Part 3
Species

Part A - Overview

Part B - Species case studies

Part A Overview

Introduction

This section of the Adaptation Manual provides an introduction to climate change adaptation for species conservation. It also includes case studies identifying practical adaptation options for a range of species, to serve as exemplars to inform wider planning. It should be read in the context of adaptation for habitats (see part 2 of this manual): habitat management is the starting point for species adaptation, but some species may require a more tailored approach to address specific aspects of vulnerability.

Adaptation planning can be approached in four steps:

- Consider the impact climate change will have on the species;
- Determine whether these impacts pose a threat or opportunity, and the level of either;
- Identify and implement appropriate interventions;
- Monitor and review actions.

Monitoring and review form part of an adaptive management cycle, in which lessons are learnt and actions and targets are adjusted on the basis of practical experience.

Different considerations apply at different scales and in different places, depending on, for example, the rarity of a species and the location of a population within its range. Adaptation for the same species may differ in different parts of the country. In this section we approach this through the perspective of national and local planning.

The focus of this section is on responding to the ecological impacts of changes in climate and related physical variables, such as soil water and sea level rise. There are also many indirect impacts resulting from human responses to climate change, which are not dealt with in detail as they are more context-specific and hard to predict.

Great crested newt. © Natural England/Peter Wakely

Impacts of climate change on species

Climate has a range of direct effects on species. Most physiological processes are affected by temperature, for example the rates of respiration and photosynthesis change with temperature. Physiological processes typically increase with temperature up to an optimum, and then decline and eventually break down as temperature rises beyond this point. The effects of climate change on water supply through changing rainfall patterns may be more important than temperature in many cases, but are typically mediated through soil water and catchment hydrology. Even the more direct physiological effects of climatic variables do not always easily translate into ecological effects because of a complex set of interactions with other influences that also need to be taken into account.

The main direct ecological impacts of climate change on species are summarised below. A fuller account can be found in the **Biodiversity Climate Change Impacts Report Card** (Morecroft & Speakman 2015).

Phenology

The timing of spring life cycle events, such as budburst, flowering and egg laying, has advanced in most of the species in which it has been studied. The average advance has been nearly two weeks in the last 30 years, lengthening the growing season. At the other end of the season, some autumnal events such as berry production have also advanced, while others such as leaf fall have been delayed, depending on the environmental triggers for these events. These changes can have a variety of effects on species. An increase in the growing season may benefit some species. However, where different species' life cycle events respond differently to changing environmental cues there may be a breakdown in the synchrony between them. This can have detrimental impacts, for example in reducing food supply, or opportunities for pollination or seed dispersal.

Population dynamics

Most species' populations are, to varying degrees, influenced by effects of weather on mortality and reproduction. The mechanisms vary and include the direct impacts of heat on survival and reduced mortality during warm winters. For well-monitored species such as birds and butterflies, there is evidence of long-term change associated with climatic change (Pearce-Higgins *et al* 2015). The interactions of species with their pathogens, parasites, predators and food sources can be affected by climate. Interactions with land use, land management and other variables also commonly influence species' responses to climate change and extreme events (Oliver *et al* 2015, 2017; Newson *et al* 2014).

Distributional shifts

Many animal species in the UK, especially those with southerly distributions, are colonising new areas to the north of their range, consistent with recorded increases in temperature. In addition, species new to Britain are arriving, and species previously found as migrants are becoming established. Good data are available for a wide range of groups in the UK. There is also evidence of some species moving to higher altitudes. Rates of change in species' range margins differ; though most are not moving fast enough to keep pace with the change in temperature we have seen in recent decades. There are fewer examples of plant populations shifting compared to animals. Being less mobile, plants have tended to respond to changes in climatic conditions by altering the timing of life cycle events and growth.

There is evidence that species with northern or montane ranges, including some birds and butterflies (e.g. the mountain ringlet), are retreating at southern or low-altitude range margins; this is less clear and so far has not happened as fast as range expansion. Changes in distribution can often be modified by sympathetic land management. There is evidence that species preferentially colonise protected conservation sites when spreading north (Thomas *et al* 2012), and also that species persist longer in protected areas at their southern range margins than they do in unprotected areas (Gillingham *et al* 2015).

Community change
Changes in populations, distributions and phenology inevitably lead to changes in ecological communities and in the interactions between species. In the UK, communities of butterflies and birds are changing, with relative increases in the proportion of southern species and decreases in northern species (Oliver *et al* 2017). Another issue is the potential for non-native invasive species or pests and diseases to survive in the UK, where previously they would not have done, or for existing non-native species to spread and start to cause disruption to ecological communities. Some native species may also become more invasive under climate change.

Extreme events
While long-term, gradual changes in patterns of temperature and precipitation play an important role in driving the changes described above, other aspects of climate change can have more immediate and direct impacts on species and their habitats. For example, droughts and floods, which are expected to become more frequent with climate change, can have significant impacts which affect populations and communities for many years, and more prolonged heatwaves are likely increase the frequency and severity of wildfires.

Rising sea levels
Sea level rise is a consequence of climate change and presents a threat to coastal habitats and the species that depend on them. Where natural processes operate, these habitats may, given time, re-establish themselves by moving progressively inland, but this is often prevented by engineered coastal defences. In addition, sea-level rise affects coastal geomorphology, which impacts on inter-tidal habitats and the species they support. For example, increased exposure to wave action can erode productive muddy, estuarine habitats and transform them to less productive sandy habitats. Rising sea levels can also have an adverse impact on freshwater habitats and species close to the coast due to increased rates of saline intrusion and overtopping of coastal defences during storms.

Vulnerability assessment for species

Adaptation planning needs to be based on an assessment of the vulnerability of a species in specific circumstances that goes beyond a generic understanding of impacts.

The assessment of vulnerability is frequently separated into three elements: **exposure**, **sensitivity** and **adaptive capacity**.

Exposure refers to the nature and extent of climate change in the particular situation. The **UK Climate Projections** published by the Met Office provide projections for key climate variables such as temperature and rainfall and for a range of scenarios and time intervals. The RSPB and Natural England often use a 25-year timeframe and scenarios based on a global temperature rise of 2° C compared to pre-industrial levels as a starting point. This provides a practical medium term perspective for developing action, and a milestone towards likely longer term continued climate change.

For many conservation purposes, the detail of climate projections is less important than the direction of travel, approximate magnitude of change and the range of possibilities. It is, however, important to take account of the range of environmental changes that are associated with climate change, including sea level rise, more intense rainfall events, flooding and, potentially, drought and wildfire. Some of these, like sea level rise, can be quantified, but others may need to be assessed qualitatively.

Sensitivity is the extent to which a species is affected by any given change in climate and associated impacts on the physical environment. This can be complex, as different aspects of climate change affect species differently and there are interactions between species and with the physical environment.

Detailed, species-specific studies that demonstrate the mechanisms which cause sensitivity are rare and indicators based on the correlation between observed population and distribution changes are often used. For example, if a species is at the southern edge of its range in the UK and has declined in recent years, this is good circumstantial evidence that it is sensitive to climate even if the precise mechanism is not known.

Adaptive capacity, in this context, is the potential for natural adjustments of species to reduce the impacts from climate change. There are a number of ways in which species can adjust naturally to climate change; for example, dispersal to newly suitable areas, physiological or behavioural responses by individuals, and genetic adaptation to changing conditions. Hence, more mobile species are more likely to disperse to new sites, and species with short generation times are more capable of quick genetic adaptation.

Given the difficulty of carrying out detailed mechanistic studies, approaches to assessing the vulnerability of most species fall into two main types; those based on changes in distribution and abundance (trend based) (Wheatley *et al* 2017), and those based on species characteristics (trait based). One widely used indicator of climate sensitivity is geographic distribution. A species at the northern edge of its distribution in the UK is likely to be limited by temperature and may therefore benefit from a warmer climate, whereas one at its southern range margin is more likely to decline. Climate envelope modelling is one approach to assessing climate sensitivity on the basis of geographic distribution, and is described in detail in section 5. While distribution based approaches are useful, they can be misleading for species which are rare, patchily distributed, or heavily influenced by non-climatic factors. They also fail to take account of adaptive capacity.

Another approach is to look at trends in species' populations over time in relation to weather and climate, if data are available. A Natural England funded project took a combined approach using both projected changes in potential species distribution and trends over time, as the climate has warmed, for over 4000 species (**Pearce-Higgins** *et al* **2015**). This is the most comprehensive model-based study for UK species. Habitat associations may also be useful in assessing climate change sensitivity; for example, species of wet places are likely to be sensitive to drought conditions. Physiological or ecological characteristics of species can also give an indication of sensitivity to different aspects of climate, and in some cases it may be possible to infer useful information for a range of similar species from detailed mechanistic studies of one species.

Uncertainty is present in all assessments of exposure, sensitivity and adaptive capacity. This is not a reason not to take action, but does need to be recognised when undertaking vulnerability assessments and considered in decision making. Uncertainty often cannot be quantified, but it is usually possible to recognise a range of plausible scenarios which can then be taken into account in adaptation planning. For example, it is best to adapt in ways that are robust under a range of possible temperature increases rather than to a single scenario.

A wide range of local and larger scale factors influence species vulnerability in any particular place. Section 5 provides more information about different approaches to assessing vulnerability.

Approaching adaptation for species

Two broad categories of adaptation for species are building resilience to prevent undesirable change and accommodating change where this is inevitable or desirable (for example where a rare species can colonise new sites in a warmer climate) (Morecroft *et al* 2012). Both need to be underpinned by monitoring and the timely review of interventions.

Climate change adaptation needs to be fully integrated with wider conservation planning and delivery if it is to be effective. For example, assessing vulnerability to climate change is a standard part of the management plan review process for National Nature Reserves managed by Natural England (Duffield & Le Bas 2017), and for the RSPB's nature reserves. It is also important that adaptation planning is done within the context of broader objectives determined by local, national and international priorities. These priorities are typically determined by the threat faced by species, the international significance of their populations, their role within ecosystems (for example as keystone species or 'ecosystem engineers'), or their 'iconic' status. An assessment of climate change vulnerability may suggest that it is best to revise objectives, typically to give more attention to species and/or locations where climate adds ecological pressure. Climate change may also influence the setting of different objectives in different locations, which is explored further in the section on adaptation at national scale below.

Adaptation at a national scale

While conservation management usually happens locally, it takes place within a wider geographical context and may form part of programmes that operate at a national scale. The overarching aims of UK and European approaches to conserving threatened species are to prevent extinction, reverse decline, build stronger populations, and reduce threat across the whole range of the species.

Shifting distributions and changing populations of species as a result of climate change may influence conservation prioritisation and strategies to achieve effective results at a national level. As well as a general northward expansion of many animal species, other patterns of spatial change are possible. One of the best documented examples is the 'short stopping' of overwintering wading birds, which remain on the eastern coast of Britain in milder winters rather than moving to the west as they had previously. In such cases, flexibility is required to ensure appropriate objectives for different sites, so that resources are available to support species conservation in new locations. Northward expansion may also require the protection and appropriate management of new sites to ensure that areas are available for colonisation within the new range.

The most important considerations when working at a national scale are summarised below:

Choice of locations for intervention

Climate change may mean that the most suitable places for targeting action for species conservation changes. For increasing numbers of species, conservation efforts may need to shift northwards and take account of changing hydrology and coastal processes. Responses will also differ according to where in a species' range a site is located. At the northern (leading) edge, actions to promote the movement of species through the landscape and encourage the colonisation of new sites may be appropriate, while at the southern (trailing) edge, promoting persistence *in situ* by building resilience or protecting and developing climatic refugia may be more appropriate. At the same time, species new to the UK are arriving and becoming established. These species may be declining in other parts of their range, and their protection in the UK may be essential to prevent global declines.

Changing targets for populations

To compensate for both anticipated and actual losses in parts of the present range where climate change is making conditions less suitable, higher population targets may be needed in other parts where conditions are becoming more suitable. In the short-term, greater investment may be needed in threatened places until populations have built up elsewhere.

Identify refugia

Within parts of the country that are becoming progressively less suitable for a species, there are likely to be some areas where a more favourable local microclimate offers a better chance of the species persisting. A greater focus on identifying and managing these areas as effective climatic refugia may help to maintain a species within a region, even if this is only a short-term measure until longer-term action is possible. Recent research (Suggitt *et al* 2014) has shown that species declining with climate change have tended to survive better in such refugia than the surrounding landscape in recent decades.

Facilitate colonisation of new sites

As well as ensuring species' populations within existing sites are large enough to support dispersal to new areas, action may be needed to assist the colonisation of new sites. This can include improving the connectivity of suitable habitats through the landscape, and proactive management of potentially suitable sites to ensure suitable habitat is available for colonisation.

In some circumstances, species may be slow or unable to colonise new areas, so artificial translocation to new sites may be the only option which allows establishment in a new location. These may include locations within the species' present range where conditions are likely to remain suitable, as well as locations in new areas of climate suitability. This has not been used as a response to climate change by Natural England or the RSPB to date, but may well be in future.

Migratory species

The needs of migratory species can be complex, and conservation efforts may be required at different sites along a species' migratory route. In many cases, this will involve sites in other countries, and international cooperation will be important. Within the UK, the main adaptation response will be to ensure a sufficient number of suitable 'landing sites'. As with resident species, the location of these sites may vary as climate changes.

Ring ouzel. © rspb-images

Adaptation at the local scale

At the local scale, for example on a nature reserve, decisions about managing individual species are made in the context of the wider range of communities and habitats on site. Climate change adaptation is no different in this respect, and adaptation of habitat management is considered in more detail in the Habitat section of the adaptation manual.

Nevertheless, there are circumstances where a more tailored approach to individual species is desired. Figure 1 provides a framework for this, based around building resilience of populations *in situ* or accommodating change.

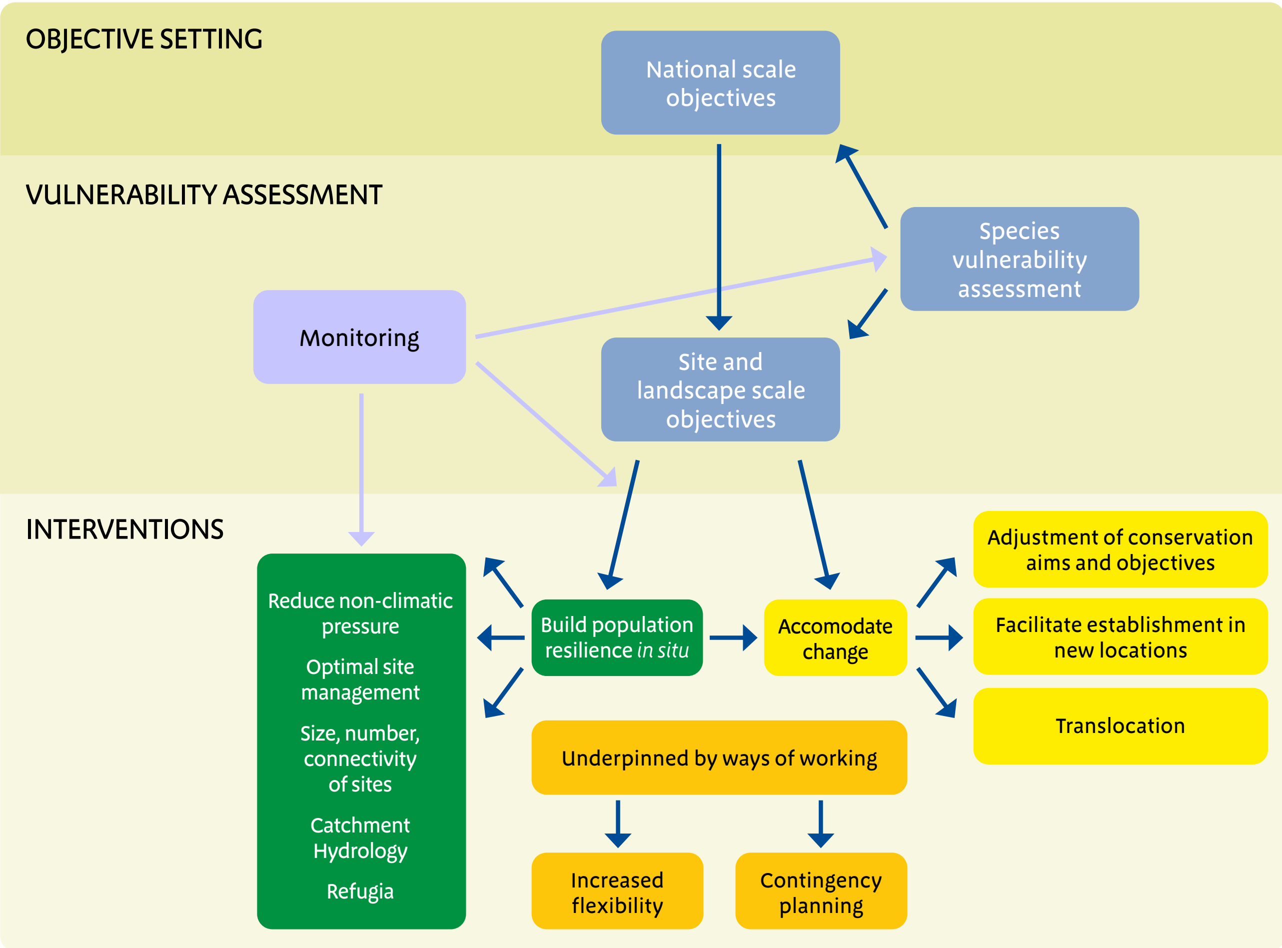

Figure 1: Approach to adaptation for species at the local scale

Building resilience of species populations *in situ* at local scale

Actions that can contribute to maintaining species *in situ* are outlined in Box 1 below.

- Enhance site quality by addressing non-climatic pressures such as inappropriate management, pollution and over-abstraction.
- Increase the size, number and connectivity of habitat patches within the landscape.
- Identify potential local refugia, and target management intervention to increase species populations in these areas.
- Create structural diversity within habitats, which increases the range of microclimates available to species. The Natural England Mosaic Approach sets this out in more detail.
- Control invasive, pest or pathogen species, which are likely to increase with climate change.
- Restore natural hydrological function, for example by blocking artificial drainage or reinstating natural river courses. Where natural hydrology cannot be restored, there may be a case for increasing control through sluices or pumps to ensure an optimal water level in locations of importance for threatened species.
- Manage competitor species which are benefiting from a warmer climate or changed hydrological conditions.
- Adopt more flexible management to respond to within and between year variation in the weather.
- Increase resilience to extreme events and use contingency planning to ensure effective recovery responses.
- For species with limited mobility, such as arctic-alpine plants, consider local translocation to suitable micro-sites, taking account of changing temperature, hydrology and coastal processes.

Box 1: Actions that can contribute to building resilience of species populations *in situ*

Implementing good conservation management under the present climate and reducing other pressures on species at site level is the most basic approach to building resilient populations. Anything which increases population size increases both the chances of a population surviving a period of adverse weather and of individuals dispersing and colonising new locations locally.

Although optimising site management and reducing pressures on the site is an essential starting point, it will not be sufficient for all species, and what constitutes optimal management will itself change as the climate changes. The impact of climate change on species is set within the context of the habitats and systems where they occur. For example, in grassland, changes in the growth rate of different species may lead to changes in their competitive ability, leading to the loss of target species. In this case, grazing or cutting regimes could be adjusted to counter this change. Other potential changes to management include managing competitor, pest or pathogen species that are likely to benefit from a warmer climate or changing hydrological conditions. Another approach would be creating more structural diversity within the landscape, which increases the range of microclimates available to species. For example, changing the height of the sward or increasing the amount of scrub and trees to create shade could be used to counter increasing temperature and the risk of drought. Natural England's Mosaic Approach sets this out in more detail. Planting trees beside water courses can also lower water temperatures and enable temperature sensitive fish species such as salmon and trout to survive; the **Keeping Rivers Cool** manual provides more information on this.

Most conservation sites in the UK are relatively small and influenced by the surrounding landscape and the catchment in which they occur. Increasing the size, number and connectivity of habitat patches can build larger, more resilient poplulations. Larger sites tend to support larger populations, and are also less influenced by surrounding land which may be unsuitable for species. For example, true woodland specialist species require deeply shaded, frequently damp, conditions which only develop well away (e.g. 100m) from the woodland edge. Where small sites can support species, the extent to which a large number of sites within a landscape can increase resilience will depend on specific circumstances, particularly the mobility of species and the degree of connectivity (including proximilty) between sites.

Where mobile species form metapopulations across a number of sites, there may be considerable benefit if new sites can be created. Species with low mobility at all stages in their life cycle are much less likely to benefit due to their inability to reach new sites. Connectivity can be increased through new sites, but also by connecting habitat such as hedgerows and corridors. 'Softening the matrix' – ensuring the the intervening land between habitat patches can allow species to pass through easily – can also help. For example pollen and nectar mixes that provide food facilitate movement between patches for some species, even if they are not suitable habitat for breeding. It is important to note that connectivity is not a panacea for all species and also carries risks. In particular invasive species, pests and pathogens may be enabled to spread by increasing connectivity.

Hydrology is a key determinant of habitat quality for wetland and aquatic species. It is also liable to change as rainfall patterns change and warmer conditions lead to higher evapo-transpiration rates. Changes in the hydrology of sites are a significant threat to many species. In these cases, the restoration of natural hydrological function may be the best way to facilitate adaptation, for example by blocking artificial drainage or reinstating a natural river course. However, many sites are small and reliant on structures and management for their continued existence, so in the short- to medium-term, where natural hydrology cannot be restored, there may be a case for increasing control through sluices or pumps to ensure optimal water levels in locations important for threatened species.

The concept of refugia (see above) is relevant at local as well as national scales. Even within a site there are often areas which are locally colder (such as higher altitudes and north facing slopes), more likely to retain water during dry summers, or less prone to flooding or erosion. Well managed refugia can both help populations to survive on a site and help to build strong populations that are more able to disperse to more climatically suitable areas.

Accommodating change at local scale

Some changes in species are inevitable with climate change, regardless of how resilient a system is. Species distributions have already changed substantially for some more mobile species (Morecroft & Speakman 2015), coastlines have changed with rising sea levels, and habitats may change as the balance between different species shifts. Conservation management may cease to be effective it fails to take account of such changes.

Adjust conservation aims and objectives

There is clear evidence that many animal species are colonising locations to the north of their previous range in the UK (Mason *et al* 2015), and that SSSIs are often the first sites to be colonised (Thomas *et al* 2012). Where a species of conservation interest colonises an area, the most important response is to recognise that it is a new interest feature on the site and to start to factor its presence into management planning and the assessment of site condition. The balance of species within communities is also changing. It is therefore important to monitor the status of species and communities and to review management plans and indicators of favourable condition on sites. Modelled projections of changes in species populations due to climate change can help to highlight those species for which particular attention may be necessary. However, given the range of factors which interact with climate change and the potential to build population resilience *in situ*, it would be premature to remove a threatened species from site management objectives while it continues to survive there. Similarly, there is no reason to accept a decline as inevitable until interventions to build resilience have been attempted.

Facilitate the colonisation and establishment of species at newly suitable locations

Although many species are colonising new climatically suitable areas without human intervention, this generally lags behind the speed of climate change, and a large number of other species have limited dispersal capacity. As climate change continues, a proactive approach may be increasingly beneficial or necessary for some species. This is a national and international issue, but it has important local implications.

There are three main ways in which colonisation of a new site may be facilitated:

1. Where a species can reach a new site but cannot establish a viable population, management to create suitable conditions may be necessary. This may involve additional habitat creation, improving the quality of the site (e.g. through sward enhancement), or modifying site management for the specific requirements of the incoming species.

2. Where a species is mobile and has the capacity to disperse, it may benefit from developing an ecological network in which species can move between sites. Physical connection, proximity, and the characteristics of the intervening land can all increase the chances of colonisation and establishment (Lawton *et al* 2010). Landscape scale conservation initiatives such as **Futurescapes** and **Living Landscapes** are useful approaches for developing ecological networks. The Nature Recovery Network also aims to create and restore ecosystems on a large scale in order to repair our national network of habitats. Please see Natural England's **Nature Networks Handbook** (Crick *et al* 2020) for more details on how to design a multifunctional ecological network. Building up populations on existing sites is also important, to ensure there are sufficient individuals with the potential to disperse and colonise new sites.

3. Where a species has limited mobility, *translocation* may be considered. Translocation involves the removal of individuals of a species from one site and transporting them to other sites, to establish new populations or augment existing threatened populations. Many habitat creation and restoration activities might be regarded as translocation, including those used to revert arable land to grassland, stabilise the surface of eroding bog, and tree planting to create new woodland, as species are artifically established outside their current locations. Translocation in the context of climate change is likely to focus in the first instance on introducing species to suitable sites on or just beyond their present northern range margins, rather than moving species hundreds of kilometres north. The impact on existing populations should be minimised by transplanting propagules or raising individuals in controlled conditions *ex situ*.

   The need for consent should be considered in all cases and permission sought if necessary. Natural England local staff can provide advice on specific situations. Outside habitat creation and restoration schemes, translocation is not currently used widely in UK conservation as a response to climate change. It may, however, be preferable to increasing connectivity in some circumstances, for example:

- For species with poor dispersal ability, where simply increasing connectivity is unlikely to be sufficient.
- Where suitable habitat cannot be easily found or created in the immediate vicinity of present sites. Many species are habitat specialists or require associations with other species, which prevents them taking advantage of newly created habitat in the wider agricultural environment.
- Where lack of opportunity or resources for improving connectivity means that physically moving species may be a more practical option.

Ways of working

The adaptation responses outlined above will often require changes to the way management interventions are planned and delivered. Key requirements are flexibility and contingency planning as well as normal management planning.

Flexibility

Climate change is already leading to increased variability in weather, both within seasons and between years. This means that greater flexibility needs to be built into long-term planning and practical management. For example, it may be more necessary to alter grazing intensity, stock movements and dates of operations.

Contingency planning

The frequency of extreme events such as drought, heatwaves and flooding is increasing. Contingency planning to ensure effective prevention and recovery responses following such events is likely to be a key action for species in areas at risk. Examples include wildfire management plans on heathland, and installing suitable sluices on coastal wetlands susceptible to saline incursion.

Supplementary information on vulnerability assessment

This section expands on the approaches to assessing vulnerability discussed in section 3.

A large amount of academic study has gone into developing methods to assess species vulnerability to climate change. Pacifici *et al* (2015) provide a review of the main approaches and issues. They recognise three broad approaches to vulnerability assessment: mechanistic, correlative, and trait-based.

Mechanistic approaches draw on a detailed understanding of the physiological and/or population responses of a species to climate. This can give a more accurate assessment of species vulnerability to climate change, although the level of understanding required is not available for the vast majority of species. Even if a single species is well known, it also requires a knowledge of key interactions with other species and the factors that affect them. There are a small number of British species where sufficient in-depth knowledge is available to help guide management. Some of these are presented in the case studies. These exemplar species can also help to identify mechanisms of vulnerability and adaptation that have a wider application.

Correlative approaches infer climate change sensitivity from current correlations between climate and species. Climate envelope modelling is the most common example, where a relationship between a species' distribution and climate is inferred from its current distribution, and used to model future potential 'climate space'. Another example would be to correlate trends in population abundance over time with changes in climatic variables.

Trait-based approaches are based on the concept that key characteristics of species can be indicators of the likely vulnerabilities of a wide range of species to climate change. They have the potential to provide a way of screening species to identify those that are most at risk, without detailed and reliable information on distribution, population change or specific mechanisms.

Wheatley *et al* (2017) reviewed a range of different vulnerability assessment methodologies for species and concluded, for British bird and butterfly species, that those based on traits alone failed to predict those species which changed most during recent climate change. In contrast, approaches that used correlative approaches including an assessment of previous trends in species, did have some success in predicting species vulnerability. This included the methodology of the Natural England funded project which assessed over 4000 UK species (Pearce-Higgins *et al* 2017, 2015). It should however be noted that even in this project, there was relatively low confidence in the projections for many species beyond birds and butterflies, so care and judgement are needed, using a wide range of different information.

Climate envelope models. The relationship between a species' distribution and climate can be modelled using climate envelope models, which quantify the relationship between distribution and climatic variables using a range of mathematical techniques. These relationships can then be used to project where suitable climate is likely to be found in future on the basis of climate change scenarios. The most up to date and comprehensive assessment using a climate envelope approach in the UK, referred to above, took account of not just modelled projections of species range change but also changing distributions (Pearce-Higgins *et al* 2015, 2017). Species maps derived from this project are available via the **Natural England Open Data Geoportal** and are used to illustrate the case studies presented at the end of this section of the manual. Earlier projects included **MONARCH** (Modelling

Natural Resource Responses to Climate Change), **BRANCH** (Biodiversity Requires Adaptation in Northwest Europe under a CHanging climate) (BRANCH Partnership, 2007, maps available **here**) and an atlas showing the impact of climate change on the distribution of Europe's breeding birds (Huntley *et al* 2007).

Climate envelope modelling has proved a valuable guide to species sensitivity to climate change. It is useful for identifying where adaptation action may be necessary, for example in places where a species is likely to be at risk or to have an opportunity to colonise. Limitations of this modelling, which need to be understood when developing adaptation action, include the following:

- If current distributions are determined largely by factors other than climate, such as soil conditions associated with a particular local geology, or human activities, including land management and persecution, the relationship between present day distribution and climate will be weak and of limited value in projecting future change. In the cases of rare or localised species, it may often simply not be possible to derive any meaningful relationship between distribution and climate (Pearce- Higgins *et al* (2017) found this was the case for 10% of the species studied).
- Climate change may result in climatic conditions for which there is no present day analogue, and therefore projections based on present climate will be unreliable.
- Distribution data available for modelling may not cover the whole geographical range of a species (for example if only UK or European distribution data are available for a species that has a wider global distribution), and so models will not give a full representation of the climate space that can be occupied.
- Climate and distribution are typically mapped at a large scale (tens of kilometres). The actual distribution of species may, in practice, be determined at a much smaller scale according to local microclimatic conditions. For example, a mountain top species may be restricted to the coolest parts of a grid square, whereas the climate value for that square reflects an average.
- Distribution maps for some species may not be accurate. Britain has better datasets than most other countries, but there are still gaps in the distribution record for more isolated areas and for harder to identify and less charismatic groups of species.
- The presence of refugia, where local climate variations and microclimates provide conditions in which a species can survive locally, but which gridded climate data are too coarse to pick up.
- Projections of future climate change are not forecasts and include inherent uncertainties about future emissions and the sensitivity of the climate systems They also cannot take account of the full range of weather conditions contained within the climate projections, such as rare events to which species may be vulnerable.

Climate envelope models indicate where climate conditions may be suitable. They do not take account of other factors, such as whether a species can reach a new potential location, or whether other requirements such as habitat or food supply will be available there. Nevertheless, climate envelope model outputs may prove useful in helping to identify where adaptation measures may make a difference.

Trait-based approaches

Particular ecological traits can be identified which may indicate a species' likely vulnerability to climate change, or potential opportunities. The term 'trait' can cover a wide range of attributes, ranging from a species' distribution to aspects of physiology and broader functional types. In most cases, a combination of traits is likely to be more valuable than any single one.

The following are potentially useful traits for which information is available in the UK.

Distribution-based traits. In the UK, the distribution of most species is known to some extent. In general, southern species, with their northern range margins within the UK, will tend to spread northwards if they are not limited by dispersal capacity or habitat fragmentation and availability. Conversely, northern species with a southern range margin in the UK are at risk of range contraction, with a loss of their southern outposts. This potential change in range may be assessed using climate envelope modelling (see above). However, it can also be used to derive indicators of a species' climatic requirements (e.g. mean temperature it occurs at) which may in turn indicate where it will be at risk and where it may have opportunities to colonise. Some indices are available to reflect this, including mean climate statistics for the UK, for a range of plant species in the **Plantatt** dataset. Species distribution data for the UK are also available on the **National Biodiversity Network Atlas** website.

Mobility. The more mobile a species is, the better it is likely to be able to change distribution to track suitable climate. Mobile species are also able to disperse locally to places where they may be better able to survive adverse weather conditions, for example, wet areas during a drought, or cooler, north facing areas during periods of high temperatures. Migratory species, in particular, are often adapted to be able to search out new areas each year, especially if they utilise relatively ephemeral habitats. However, some migratory individuals become relatively fixed in their migratory patterns after their first migration, so changes in location may only occur with each new generation.

Reproduction/life cycle traits. Species with high reproductive rates and short generation times, described as r-selected species, can produce more offspring, increasing the potential for dispersal to new sites, and also have the potential for more rapid genetic adaptation to changing conditions. Conversely, K-selected species, which are typically long-lived and slow reproducing, may be better able to survive *in situ*, at least in the short term, but less able to adapt to changing conditions.

Plant CSR strategies. The Competitor – Stress tolerator – Ruderal scheme for categorising plants (Grime, 1974) is a widely used approach to functional types. Competitor species can grow quickly when conditions are favourable and resources available; stress tolerant species are slow growing and adapted to survive low levels of resources; and ruderal species reproduce quickly and exploit temporary habitat availability. Intermediate types can be recognised along a spectrum between the extremes. Different aspects of climate change may favour one type or another, so, for example, species with stress tolerant characteristics may be better able to survive a drought; ruderals to colonise bare patches of ground after a drought, flood or wild fire, and competitors to benefit from increasing mean temperatures and a longer growing season.

Specialism/generalism. The greater the level of specialism, the greater the level of reliance on a narrow range of niches, such as microclimate or other species. This, in turn, means that the influence of climate change may act through its impact on other ecosystem components upon which a species relies, as well as directly on the species. The more generalist a species, the more likely it is to be able to exploit multiple niches and habitats, which may reduce the impact of climate change, or enable it to benefit from new opportunities.

Modelling changes in tree growth

An analogous approach to climate envelope modelling has been developed for predicting the growth of trees in the Ecological Site Classification Decisions Support System developed by Forest Research. This models the future 'suitability' of woodland types and individual species based on correlations between measured growth rates of different tree species with physical variables, including climatic, at sites throughout the UK. For conservation purposes, it is worth noting that a species may still survive at a site even if it produces a poor timber yield.

Modelling changes in species populations

Modelling of changes in species populations in relation to weather conditions has been carried out for some species, particularly through the BICCO-Net project (Pearce-Higgins *et al* 2015). It is not widely available as a tool for conservation practitioners at the present time but offers potential for future development. Qualitative information about the impacts of periods of contrasting weather can also be useful in conservation management.

Ecological studies

Experiments, ecophysiology and auto-ecological studies can all provide invaluable information on the responses of species to climate change, although this detailed information is only available for a small proportion of UK species. Natural England's specialist staff can provide advice, as may other local experts, and both Natural England's and the RSPB's species priorities and recovery programmes are underpinned by good ecological knowledge. Some nature conservation sites, including a number of National Nature Reserves, have been used for research over a long period of time and this may help to inform decision making.

Factors modifying species vulnerability to climate change

A variety of other environmental factors, including habitat fragmentation and degradation, can exacerbate vulnerability to climate change, by increasing exposure to new climatic conditions or reducing the adaptive capacity of species. Possible factors that could increase the vulnerability to climate change, and which should form part of a vulnerability assessment, are outlined in the table below.

Table 2: Environmental factors increasing the vulnerability of species to climate change approach to adaptation for species at the local scale

Environmental factor	Reason
Isolated habitats	Isolated populations are less able to colonise new sites with more favourable climate or microclimate.
Small site size	Small sites generally support small populations, which are more vulnerable to extreme events and disease etc. Small sites are also generally less heterogeneous and have less microclimatic variation, and are therefore more prone to damage from extreme events.
Poor site condition	Sites in poor condition generally support smaller populations, and are therefore more vulnerable to extreme events.
Topgraphic homogeneity	A more homogeneous landscape will generally have less variation in microclimate, and therefore fewer opportunities for species to survive in local refugia.
Non-climatic pressures	If populations are under pressure from non-climatic factors such as pollution or competition from invasive species, their ability to withstand climate change may be compromised.

In some instances, environmental factors may locally reduce the vulnerability for some species. These are illustrated in table 3.

Table 3: Examples of environmental factors which may locally reduce vulnerability of species to climate change

Environmental factor	Reason
Locally cool microclimates, such as north facing slopes and high altitudes	These may act as refugia for some species.
Ground water fed wetlands and water courses	These may buffer water supply against fluctuating rainfall and a trend towards drier summers with wetter winters.
Topographic heterogeneity	More heterogeneous landscapes will generally have a greater range of available microclimatic niches.
Proximity to the coast	The maritime influence helps to moderate temperature extremes (although it may cause other vulnerabilities e.g. saline intrusion, wave action).
Large sites	Large sites generally support larger and more resilient populations, provide a wider range of environmental conditions, and usually exhibit fewer edge effects.

Finally, various forms of human activity can influence the vulnerability of a species, both locally and across landscapes, and so need to be considered as part of species vulnerability assessments. Some examples are given in table 4.

Table 4: Examples of anthropogenic factors that may influence the vulnerability of species to climate change

Environmental factor	Reason
Coastal defences	Coastal defences have the ability to protect some coastal and wetland sites. However, they can also prevent natural coastal processes and roll-back, and increase the vulnerability of sites to sea level rise and wave action.
Water control and abstraction	Control over hydrology has the potential to reduce the impact of changes in rainfall and extreme events. Abstraction has the potential to exacerbate problems of limited water availability.
Management practice	Flexibility in land management, including changes to the timing and nature of farming operations, can be an effective response to changing weather patterns. Conversely, a more rigid approach, for example fixed dates for hedge or hay cutting, that does not take into account seasonal variations in the timing of natural events such as nesting or seeding, could make some species more vulnerable.

In conclusion, there is a range of approaches to assessing the vulnerability of species to climate change, and many environmental and management variables that may increase or reduce that vulnerability. There is no single 'right' approach to vulnerability assessment – the specific context will determine what is appropriate and practical. Decisions will inevitably need to be made in the face of incomplete knowledge, but an adaptive management approach in which the effectiveness of management actions is monitored, reviewed and if necessary adjusted is a good approach and will help to ensure that lessons are learnt from experience.

References

Balmer, D.E., Gillings, S., Caffrey, B.J., Swann, R.L., Downie, I.S., Fuller, R.J., (2013). Bird Atlas 2007–11: the Breeding and Wintering Birds of Britain and Ireland. BTO Books, Thetford.

BRANCH partnership (2007), **Planning for biodiversity in a changing climate** – BRANCH project Final Report, Natural England, UK.

Crick, H.Q.P., Crosher, I. E., Mainstone, C. P., Taylor S. D., Wharton, A., Langford, P., Larwood, J., Lusardi, J., Appleton, D., Brotherton, P. N. M., Duffield, S. J. & Macgregor N. A. (2020) **Nature Networks Evidence Handbook**. Natural England Research Report NERR081. Natural England, York.

Duffield, S., & Le Bas B., (2017). Climate Change at the local scale: taking climate change into account in the management of nature reserves. Conservation Land Management Autumn 2017, 16-20.

Gillingham, P. K., Bradbury, R. B., Roy, D. B., Anderson, B. J., Baxter, J. M., Bourn, N. A. D., Crick, H. Q. P., Findon, R. A., Fox, R., Franco, A., Hill, J. K., Hodgson, J. A., Holt, A. R., Morecroft, M. D., O'Hanlon, N. J., Oliver, T. H., Pearce-Higgins, J. W., Procter, D. A., Thomas, J. A., Walker, K. J., Walmsley, C. A., Wilson, R. J. & Thomas, C. D. (2015). The effectiveness of protected areas in the conservation of species with changing geographical ranges. Biological Journal of the Linnean Society, 115: 707-717.

Grime, J. P., (1974). Vegetation classification by reference to strategies. Nature, 250(5461), 26-31.

Huntley, B., Green, R.E., Collingham, Y.C., and Willis, S.G., (2007). A climatic atlas of European breeding birds. Durham University, The RSPB and Lynx Edicions, Barcelona.

Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.A., Tew, T.E., Varley, J. & Wynne, G.R. (2010) **Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network**. Report to Defra.Department of Environment, Food and Rural Affairs,UK.

Mason, S. C., Palmer, G., Fox, R., Gillings, S., Hill, J. K., Thomas, C. D., & Oliver, T. H. (2015). Geographical range margins of many taxonomic groups continue to shift polewards. Biological Journal of the Linnean Society, 115(3), 586-597.

Morecroft, M., and Speakman, L., (eds.) (2015). **Terrestrial Biodiversity Climate Change Impacts Summary Report**. Living With Environmental Change, Swindon.

Morecroft, M.D., Crick, H.Q.P., Duffield, S.J., Macgregor, N.A. (2012). Resilience to climate change: translating principles into practice. Journal of Applied Ecology. 49: 547-551.

Newson, S.E., Oliver, T.H., Gillings, S., Crick, H.Q.P., Morecroft, M.D., Duffield, S.J., Macgregor, N.A. & Pearce-Higgins, J.W. (2014). Can site and landscape-scale environmental attributes buffer bird populations against weather events? Ecography 37, 872-882.

Oliver, T. H., Marshall, H. H., Morecroft, M. D., Brereton, T., Prudhomme, C. & Huntingford, C. (2015). Interacting effects of climate change and habitat fragmentation on drought-sensitive butterflies. Nature Climate Change 5, 941–945.

Oliver, T.H., Gillings., S., Pearce-Higgins, J.W., Brereton, T., Crick, H.Q.P., Duffield S.J., Morecroft, M.D., Roy, D.B. (2017). Large extents of intensive land use limit community reorganisation during climate warming. Global Change Biology, 23: 2272–2283.

Pacifici, M., Foden, W.B., Visconti, P., Watson, J.E., Butchart, S.H., Kovacs, K.M., Scheffers, B.R., Hole, D.G., Martin, T.G., Akcakaya, H.R. and Corlett, R.T. (2015) Assessing species vulnerability to climate change. Nature Climate Change, 5(3): 215-225.

Pearce-Higgins, J.W., Ausden, M.A., Beale, C.M., Oliver, T.H. & Crick, H.Q.P. (eds). 2015. **Research on the assessment of risks and opportunities for species in England as a result of climate change**. Natural England Commissioned Reports, Number NECR175.

Pearce-Higgins, J.W., Brewer, M.J., Elston, D.A., Martay, B., Powney, G.D., Isaac, N.J.B., Monteith, D., Henrys, P.A., Vaughan, I.P., Ormerod, S.J., Durance, I., Green, S., Edwards, F.K., Johnston, A., Bell, J.R., Harrington, R., Brereton, T.M., Barlow, K.E, Batterbee, R, Shilland, E,. (2015) Final report to the Biological Impacts of Climate Change Observation Network (BICCO-Net) Steering Group. Defra, London.

Pearce-Higgins, J.W., Beale, C.M., Oliver, T.H., August, T.A., Carroll, M., Massimino, D., Ockendon, N., Savage, J., Wheatley, C.J., Ausden, M.A., Bradbury, R.B., Duffield, S.J., Macgregor, N.A., Clean, C.J., Morecroft, M.D., Thomas, C.D., Watts, O., Beckmann, B.C., Fox, R., Roy, H.E., Sutton, P.G., Walker, K.J., Crick, H.Q.P. (2017). A national-scale assessment of climate change impacts on species: Assessing the balance of risks and opportunities for multiple taxa. Biological Conservation 213, 124–134.

Suggitt, A.J., Wilson, R.J., August, T.A., Beale, C.M., Bennie, J.J., Dordolo, A., Fox, R., Hopkins, J.J., Isaac, N.J.B., Jorieux, P., Macgregor, N.A., Marcetteau, J., Massimino, D., Morecroft, M.D., Pearce-Higgins, J.W., Walker, K. & Maclean, I.M.D.(2014) **Climate change refugia for the flora and fauna of England**. Natural England Commissioned Reports, Number 162.

Thomas, C. D., Hill, J. K., Anderson, B. J., Bailey, S., Beale, C. M., Bradbury, R. B., … Yardley, T. (2011). A framework for assessing threats and benefits to species responding to climate change. Methods in Ecology and Evolution, 2, 125–142.

Thomas, C.D., Gillingham, P.K., Bradbury, R.B., Roy, D.B., Anderson, B.J., Baxter, J.M., Bourn, N.A.D., Crick, H.Q.P., Findon, R.A., Fox, R., Hodgson, J.A., Holt A.R., Morecroft, M.D., O'Hanlon, N.J., Oliver, T.H., Pearce-Higgins, J.W., Procter, D.A., Thomas, J.A., Walker, K.J., Walmsley, C.A., Wilson, R.J., Hill, J.K. (2012) Protected areas facilitate species' range expansions. Proceedings of the National Academy of Sciences 109: 14063–14068.

Wheatley, C.J., Beale, C.M., Bradbury, R.B., Pearce-Higgins, J.W., Critchlow, R., Thomas, C.D., (2017). Climate change vulnerability for species—Assessing the assessments. Global Change Biology 2017;23:3704–3715.

Part B Species case studies

Introduction to species case studies

The preceding sections outlined the issues to be taken into account when considering appropriate adaptation actions. These include an assessment of the impacts of climate change in order to determine the threat or opportunity that it may pose. Consideration of other pressures and the effectiveness of different forms of intervention are then required to identify the range of potential actions.

The following species case studies provide examples of how these steps have been applied to a range of species that are sensitive to climate change. Each case study uses the same format to describe the general ecology and distribution of the species and the likely impacts of climate change, together with an assessment of the confidence level in these impacts. This is followed by a range of potential adaptation options that may be appropriate in individual locations. Examples of where these actions are being implemented and links to the wider literature are also provided.

The species selected for case studies are all species of conservation interest for which the evidence suggests that climate change is likely to be an important conservation issue. They have been selected to represent a variety of species groups, and to illustrate a range of approaches to adaptation. It is envisaged that the list of case studies will be added to over time.

Each case study is structured as follows:

1 Summary table

This table summarises the threats and opportunities that climate change presents to that species and the ability of interventions to address them. Each element is scored according to a simple Red – Amber – Green (RAG) assessment. Where climate change will benefit a species, the sensitivity box is coloured green and the text reads *Potential Benefit*.

Climate change sensitivity is determined from a range of sources. The primary source is the species risks and opportunities report basic and migratory bird assessment tables (Pearce-Higgins *et al* 2015), while for butterflies, the assessment in Thomas *et al* (2011) has been used. For species not covered in these analyses, a review of other published evidence has been used. Where climate change will benefit a species, the sensitivity box is coloured green and the text reads *Potential Benefit*.

Non-climatic threats. This assessment considers the severity of non-climatic pressures affecting the species, including land use change, pollution, and habitat fragmentation. The judgement is derived from a literature appraisal. The severity of non-climatic pressures influences the capacity of the species to respond to climate change.

Ability to manage. This assessment considers the ability of management to address the adverse impacts of climate change, such as altering grazing regimes to address changes to growth characteristics or competition, or controlling water levels to balance increased water deficit. The rating relates to how effective *in-situ* management is likely to be in addressing the threats posed by climate change. **Please note** - the RAG status in this assessment works in the opposite way to the above assessments, i.e. a high ability to manage is coloured green and a low ability is coloured red.

Vulnerability. The overall vulnerability assessment for the species is based on consideration of the results of the three other boxes.

The table below brings together these assessments for all the species in this section:

Species	Climate change sensitivity	Non climatic threats	Ability to Manage	Vulnerability
Adonis blue	Potential Benefit	Medium	High	Low
Alpine lady's-mantle	High	Low	Low	High
Atlantic salmon	High	High	Medium	High
Baltic sphagnum (*Sphagnum balticum*)	High	Medium	Medium	High
Beech	Medium (high for drought)	Low	Medium	Medium
Bilberry	Medium	Medium	Medium	Medium
Bluebell	High	Medium	Medium	Medium
Common green grasshopper	High	Medium	Medium	Medium
Curlew	Medium	High	Medium	High
Dartford warbler	Potential Benefit	Medium	Medium	Low
Forester	Medium	High	Medium	Medium
Golden plover (breeding)	High	High	High	Medium
Golden plover (wintering)	Potential Benefit	Low	Low	Low
Great crested newt	Medium	High	High	Medium
Keeled skimmer	High	Medium	Medium	Medium
Large heath	High	High	Medium	High
Little tern	High	High	Medium	High
Mountain bumblebee	High	Medium	Low	High
Mountain ringlet	High	Low	Low	High
Northern brown argus	High	Medium	Medium	High
Ring ouzel	High	Medium	Medium	High
Silver spotted skipper	Potential Benefit	Medium	High	Low
Small red damselfly	High	High	Medium	High
Tree lungwort	High	High	Medium	High
Twite	High	High	Medium	High
White faced darter	High	Medium	Medium	High
Whitefish, vendace and Arctic charr	High	High	Low	High

2 Summary

The summary provides a brief overview of the key facts from the following sections.

3 Description

This provides a general description of the species.

4 Ecology and Distribution

This section describes the general ecology and UK distribution of the species, focusing on those aspects most relevant to climate change; for example, particular aspects of its ecology that may make a species vulnerable to climate change, such as a preference for cool, shady microclimates, or areas with higher water tables.

The species distribution is shown on a map derived from a range of recording schemes. For example, For bird species, maps from the BTO Atlas of Breeding and Wintering Birds of Britain and Ireland (Balmer *et al* 2013) have been used. This is shown for two time periods, pre and post 1990, to show its historic distribution and any recent change. Changes to the distribution can be used to infer climate change sensitivity. These maps show all 10km² grid squares for which a species was recorded during each of the time periods. The post-1990 record does not necessarily represent the current distribution.

White faced darter. © rspb-images.com

5 Climate Change Impacts

This section describes how the species is expected to be affected by climate change.

The initial table provides a RAG assessment of how confident we are that changes in the *Distribution* of the species are primarily due to climate change, and our understanding of the *Mechanism* behind observed changes; both of which are important considerations when identifying appropriate interventions.

The table below brings together these assessments for all the species in this section:

Species	Distribution change	Mechanism
Adonis blue	Medium confidence	High confidence
Alpine lady's-mantle	High confidence	Medium confidence
Atlantic salmon	NA	NA
Baltic sphagnum (*Sphagnum balticum*)	High confidence	Low confidence
Beech	High confidence	High confidence
Bilberry	Medium confidence	Medium confidence
Bluebell	Medium confidence	Low confidence
Common green grasshopper	Low confidence	Low confidence
Curlew	High confidence	Low confidence
Dartford warbler	High confidence	High confidence
Forester	Low confidence	Low confidence
Golden plover (breeding)	High confidence	High confidence
Golden plover (wintering)	High confidence	Medium confidence
Great crested newt	Low confidence	Medium confidence
Keeled skimmer	Medium confidence	Medium confidence
Large heath	Medium confidence	Low confidence
Little tern	High confidence	Medium confidence
Mountain bumblebee	Medium confidence	Low confidence
Mountain ringlet	High confidence	Low confidence
Northern brown argus	High confidence	Low confidence
Ring ouzel	High confidence	Low confidence
Silver spotted skipper	High confidence	High confidence
Small red damselfly	Low confidence	Low confidence
Tree lungwort	High confidence	Medium confidence
Twite	High confidence	Low confidence
White faced darter	High confidence	Low confidence
Whitefish, vendace and Arctic charr	NA	NA

The text describes the observed and predicted impacts of climate change on the species, evidenced from the literature, and covers likely distribution and population changes, and other climate change threats or opportunities. Where there is evidence about the mechanism responsible for change, this is presented.

For most species, maps showing the projected change in the suitability of the climate under a 2°C warming scenario are provided. These are derived from **research** undertaken for Natural England in 2015 (Pearce-Higgins *et al* 2015) and are based on modelled data. Where maps are not included, this is because either the species concerned was not covered by the original research, or because there is low confidence in the model for that species. This is most likely to occur for very rare species with a highly restricted distribution, species whose current distribution consists of remnant, disjunct populations, and species whose UK distribution reflects only a very small portion of its true climatic range.

These maps are created using statistical models which describe the probability that a species will be found in a 10km grid square, based on its current distribution and its relationship to a number of climatic variables. These can be used to model the suitability of grid squares for a species under possible future climates when climate change projections are taken into account. Please note that the maps show only climate suitability and do not take any account of the other factors that might influence a species' distribution.

More information on climate envelope modelling and the use of climate suitability maps is provided in section 3 of this chapter.

6 Adaptation options

This section outlines a range of potential adaptation options for that species, based on an understanding of the species' ecology, its vulnerability to climate change and other pressures, and the likely effectiveness of management interventions. Options include measures to promote ecological resilience and accommodate change, as well as changes to ways of working, including greater flexibility, contingency planning and adaptive management. Where there are gaps in our knowledge, areas for further research and development are suggested.

The options represent a range of actions likely to be effective in promoting the conservation of the species in the face of climate change. They need to be interpreted in the context of local conditions to determine which actions are likely to be most effective and relevant for a particular situation. This consideration needs to take account of the specific local threats, the availability of management options, and the position of that locality within the species' range.

7 Relevant Countryside Stewardship options

Agri-environment schemes are an important mechanism for supporting species adaptation. This section outlines the most relevant options under the Countryside Stewardship scheme.

8 Case studies

Where available, links are provided to relevant case studies that illustrate examples of practical adaptation.

9 References and further reading

This lists the main reports, journal papers, and other publications that have helped inform the species account. Where possible, web links have been provided.