a Search Feature under the Scottish Marine Protected Area project, making it a marine conservation priority and highlighting its importance nationally as well as internationally.

### HOW WILL IT BE AFFECTED:

Climate change is the single largest threat facing the white-beaked dolphin. Forecasts indicate that Scotland may lose its white-beaked dolphin populations, as it is already at the edge of its range here and is being pushed further north with warming seas.

### Sea birds

Climate change is considered as the primary cause of seabird decline, although this is often via indirect links, such as a reduction in food availability, rather than as a direct response to increased temperatures<sup>45</sup>.

Within the UK's seabird population, kittiwakes have declined by approximately 60% since 1986. Kittiwakes are on the amber list of Birds of Conservation Concern in the EU Birds Directive. In the North Sea they rely on sandeels during the breeding season and changing ocean conditions appear to be affecting sandeel populations. Sandeels feed on zooplankton, including the copepod *Calanus finmarchicus*. Studies have found that warming waters are less likely to be suitable for this copepod, leading to reduced abundance in the southern extent of its range, which includes the North Sea. This, in turn, leads to a decline in sandeel populations, which is then linked to low reproductive success in seabird species such as kittiwakes<sup>69,70</sup>.

**Impacts may also be felt even further up the food chain, such as on great skuas that can prey on kittiwakes<sup>45</sup>.**

However, birds such as great skua can be generalists – they are more flexible and will switch prey species if required. Other birds, such as black-headed gulls and guillemots will follow a similar strategy. Populations of these species showed an increase between 2000 and 2015, suggesting that flexibility in food source selection may make some species more adaptable to climate change<sup>45</sup>.

### Molluscs

Ocean acidification impacts on the ability of mollusc species to form their characteristic shells. This effect has been studied in many species globally and a combined analysis of multiple studies found that the likely future levels of ocean acidification could reduce calcification (the process by which these species build shells) in molluscs by 40%<sup>71</sup>. This has the potential to be detrimental not just to naturally occurring mollusc species, but also for commercial users of molluscs, such as the oyster and mussel farming industries.

### Machair

Machair is a unique habitat that is only found in northern Scotland and north-western Ireland. It is listed on Annex 1 of the EU Habitats Directive, and has a total global area of just 19,000 hectares<sup>72</sup>. It is the result of both physical factors (sand partly consisting of shell fragments, a low-lying coastline and strong winds) and the particular way in which the land has been managed over the centuries<sup>73</sup>. Its location in a low-lying, relatively flat landscape means it is particularly vulnerable to sea level rise. A combination of coastal flooding and increased winter precipitation levels could result in standing waters remaining on machair land for longer periods of time (as is already anecdotally suggested by Western Isles crofters). This would make the land harder to plough and cultivate and may result in more land falling into disuse. But it is this human intervention in the form of cultivation which is a key component in maintaining the diversity of machair. If traditional land management techniques are no longer feasible because of increased flooding, this unique habitat may be lost from much of its existing range.



## KITTIWAKE

### WHAT SPECIES:

Kittiwake. The ringing clamour of this delicate gull, so characteristic of many of Scotland's seabird cliffs, gave the kittiwake its name.

### WHERE IS IT FOUND:

In seabird colonies around the UK. The largest colonies are on the east coast, from St Abbs Head to Shetland.

### WHY IS IT IMPORTANT:

The population has declined more rapidly than almost any other species of seabird, recording a 66% decline in Scotland between 1986 and 2011. On some colonies, such as St Kilda, the decline has approached 90%<sup>66</sup>. It is on the amber list in the UK's birds of conservation concern.

### HOW WILL IT BE AFFECTED:

Steadily rising sea temperatures are believed to be contributing to breeding failure. This species eats a variety of small fish with sandeels forming the bulk of the diet in the east and sprats more important in the west. Breeding productivity is closely linked to reduction in food source, due to diminished sandeel abundance, which thrive in low sea temperatures.

### BLUE CARBON

The marine environment also has an important role to play in our efforts to mitigate climate change. Recent research has estimated that significant amounts of carbon are captured and stored in the Scottish marine environment<sup>74</sup>. It is therefore important that these habitats are protected and enhanced in the future, to avoid any human impacts reducing their carbon storage capacity.



Photo Credit: Danny Carden

# Mountain habitats

It is not difficult to imagine how a changing climate might affect our montane environments – a warmer world will inevitably impact on the snow and ice at the tops of Scotland's iconic mountains.

## HABITAT CHANGES DUE TO CLIMATE CHANGE

Scotland's mountains are relatively small by European standards, with a maximum height of just 1344m, but climatic conditions change rapidly as altitude increases<sup>75</sup>.

### Snow cover

Mean air temperatures are predicted to rise in Scotland because of climate change. This will reduce the number of days with surface temperatures below zero, which will reduce the number of days where any precipitation falls or lies as snow<sup>76</sup>. The UK climate projections (2009) do not provide projections for future changes to snowfall rate, but the Met Office Hadley Centre RCM ensemble predicts in a medium emissions scenario a reduction in mean winter snowfall of 65-80% over mountain areas in the UK by the 2080s.

Estimates of snow cover have been produced by The Scottish Executive Central Research Unit<sup>77</sup>. Their emissions scenarios vary slightly from the UK climate projections (2009) models, but the estimates for Scotland suggest a decrease of between 7 and 19 days of snow cover by the 2050s. Predictions vary for different regions of Scotland, but for the Highlands snow cover days are predicted to decrease by 30% by the 2050s whilst in the Grampian region a decrease of 33% is predicted<sup>78</sup>.



## SNOW BUNTING

### WHAT SPECIES:

Snow bunting. Weighing no more than a golf ball, this small bird with its striking 'snowy' plumage is one of the rarest breeding birds in the UK.

### WHERE IS IT FOUND:

Breeding populations are found on the high tops of Scotland's mountains. Snow buntings build their nests in rock crevices on bare mountain slopes or rocky shores and lay four to six eggs.

### WHY IS IT IMPORTANT:

It is a scarce breeding species in the UK, making it an Amber List species. In Scotland, it is currently one of the rarest breeding bird species with a population of only 60 breeding pairs. Future changes in the snow bunting population will help to explain how the snow bunting is responding to the changes in its montane environment<sup>61</sup>.

### HOW WILL IT BE AFFECTED:

Increased temperatures will lead to reduced range.

## HAVE PHYSICAL CHANGES ALREADY BEEN DOCUMENTED?

### Snow cover

Statistically significant decreases in days of snow cover have been seen between 1961 and 2004 for autumn and spring. Overall, across Scotland, the number of days of snow cover has declined by 32.1% over the last 43 years<sup>79</sup>. As the most significant decreases have been in autumn and spring, the length of the snow season is shortening.

Researchers found that the 1°C rise in temperature corresponded to a 15-day reduction in snow cover at 130 m and a 33-day reduction at 750 m at Ben Lawers<sup>80</sup>. Therefore, in warmer years, late-lying snow will be less prevalent and the remnant snow patches much reduced in size. This may also translate into an increase in river levels downstream, as more precipitation will flow directly into rivers, rather than being 'held up' in the mountains as snow cover.

## IMPACTS ON BIODIVERSITY

### Loss of habitat

Air temperature declines with altitude, so the higher slopes of our mountains provide habitat for species which adapt to colder environments. As average temperatures increase under climate change it is likely that there will be a decline in climatically suitable habitat for montane and Arctic-alpine species<sup>61</sup>. Additionally, species which are more associated with warmer climates will be able to expand further uphill and may replace some of the Arctic / alpine specialists<sup>83</sup>.

For example, researchers looked at the likely loss of suitable climate space for Arctic / montane species at three sites in Scotland (Ben Lawers, Ben Heasgarnich and Meall na Samhna).

They found that in a low emissions scenario, 78% of the locations they studied would no longer be climatically suitable for Arctic / montane species, such as dwarf willow, moss campion and stiff sedge whilst in a high emission scenario 93% of the studied locations would become unsuitable<sup>61</sup>. Many of these species form part of plant communities protected under the EU Habitats Directive as Annex 1 habitats, so their loss or alteration is particularly significant.

Bird species which are at the southern edge of their range in UK are also likely to decline. Scientists in Finland<sup>15</sup> used a combination of climatic and bird sighting data to establish a modelled 'climate space' for a variety of species, which then determines their range. This is usually modelled either by correlating current species distributions with climate variables<sup>84</sup>, as in this case, or by an assessment of a species' physiological responses to climate variables. They then modelled how that climate envelope might vary with future climate change, and what effect this might have on the distribution of certain birds.

**They found that within northern Scandinavia, the distribution of snow buntings, a bird also strongly associated with Scottish mountain environments, could decrease by 59% by 2050 under a high emissions scenario and 51% under a low emissions scenario.**

For ptarmigan also an important Scottish bird, the decline in distribution in their study area was modelled as 90% by 2080 under a low emissions scenario, and 98% under a high emissions scenario.



**DWARF WILLOW****WHAT SPECIES:**

Dwarf willow. One of the shortest woody plants in the world, barely if ever reaching 2 inches above the ground.

**WHERE IS IT FOUND:**

In high mountainous bare and rocky ground.

**WHY IS IT IMPORTANT:**

Scotland is an international stronghold of dwarf shrub moorland. Dwarf willow is part of Scotland's alpine and montane plant community, providing species diversity. A long-term study indicates that species diversity and vegetation of moorlands has changed over time resulting in reduced biodiversity value, with the loss of specialist species like dwarf willow<sup>82</sup>.

**HOW WILL IT BE AFFECTED:**

The species is likely to experience loss of suitable climate space and could decline in cover.

**Community changes**

Amongst plant communities, some species will fare better than others on Scotland's mountains. Large scale re-surveys of vegetation plots have reported declines in Arctic and montane species. When researchers resurveyed plots that were first surveyed in 1956-58, they found that nearly a third of all species with an Arctic / montane distribution, such as crowberry and alpine lady's mantle had declined<sup>65</sup>.

**Across 126 plots in upland vegetation, they found that 79 species had been lost and only 13 new species gained.**

In general, this was the result of rarer species being replaced by generalists, with the vegetative composition of the plots becoming increasingly similar.

In contrast, other surveyors have found an increase in species richness in alpine habitats, but this has been as a result of an increase in lowland generalist species, whilst northern and alpine species declined. This is particularly the case in snowbed vegetation, where larger plants have colonised the area and may outcompete the specialised mosses and liverworts which were previously associated with areas of late-lying snow<sup>85</sup>.

Many of these species are also being affected by other pressures. For example, excess nitrogen in the atmosphere is also changing the nature of arctic/alpine heath. In this habitat, moss cover has been found to drop from 90% to 20% as nitrogen levels increase, while grasses, sedges and rushes increase from 5% to 55% cover<sup>86</sup>.



Photo Credit: Adobe Stock

# Moorland

Purple blooming heather on a swathe of moorland is one of the iconic images of Scotland. Already affected by processes such as over-grazing and drainage, our moorlands are also at risk from climate change.

## HABITAT CHANGES DUE TO CLIMATE CHANGE

Heather-dominated moorland is found throughout Scotland, including on coastal heaths, but it is most common in the uplands, above the zone of enclosed farmland. The UK holds approximately 75% of the total global area of this vegetation type and more than 70% of this is within Scotland<sup>67</sup>.

Heather dominated moorlands will be subject to the same physical changes as other habitats – increased temperatures, decreased snow cover, increases in winter precipitation and decreases in summer precipitation.

However, the moorlands have already experienced several physical changes as a result of human activity. These include grazing by both domestic herbivores and deer; land drainage; excessive muirburn; afforestation for commercial forestry and nitrogen deposition<sup>68</sup>. This means that separating out the effects of these physical changes from those resulting from climate change is difficult<sup>67</sup>.

## GOLDEN PLOVER

### WHAT SPECIES:

Golden plover. This is a medium-sized plover with a distinctive gold and black summer plumage which in the winter is replaced by buff and white.

### WHERE IS IT FOUND:

The golden plover is a small wading bird that breeds on higher moorlands and spends the winter in sizeable flocks at lowland sites on the coast or inland in river valleys or on arable land.

### WHY IS IT IMPORTANT:

The UK holds about 8% of the global breeding population and around a quarter of the global population in winter, it is currently Amber listed in UK's birds of conservation concern. The Scottish breeding population has declined by a quarter over the last 20 years<sup>89</sup>.

### HOW WILL IT BE AFFECTED:

Climate change appears to be a significant threat to the golden plover, not only through direct impacts on key habitats, but also causing a mismatch in the annual timing of breeding and of the annual emergence of their chicks' critical invertebrate prey, crane flies.



Photo Credit: Adobe Stock

## IMPACTS ON BIODIVERSITY

### Vegetation composition

Long term studies of moorland vegetation have found that species composition within moorland vegetation is changing. A re-survey of vegetation plots in Scotland which had been sampled 35 years previously found that species richness had increased. Whilst an increase can sound like a good thing, in general the increase was because of commoner species moving in, and in particular, from species that prefer warmer climates moving upslope<sup>67</sup>. Rarer species declined, particularly those associated with higher altitudes. Some of the changes were also attributed to pollutant deposition and grazing patterns, which also impact on vegetation community composition. In combination, these factors appear to be resulting in a gradual loss of the unique biodiversity value of Scotland's moorlands.

### Birds

A changing climate may impact a species directly, or it can affect them indirectly through altering other factors. Scientists investigated the importance of different insect groups to upland insectivorous birds, and then also assessed the sensitivity of those different insect groups to a changing climate<sup>70</sup>. They found that Tipulidae (crane flies) are particularly important for birds such as dunlin and red grouse. However, in years with a summer drought, there is a high mortality rate amongst the young larvae, which leads to a reduced emergence of the crane flies after a hot, dry summer. For those birds which rely on these insect groups for food, a reduced emergence could lead to reduced food availability at key lifecycle stages. For example, the snow bunting which is dependent on the crane flies as food source is on the amber list, and is Scotland's rarest breeding species, with only 60 pairs currently found in Scotland<sup>90</sup>. Populations of golden plover, which are at the southern edge of their range in the UK also feed on crane flies.

In years with high August temperatures, crane fly abundance is reduced, which leads to a reduced survival of golden plover chicks in subsequent years. Golden plover population in the Pennines was also studied, where August temperatures were found to have increased by 1.9°C between 1971 and 2005. Based on the impact of high August temperatures on golden plover populations (via the loss of crane flies as a food source), the researchers forecasted that with an ongoing rate of temperature rise of this scale, the population had a 96% likelihood of extinction by 2100. With a reduced rise of only another 2°C for the remainder of the 21<sup>st</sup> century, the population would still decline by 44%, but would not be at risk of extinction<sup>91</sup>.

One way to tackle this issue appears to be restoring degraded peatland areas. Managing the peatland area so that soil moisture levels are maintained or increased can increase crane fly populations. This obviously benefits for crane fly predators, such as golden plover, but it also enables peatland areas to store more carbon<sup>92</sup>.

### Invertebrates

Several butterfly species associated with the north of the UK were studied to see if they were moving further northwards in response to climate change. These species are all associated with upland grassland habitats, which are often found in a mosaic with heather dominated moorland. Three of the studied species (mountain ringlet, scotch argus and northern brown argus) all showed changes in distribution that were linked to climate, whilst a fourth species (Large heath) appeared to have declined primarily due to loss of habitat<sup>93</sup>. As species change their ranges in response to climate change, habitat loss and fragmentation may prevent them from moving into new climate spaces, as well as causing locally based population extinctions.

# Woodlands and forests

Scotland's woodlands include the iconic landscapes associated with our ancient Caledonian pinewoods and the rich plant life of our wet Atlantic woodland.

Standing beneath majestic trees like the Birnam oak, immortalised in Shakespeare's *Macbeth*, it can be easy to think that trees can withstand almost anything. But our woodlands and forests are also susceptible to climate change, particularly where there are small and isolated pockets of woodland in a heavily managed landscape.

The challenges posed by climate change become even more significant when we consider that most of woodland expansion has been of non-native commercial species and as of 2011, native woodland accounts for only 22.5% of the current Scottish woodland area and 4% of the total land area of Scotland. Less than half of those native woodlands are in good condition for biodiversity

## CLIMATE CHANGE IMPACTS

Spread throughout Scotland, woodlands in different geographical parts of the country currently experience different climatic conditions. For example, our broad-leaved Atlantic woodlands are generally found in the milder, wetter areas of Western Scotland, where high rainfall levels result in extensive carpets of bryophytes and lichens<sup>94</sup>.

Scottish woodlands will be subject to the same physical changes as other habitats but are most likely to be affected by increased temperatures, increases in winter precipitation and decreases in summer precipitation. An increase in extreme weather events may also affect woodlands, particularly if they result in high wind speeds.



Photo Credit: Charlie Phillips

## CAPERCAILLIE

### WHAT SPECIES:

Capercaillie. The capercaillie is a large woodland grouse.

### WHERE IS IT FOUND:

It is famous for its 'lekking' behaviour, where groups of males display to females in spring. It is found in the Caledonian pine forests – itself a rare and vulnerable habitat, also mature coniferous forests with abundant blaeberry<sup>98</sup>.

### WHY IS IT IMPORTANT:

It was extinct by the early 19<sup>th</sup> century and was successfully reintroduced in the 1830s but is now again at risk of Scottish extinction. The overall decline may have slowed but the capercaillie has more recently abandoned large areas of its range, with most birds now found in Strathspey. It is currently red listed in UK's birds of conservation concern, Annex 1 species in EU Birds Directive.

### HOW WILL IT BE AFFECTED:

Loss of climate space (area of land climatically suitable for the habitat), low breeding productivity from a combination of cold, wet weather during the breeding season and wetter spring months reduce chick survival.

Woodland cover has increased in Scotland, rising from 5% at the start of the 20<sup>th</sup> century to 19% of land area today<sup>95</sup>. However, much of this increase is due to large-scale afforestation activities carried out over the last century which non-native commercial species, such as Sitka spruce<sup>96</sup>.

Much of our woodland continues to be in isolated patches, often surrounded by intensively managed agricultural or urban areas<sup>97</sup>. This fragmentation is just one of the pressures affecting woodland today. Other woodland areas can also be affected by pollution, invasive species and poor grazing management. This combination of adverse impacts may make woodland more susceptible to the additional impacts of climate change.

### IMPACTS ON BIODIVERSITY

#### Slow movers

In common with other plant and animal species, trees have a climatic range where they can grow successfully. As the climate changes, that range is expected to move and follow the new climatic conditions. However, trees are slow growers and so their range will only shift very slowly. Tree range expansions into areas with suitable climatic conditions are therefore expected to be limited unless they are assisted by planting activities.

Where the woodland habitats become fragmented, it will be harder for species to disperse to new areas<sup>99</sup>. Many woodland bird species also appear to be slow dispersers, which may limit their ability to track new climate ranges. This means that woodland species could be particularly sensitive to the effects of climate change.

Climate change also affects tree species phenology (the timings of when leaves/buds/ seeds appear) and can cause a phenological mismatch, where other species depending on these timings, such as migrant bird species, are adversely affected<sup>100</sup>. This is something the Woodland Trust is tracking through a citizen science programme called Nature's Calendar<sup>101</sup>.

#### Birds

An increase in winter temperatures could increase survival rates over the winter period for some woodland bird species. However, if that is also accompanied by an increase in precipitation, this could have a negative effect on survival. When precipitation levels are high, a bird's plumage will become wet, making it less effective at insulation. So, birds that are exposed to damp conditions can be particularly badly affected. For example, treecreepers move up the trunks of mature trees. In doing so, they encounter the wet bark of the tree, which can quickly soak their breast plumage. Birds such as treecreepers may therefore have reduced winter survival if precipitation levels increase, even if that is associated with warmer conditions<sup>102</sup>.

Higher precipitation levels in early summer can also have a negative effect on capercaillie breeding success. Research shows that a wet June reduces the capercaillie chick's ability to forage for insects, with those chicks that eat less well having a reduced chance of survival.

The capercaillie population has already declined substantially in Scotland, and it is on the red list of birds of conservation concern in the UK. Modelling of climate space for capercaillie shows that with a rise of 0.7°C by the 2050s, it can be expected to lose 59% of its potential climate space. But with a higher rise of 1.9°C by the 2050s, capercaillie loses 99% of its potential space. Given the already precarious state of the Scottish capercaillie population, the outlook for this species is not promising under these conditions<sup>103</sup>, unless efforts are made to enhance capercaillie preferred habitats.

The phenomenon of phenological mismatch has also been recorded in several birds, such as pied flycatcher, another red listed species in the UK's birds of conservation concern. As spring temperatures become higher, peak caterpillar abundance, the main diet of pied flycatcher chicks, is taking place earlier and so is out of sync with the main hatching period of this species.

The recently published Index of Abundance for Scottish Terrestrial Breeding Birds<sup>104</sup> shows increases in 19 of 23 woodland bird species, and an overall increase since 1994 of around 69% in the woodland species included in the index of abundance. This contrasts with trends in Scottish seabirds, upland and farmland birds, and with woodland birds in other parts of the UK and Europe. Some key woodland species, notably trans-Saharan migrant song birds such as pied and spotted flycatcher, redstart and wood warbler, are currently not encountered often enough in areas monitored by volunteer ornithologists in Scotland to be included in this woodland bird indicator. There is compelling evidence that European populations of such migrant birds have declined in recent decades, often to a greater degree than resident or short-distance migrants<sup>105</sup>.

### Plants

The composition of our wooded landscapes will alter with a changed climate. A changing environment will affect both woodlands and individual trees outside of woodland, such as hedgerow trees and open grown ancient and veteran trees. For example, a key habitat which will be affected is our Atlantic woodland. These woodlands may experience milder winters, stronger winter gales and drier summers, which could lead to a loss of some of their characteristic bryophyte and lichen flora<sup>106</sup>. This flora is adapted to the wet oceanic habitat, particularly on the west coast of Scotland. Often these specialist species which are adapted to the oceanic habitat are sensitive to micro and macro climatic changes<sup>107</sup>. As such there is a need to manage at multiple scales to maintain these species. This includes increasing the extent and complexity of woodland sites to promote habitat diversity. It will also include ensuring a sufficient width of riverside buffer zone woodland to enable populations to adjust to changing macroclimates.

Research<sup>108</sup> shows that the eastern range of habitat suitable for the oceanic bryophytes and lichens that are characteristic of the Atlantic woodlands will shrink under climate change scenarios. The Atlantic woodlands or temperate rainforest on the west coast of Scotland is the last and largest remnant of the habitat that used to extend along Europe's Atlantic sea-board. If it declines and is lost, rainforest biodiversity has nowhere else to migrate to as climate changes. Scotland must therefore conserve the habitat that remains and safeguard and protect it to ensure it continues to offer a haven to some of the world's rarest biodiversity.

Tree species will also have differing responses to climate change. Species that are sensitive to drought may be adversely affected by any decrease in summer precipitation; cases of drought and heat induced tree mortality have been reported from around the world<sup>109</sup>. Some species which are planted in commercial forestry are also sensitive to drought, such as Sitka spruce. A Forestry Commission Scotland study found 288 medium or high drought risk forest sites in eastern Scotland. Nearly half of these contained Sitka Spruce, which has previously responded to drought in eastern Scotland through either tree stem cracking or complete tree death<sup>110</sup>.

### IMPLICATIONS FOR TREE PLANTING

Planting more trees is often seen as a simple solution to climate change and there is no doubt that it plays an important role in climate change mitigation. Scotland has ambitious targets for tree planting, which should rightly be applauded. However, care must be taken with the type and location of planting, to avoid adverse impacts on biodiversity.

Climate change could create more favourable conditions for pests and diseases, and therefore, exacerbate their impact across Scotland and the UK. In relation to this, it is important to avoid monoculture planting (notably the reliance on one species, of the same age, planted in rows) as that can be more susceptible to the impacts of pests and diseases. The consequences of this could be devastating, particularly for the commercial sector where monoculture planting is currently the norm. The spread of invasive non-native species such as rhododendron which has already caused much damage to Scotland's woodlands, could be facilitated by changing climatic conditions.

Care must be taken with the type and location of planting to avoid adverse impacts on biodiversity and carbon storage potential of other habitats such as peatlands. It is also only one of the solutions to making our woodlands more resilient to climate change.

### IMPLICATIONS FOR WOODLAND EXPANSION

Emphasis should also be placed on expanding woodlands through natural regeneration as this allows for woodlands to be better adapted to local site conditions and will improve their resilience to environmental change. Currently such regeneration across Scotland is severely impacted by grazing from herbivores, particularly deer. Woodland regeneration could allow for the creation of resilient woodlands, with a healthy mix of species, of various age ranges and sizes with a natural distribution pattern. These woodlands could provide both, new habitat and extend existing ranges for many woodland-dependant species.

As highlighted earlier, tree species selection is important for any new planting, so that the selected species is able to cope with a changed climate, including lower summer rainfall. Planting on existing 'open' species-rich habitats, such as grasslands and heathlands, should be avoided as it can lead to a loss of biodiversity. Equally, regeneration and self-seeding of non-native commercial species, not to be confused with natural regeneration of native woodland within its historical range, must be prevented and removed from precious open habitat. As acknowledged by the Forestry Commission, lessons should be learnt from previous policies which encouraged the planting of commercial species on blanket bog<sup>111</sup>.

Many of these habitats already provide important ecosystem services, including carbon sequestration and it will be important to maintain those services in the future. Tree-planting policies must therefore be based on ensuring 'the right tree in the right place' to help Scotland respond to climate change.

Our native trees and woodland have, in general, high levels of genetic diversity<sup>112</sup>. This provides an opportunity for evolutionary adaptation to changing conditions. However, this process requires multiple successive generations of trees which are subject to the selection pressure of a changing climate. We need to ensure that there are sufficient opportunities within woods to provide the possibilities for new generations of trees, ideally through natural regeneration. Native woodland of diverse structure and tree species appropriate to the site will provide the greatest chances for adaptive change. This may mean planting more minor species where these are appropriate to the site and using a mix of UK provenances rather than just local provenance planting stock. Evidence does not suggest that non-UK provenances or species are needed to increase resilience of ancient and native woods.

Scottish Natural Heritage (SNH) outline of the uncertainties around climate change and new pests and pathogens means that we cannot assume that any single approach will be effective at protecting our woodlands and helping them to adapt to new and dynamic conditions resulting from climate change<sup>113</sup>.

## Other risks from climate change

The case studies above highlight some of the direct risks from climate change faced by species and habitats in Scotland. However, there are other indirect risks which may also affect our biodiversity.

One major risk is that a changing climate may allow more invasive species to spread within Scotland. These species can spread quickly and reduce the resilience of our ecosystems and the services they provide. For example, the spread of water hyacinth is currently limited by winter frosts in the UK. However, with an increase in winter temperatures and a reduction in frosts, the plant may become more successful in the UK<sup>14</sup>. Water hyacinth is regarded as a highly invasive plant, which can quickly choke waterways. Likewise, nuisance filamentous algae such as water-net are thought to be spreading more rapidly in response to warmer summers.

Other pests and diseases may also be able to spread more quickly under changed climatic conditions. For example, red band needle blight is a disease which affects pine trees, causing them to drop their needles prematurely. The disease has only been detected in Scotland recently, but there are concerns that a changing climate, particularly warmer spring months, could allow it to become more prevalent<sup>15</sup>.

Warmer and drier summers may also lead to an increase in wildfire risk. Whilst this has obvious implications for human health, it can also cause catastrophic damage to ecosystems which have not evolved with a significant fire risk.

## Future Outlook

The current commitments submitted by governments as part of the Paris Agreement are not sufficient to keep global temperature rise below 2°C.

It is estimated that the current level of commitment will result in a median warming of 2.6 – 3.1°C by 2100<sup>16</sup>. In order to limit temperature rise to less than 2°C, governments will need to do more to cut emissions and do it more quickly.

Both globally and within Scotland, biodiversity is suffering from a wide range of pressures, including habitat fragmentation, pollution and over-grazing. Already we know that more than half of Scotland's plant species and over a third of our butterfly species have declined.

Scotland's Biodiversity Intactness Index shows that our biodiversity is no longer in a condition to meet society's needs. Other legislation which seeks to protect biodiversity in Scotland will require review and enhancement to reverse that decline.

Climate change is yet another pressure which is already starting to impact on our biodiversity. As the case studies in this report show, climate change will accelerate the already rapid rate of decline of our biodiversity, resulting in the loss of species and a disruption to the ecosystem services on which we depend.

**Immediate and substantial action is clearly required to prevent catastrophic damage on both a global and Scottish scale. Rapid reduction of greenhouse gas emissions and the achievement of net zero emissions as soon as possible will give Scotland an opportunity to both protect our own wildlife and demonstrate world leadership in climate change mitigation.**



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