Terrestrial biodiversity Climate change impacts report card technical paper

4. Implications of Climate Change for SSSIs and other Protected Areas

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Executive Summary

Sites of special scientific interest (SSSIs) cover just under 7% of England, around 12 % of Wales and around 13 % of Scotland. In recent years, investments have been made to bring the habitats and species that SSSIs were designated for into ‘favourable’ condition. However, some SSSIs and other protected areas (PAs) are under direct physical threat from inundation following sea level rise, and changes in climate will affect the species and habitats that are present on most PAs. This report summarises these threats and considers options for changing the way that the protected area network is managed.

The following impacts of climate change have already been detected on PAs;

- Saltmarshes have been lost to coastal squeeze, and coastal freshwater habitats including grazing marsh and lowland raised bog are at risk of inundation by seawater under current conditions
- Northern species have decreased in density, whilst southern species have increased in density. Whilst most evidence for this occurring on PAs comes from outside the UK, there is evidence that these patterns are occurring within the UK as well
- Southern species in the UK have used PAs to facilitate their northwards expansion

In addition, the following impacts of climate change have been predicted to occur in future;

- The composition of flora and fauna on each PA will change – high confidence (medium evidence, high agreement)
- Cold adapted species of high latitudes and altitudes will tend to decrease on PAs, whilst warm adapted species will tend to increase – medium confidence (medium evidence, medium agreement)
- PAs in the North of the UK will gain plant species overall, whilst PAs in the south are likely to lose plant species. This pattern is reversed for UK breeding birds – low confidence (medium evidence, low agreement)
- Species with lower dispersal capacities and those for which urban areas are a barrier to dispersal will be unable to colonize PAs that become climatically suitable – low confidence (limited evidence, medium agreement)
- Work in Africa predicted that some Important Bird Areas (IBAs) may lose all the species for which they were designated by 2085, although for around 90 % of species at least one currently occupied IBA should remain suitable. In Europe, species turnover is predicted to be faster than in Africa – medium confidence (medium evidence, medium agreement)
- Increasing range mismatching of interacting species, such as butterflies and their host plants, might mean that more management is necessary on PAs to preserve species that interact with each other – low confidence (limited evidence, medium agreement)
- Hotspots of bird diversity in Finland and Norway may no longer coincide geographically with PA boundaries – low confidence (limited evidence, medium agreement)

Integrating consideration of climate change into management plans for the PA network is likely to result in more effective (and cost-effective) conservation solutions. In order to

facilitate this integration, monitoring of climate change impacts and management actions should be carried out to enable adaptive decision making.

Introduction

Protected areas (PAs) cover 10.1-15.5 % of the globe (depending on definition; Chape *et al.* 2005, Soutullo 2010), and the Aichi Targets of the Convention on Biological Diversity aim to increase this to 17% (Harrop 2011). In the UK, there are many different conservation designations. Areas designated primarily for the protection of biodiversity cover just under 7 % of England, around 12 % of Wales and around 13 % of Scotland, (Sites of Special Scientific Interest (SSSI) which encompass Special Areas of Conservation (SACs, designated under the EU Habitats Directive), Special Protection Areas (SPAs, designated under the EU Birds Directive) and Ramsar sites (designated under the Ramsar convention)). The area protected increases to over 23 % of England and over 25 % of Wales if all designations are considered, including those primarily designated for the landscape character, such as Areas of Outstanding Natural Beauty and National Parks (Lawton *et al.* 2010). Even these less biodiversity-focussed designations may decrease the likelihood of activities that are potentially harmful to wildlife occurring (Bate *et al.* 2010).

Patterns in the distribution and size of the UK's protected sites

Protected areas are not spread uniformly across the UK, so this paper begins by examining patterns in the distribution and size of the UK's protected sites. Ancient Woodland habitats are covered by the planning system as well as by SSSI designation (less than 22 % of broadleaved woodland in England is within SSSIs, Lawton *et al.* 2010), so patterns in their distribution have been investigated in addition to SSSIs. Within the UK, 1 km grid squares at higher altitudes tend to have a higher percentage cover of SSSI (Spearman's Rank Correlation, rho=0.28, $P<0.0001$), reflecting the greater proportion of semi-natural habitat in the uplands. Conversely, 1 km grid squares with high percentage cover of ancient woodland are often found at lower altitudes (Spearman's Rank Correlation, rho=0.05, $P<0.0001$ – the relationship is very weak despite the highly significant p-value). In addition to this, across the whole of the UK, higher latitudes tend to have a higher percentage of SSSI (Spearman's Rank Correlation, rho=0.26, $P<0.0001$), whilst the distribution of Ancient Woodland shows a bimodal distribution with latitude, so that there is a higher percentage of cover at low and high latitudes, with less at the central latitudes. This pattern in distribution reflects the land use history of different soil types and topographies. Many areas of ancient woodland in the UK are very small (modal value is 0.29 hectares) although this differs between countries – England and Wales have many small areas of ancient woodland (mode 0.28 hectares for England, 0.27 hectares for Wales, >44,000 recorded sites in England, >48,000 recorded sites in Wales), whilst Scotland has fewer but larger areas of this habitat (mode 1.97 hectares, <29,000 recorded sites).

Importance of Protected Areas to conservation

In the UK, where areas outside PAs are often highly modified, some plant species are entirely confined to PAs and most are well represented in PAs, although some critically endangered species appear not to be represented within their borders (Jackson *et al.* 2009). Across Europe, there is some evidence that SPAs improve the population trends of the species they were designed to protect. Donald *et al.* (2007) found an association between the percentage of land protected and the population trend of European breeding birds between two survey periods. This relationship was stronger for species protected under Annex 1 of the Birds Directive, for which SPAs are designated, but still held for non-Annex 1 species. However, the contribution of SSSIs to conserving non-target species can be variable. In a study of eight British butterflies, Davies *et al.* (2007) found that whilst population trends tended to be positive on SSSIs, half the species studied maintained higher populations on SSSIs in unfavourable condition than they did on SSSIs in favourable condition according to common standards monitoring. They concluded that management for biodiversity in Britain is detrimental to butterflies associated with later seral stages of grassland and scrub/grassland mosaics, which suggests there may be more that can be done to conserve biodiversity on SSSIs. A more recent study (Brereton *et al.* 2011) found that population trends for 12 specialist butterflies were no different on SSSIs than on unprotected land, and numbers of these species were declining across the UK. In addition to benefitting biodiversity, SSSIs also contribute significant economic benefits in terms of the ecosystem services they provide; Christie and Rayment (2012) found that the general public in England and Wales were willing to pay almost nine times more than the current cost of SSSI management for the ecosystem services they provide.

Vulnerability of Protected Areas to Climate Change

Protected areas have different vulnerabilities to the effects of climate change depending on their location, size, sensitivity of component habitats and species, current condition and the presence of non-climatic factors such as pollution (Wilson *et al.* 2010). Coastal habitats are particularly vulnerable to inundation by seawater and coastal erosion. For example, large areas of many saltmarshes protected in SPAs have been lost to coastal squeeze since their designation (Haskoning 2006). Fresh water habitats located close to the coast are also at risk from sea-level rise (DEFRA 2011) with 1,531 ha of SSSI habitat in England (3.5 % of total SSSI area present in the coastal floodplain, including grazing marsh and lowland raised bog) at risk under current (2010) conditions. This increases to 4.7 % by 2100 under a medium emissions scenario with degraded defences, and recovery from inundation is not guaranteed. Recent wetland creation work has resulted in an increase in the number of sites occupied by Bittern *Botaurus stellaris*. However, this population growth could be threatened by the loss of just three sites in Suffolk that are currently under threat from sea level rise (Gilbert *et al.* 2010). Small PAs are less likely to retain areas with similar climatic conditions in the future (Loarie *et al.* 2009) so are less likely to retain the species that are currently resident than larger PAs due to a lack of climate connectivity (Hodgson *et al.* 2009). Because important habitats tend to be more fragmented in England and Wales than Scotland (see section on distribution of PAs), we might expect a higher level of vulnerability in these two countries. Different taxonomic groups may also have different vulnerabilities. In recent work carried out by the Joint Nature Conservation Committee, fish were the species group least likely to have been assessed as favourable, and lowland and upland heath were the habitat types with the lowest percentages assessed as favourable under common standards monitoring (Williams 2006). Since current condition can affect vulnerability to climate change, these habitats might therefore be expected to be especially vulnerable.

Implications of changing species distributions for Protected Areas

A concern for some authors is that PAs are fairly static in space, whilst species respond to climate change by moving their distributions. This potential problem was recognised as early as 1985, when Peters and Darling (1985) used paleoecological data to show that the predominant response of species to climate change was to shift their distributions to more suitable locations. Despite this early recognition of the problem, as recently as 2004, climate change was not recognised globally by reserve managers as a potential threat to conserving species within PAs (WWF 2004). Climate change is expected to become a particular problem at the southern range margins of species distributions, where species may move out of reserves which were designated for them (Araújo *et al.* 2004, 2011). In recent years, some reserves have been degazetted in response to loss of the species that they were designated for (Mascia and Pailler 2011), and this could become a problem in the UK, particularly in reserves designated for one or a few species or habitat types. So far only one study has specifically assessed the current effectiveness of protected areas in retaining UK species with retracting ranges (Gillingham *et al.* in prep). Using data from repeat surveys of four northern butterflies and six northern birds, they concluded that there was no noticeable effect of protection on the likelihood of persistence of species. Studies such as this are very difficult to do for most species due to the requirement for repeat surveys of the same locations to determine where extinctions have occurred within the UK. In Australia, there have been calls to replace 'underperforming' PAs (Fuller *et al.* 2010). Other authors have also discussed the possibility of declassifying and selling some reserves in order to purchase or designate others (Strange *et al.* 2011). However, the performance criteria used by Fuller *et al.* (2010) did not include the potential future effectiveness of PAs under changed climatic conditions. In the UK, where many PAs are privately owned, degazetting one PA would not free up funds for the designation of others.

Because many species have expanded their distributions northwards into new areas in response to climate change (e.g. Hickling *et al.* 2006), we should expect that species will disperse into PAs as well as out of them. In support of this theory, there is evidence that a wide range of invertebrate species, as well as some birds, disproportionately colonise SSSIs in Great Britain when expanding their distributions northwards (Thomas *et al.* 2012). This means that PAs should continue to be useful locations for conserving biodiversity in the UK in future, even if some species move out of them. Specialists were found to be more reliant on SSSIs than generalists, suggesting that it is the habitats found within UK PAs that drive this pattern. However, this latter effect was only investigated for colonising butterflies, so the extent to which this rule holds for other taxa is a knowledge gap at present. Reserve managers in the UK already monitor and manage habitats for some species that reserves were not originally designated for (Davies *et al.* 2007), and this presents an opportunity to increase the biodiversity under protection in the UK, which is one of the few countries in Europe predicted to 'win' overall in terms of the numbers of species that should find climatic conditions suitable in the future (IPCC 2007). This sort of pattern has been picked up in other European countries; on PAs in Finland, northern bird species have decreased in density in recent years, whilst southern species have increased, probably in response to a changing climate (Kujala *et al.* 2011, Virkkala and Rajasärkkä 2011).

1. Lessons from modelling bird distributions in sub-saharan Africa and Europe

Using climate envelope models, Hole *et al.* (2009) modelled the potential future distributions of 1,608 bird species breeding in 803 Important Bird Areas (IBAs). 815 of these were 'priority' species for which IBAs are designated. For 88-92 % of priority species (depending on climate scenario used) at least one of the IBAs projected to be climatically suitable in 2085 is currently designated for the species (i.e. there is an overlap in current and projected future range), and less than 1 % are projected to lose all suitable climate space within the network by 2085. However, 51-55 % of IBAs are projected to lose all the priority species for which they are currently designated, and range extent for priority species is projected to decline to 74 % of the current area occupied. In addition, in parts of the continent IBAs are separated by distances of > 500 km, which is substantially greater than the dispersal distances even bird species are capable of attaining, especially if the intervening terrain is inhospitable.

Modelling the distributions of 487 breeding birds in Europe, Huntley *et al.* (2010) found that species turnover was predicted to be higher and persistence lower in PAs in Europe than in Africa, with the 156 Annexe 1 species projected to be particularly affected. However, northern Scotland was predicted to have high persistence of species, probably reflecting the high topographic heterogeneity and hence wide range of microclimatic conditions present.

Lessons learned – Reserve networks can be effective in protecting biodiversity in the short term even without significant dispersal of species, and PAs in the UK can contribute to international conservation objectives. However, in the longer term, actions that help species move between protected areas (such as habitat creation between isolated reserves, sympathetic management of areas surrounding reserves or even assisted colonisation) may be important. Flexibility in reserve designation may also be required, since some reserves may well lose all the species they have been designated for. These conclusions are echoed in part by a study from North America that looked at trees, birds, mammals and amphibians (Lawler and Hepinstall-Cymerman 2010).

Projecting future impacts of climate change on PAs

Modelling work in the US has shown that the composition of flora and fauna on individual PAs is likely to change (Lawler and Hepinstall-Cymerman 2010), and other studies have predicted that the representation of northern biomes on PAs will decrease, whilst representation of southern biomes will increase in both Canada and the UK (Lemieux and Scott 2005, Trivedi *et al.* 2008). Some PAs in Africa may lose all the species for which they were designated (Hole *et al.* 2009, Huntley *et al.* 2012, see box 1), and the likelihood of this occurring will increase with more severe climatic change. Despite these losses, around 90 % of the bird species modelled were predicted to retain suitable climatic conditions in at least one PA. In addition, colonisation of PAs by expanding species will mean that some PAs will likely gain species overall, whilst others will lose species overall. PAs in the north of the UK have been predicted to gain plant species, whilst PAs in the south are likely to lose plant species (Dockerty *et al.* 2003, see box 3). This pattern is reversed for UK breeding birds however (Pearce-Higgins *et al.* 2011, see box 4), so there is uncertainty in what the relative impacts of climate change will be on different taxonomic groups and sites. Using predicted range changes of species, PAs can be classified as likely to have high persistence of species, increasing specialisation, high predicted turnover, increasing value or increasing diversification. These different types of PA will have different optimum management strategies (Hole *et al.* 2011) if their biodiversity is to be conserved effectively.

2. UK Bryophytes and Climate Change

Anderson and Ohlemüller (2011) modelled the distributions of 43 rare UK bryophytes under current and future climates. Across all species, there was an increase in coverage within protected areas of the area considered climatically suitable, from 8.9 % in 1990-2020 to 10.2 % in 2051-2080. Suitable climate space moves uphill and to higher latitudes, which have a higher percentage covered within the protected area network. However, the median overlap between the current range and the climate space that is predicted to be suitable in future decreases from 21 % in 1990-2020 to 10 % in 2051-2080. At least a quarter of all species have no overlap between their current distribution and areas with analogous climates in future. Many species may therefore find it difficult to migrate to areas that are suitable in the future.

3. Plants in UK protected areas

Dockerty *et al.* (2003) classified 200 species as ‘declining’, ‘increasing’ or ‘no change’ between current and projected future distributions on 66 nature reserves in the UK. Future moisture levels and temperature were projected to stay within the ranges already experienced by all 200 species in some part of their current European ranges. Northerly sites were projected to have more increasing trends in the probability of occurrence, whilst southerly sites were predicted to have more decreasing trends. At a single reserve (Backwarden SSSI in Essex), depending on the climate scenario used, 17-20 % of species showed increasing probability of occurrence, 28-48 % showed no change and 29-49 % showed a decreasing trend, including 3 species identified as of conservation priority by the site managers. Warming is likely to favour southern-temperate and Mediterranean types, with arctic-montane and boreal-montane types likely to decline (Trivedi *et al.* 2008).

Not all species will be able to colonise all newly suitable PAs (see boxes 1 and 2). Species with lower dispersal capacities and those that are sensitive to urban barriers, such as the pool frog, may find it difficult to colonize areas that become climatically suitable (BRANCH partnership 2007, Anderson and Ohlemüller 2011, Pellatt *et al.* 2012). Because species have different dispersal capabilities, there may in future be an increasing mismatch in the ranges of interacting species, such as butterflies and their host plants (Schweiger *et al.* 2012), although a lack of data on dispersal distances and how this interacts with habitat fragmentation to affect the ability of species to track climate change (Hodgson *et al.* 2012) mean that it is difficult to assess where these mismatches might occur. Projections of bird distributions in Finland and Norway showed that in those countries, even if species colonise new areas, hotspots of species diversity may no longer coincide geographically with PA boundaries (Virkkala *et al.* 2010). However, in the UK, where there is extensive human-dominated use of the landscape between PAs, this is less likely since PAs represent the most suitable places for many species to colonise (Thomas *et al.* 2012).

4. The impact of climate change on UK birds on SPAs (CHAINSPAN project)

An important criterion for SPA designation is based on numerical thresholds – for instance, whether >1% of the UK population of a species is present at a site, or whether the site holds an important congregation of species. Changes in abundance at individual sites could therefore cause SPAs to be degazetted if they become less suitable for the species they were selected for. These criteria also result in poor representation of certain species groups, such as migratory passerines, in the UK SPA network.

Until recently, most modelling of potential climate impacts looked at impacts on range, rather than the population criterion on which designation is based. Pearce-Higgins *et al.* (2011) therefore projected future changes in abundance of bird species at individual Special Protection Areas (SPAs) as a result of climate change, using data from the UK, Ireland, the Netherlands and France. Sufficient data existed to fit 118 models (including separate models for some species in two seasons). Climate was a reasonable predictor of distribution across the models fitted, but it was a weak predictor of abundance at individual sites. In 33 of the models, climate had very low predictive power and only six models fitted the data well ($r > 0.5$), with climate accounting for approximately 19 % of variation in recent population trends across all populations modelled. This suggests that other factors are currently more important in determining the abundances of birds within individual SPAs. Therefore, site-based management is likely to be of use in reducing the adverse effects of climate change. Many species were projected to respond favourably to climate change in the short term, but with increasing severity of change, a greater proportion of species were projected to decline. The most vulnerable groups were predicted to be northern breeding seabirds and terrestrial species. Northern SPAs were predicted to lose qualifying features whilst many southern sites were predicted to gain features, but larger sites should continue to support more birds.

Several knowledge gaps were highlighted, as there were insufficient data to produce models for several of the most threatened terrestrial species. There is also currently no consistent approach to the management of UK SPAs, or requirement to take climate change into account when creating future management plans.

Clearly, sites designated for several species or habitats of interest will be less vulnerable to being degazetted as species move in response to climate change than sites designated for one or a few species or habitats. Since the presence of Annex-listed species determines the management of Natura 2000 sites (Verschuuren 2010), adding species of conservation concern to designation criteria as they colonise new areas should result in a lower likelihood of degazettement along with appropriate management being planned to ensure long-term survival of these colonising species. However, species with their warm range margins within the UK, for which dispersal to new areas would be difficult, could be disadvantaged by such actions if they were to result in less available suitable habitat. A complementary strategy would be to integrate expected shifts in species' distributions due to climate change into the conservation strategy of the Habitats Directive (as suggested by Normand *et al.* 2007).

Managing climate change impacts in PAs

As well as preventing harmful activities from occurring within their borders, PAs also have the potential for positive management. In some cases, appropriate management may have potential to reduce the negative impact of climate change by reducing the impacts of other negative drivers of population density (Pyke and Marty 2005, Pearce-Higgins 2011a, Singh and Milner-Gulland 2011). For example, the Golden Plover *Pluvialis apricaria* is dependent on the abundance of adult craneflies (Diptera: Tipulidae), which are a key prey item during the breeding season (Pearce-Higgins *et al.* 2010). Re-wetting peat by blocking drainage channels is expected to increase the numbers of craneflies available as a food source (Carroll *et al.* 2011), which may help the Golden Plover persist in the face of climate change. However, there are trade-offs to be considered with such a course of action. A single management action can affect species of conservation concern differentially. For example, intensively managed grouse moors in upland Britain are associated with lower declines of Lapwing *Vanellus vanellus* but faster declines of Golden Plover *P. apricaria* (Amar *et al.* 2011). In addition, management to restore one vegetation type can negatively impact the cover of other desirable plants (Mitchell *et al.* 2009).

Another potential management action is to create habitat suitable for expanding species in areas that become climatically suitable for them. The Royal Society for the Protection of Birds (RSPB) has recently re-created heathland suitable for the Dartford Warbler from a conifer plantation, to enable it to colonise new areas during its current northwards expansion (RSPB 2010). Habitat management may also be necessary if translocations are to be considered to aid species to track climate change (e.g. Willis *et al.* 2009). There is a trade-off to consider here, as maintaining habitat for retreating species may discourage expanding species from colonising protected areas. In a world where conservation resources are limited, some management actions may use resources that could potentially be spent elsewhere. In the UK in recent years, beech *Fagus sylvatica* has been removed from woodland in the North West, where it is was not previously found. However, in Southern England, where conditions are becoming unsuitable for it, it is managed to enable persistence (Gaston *et al.* 2006). If species distributions and losses were considered in terms of whole-range dynamics, such management actions might be changed to allow the species in question to colonise areas that become climatically suitable (Monzón *et al.* 2011). A new policy of facilitating movement across the landscape could result in more cost-effective conservation outcomes, enabling resources to be redirected. This would require new interest features to be added to reserve management plans, whilst species that have been irreversibly lost from a site would be removed from the designation and management objectives to ensure efficient use of resources. In all cases, new objectives for individual PAs should take into account species' wider conservation status and distributions (Dodd *et al.* 2012). This approach is already adopted by Natural England (Natural England 2012), who have committed to revise the conservation objectives for SSSIs and develop new SSSI guidance that will take into account climate change issues. They will also implement a Notification Strategy which includes a boundary and feature review of all SSSIs, ensuring that climate change adaptation is considered.

Habitat associations of species change along climatic gradients (Oliver 2009, Suggitt *et al.* 2012), which may complicate the picture further as it will be difficult for reserve managers to predict how best to manage for a particular species in the future. At the leading edge of species' ranges, habitat breadth can expand as the climate becomes more suitable, enabling species to exploit a wider range of habitats (Pateman *et al.* 2012), which might facilitate range expansions in response to climate change. Given this information, it is reasonable to expect that habitat breadth might decrease at the trailing edge of species' ranges, as the climate becomes less suitable. In addition, other environmental drivers can reduce habitat breadth despite climatic release (Oliver *et al.* 2012). Hen Harrier *Circus cyaneus* shows differential responses to management at different sites within the UK, meaning that habitat management guidelines have had to be developed on a site by site basis (Arroyo *et al.* 2005). The likely changes of habitat preference under climatic change and at different latitudes and elevations is a major knowledge gap, as most of the available literature is concentrated on the Lepidoptera, and it is not currently known to what extent other species might follow similar patterns.

Adapting the PA network to ameliorate climate change

Based on the best current knowledge, Lawton *et al.* (2010) concluded that England's protected area network would need to be modified in order to adapt to the challenges posed by climate change. Several options have been proposed when designating new PAs in response to climate change. Because climate change and habitat fragmentation act synergistically to decrease the abundance and range of species (Opdam and Wascher 2004), many authors have suggested increasing physical connectivity between habitats (Heller and Zavaleta 2009) or temporal connectivity between suitable climate space (Hodgson *et al.* 2009) by including areas of topographic and climatic heterogeneity within PAs (Carroll *et al.* 2010). Some authors advocate designating dynamic PAs to complement existing static ones in the marine environment (Game *et al.* 2009), but this would be difficult to achieve within the UK's highly modified terrestrial environment. The use of dynamic reserves are constrained by habitat fragmentation outside reserves, necessitating management of the matrix (Rayfield *et al.* 2008), and other authors have stressed that expanding and connecting reserve networks will be insufficient to conserve biodiversity under climate change (Kostyack *et al.* 2011), so management of land between reserves will be necessary anyway. Others have suggested that reserves should be designated based on criteria that include future performance (Singh and Milner-Gulland 2011) or that new reserves should be established in the expected direction of travel of suitable climate space (Pearson and Dawson 2005). These approaches are species-centric and could be expensive to apply to a large number of species, many of which will have competing demands, as well as relying on uncertain model predictions. However, only a small amount of additional land may be necessary to create a climatically robust representation of some species (Pyke and Fischer 2005), and if this did not involve a high economic cost might be worth considering when designating new reserves. Monzón *et al.* (2011) suggested that management should be changed within reserves to take account of the dynamism of species responses to climate change, so that resources are not wasted on maintaining species at a site once the climate has become unsuitable, assuming that the species in question has expanded its distribution elsewhere. The use of long-term monitoring of population densities will be important in detecting initial responses to climate change, as well as the effectiveness of any management actions (see Figure 1).

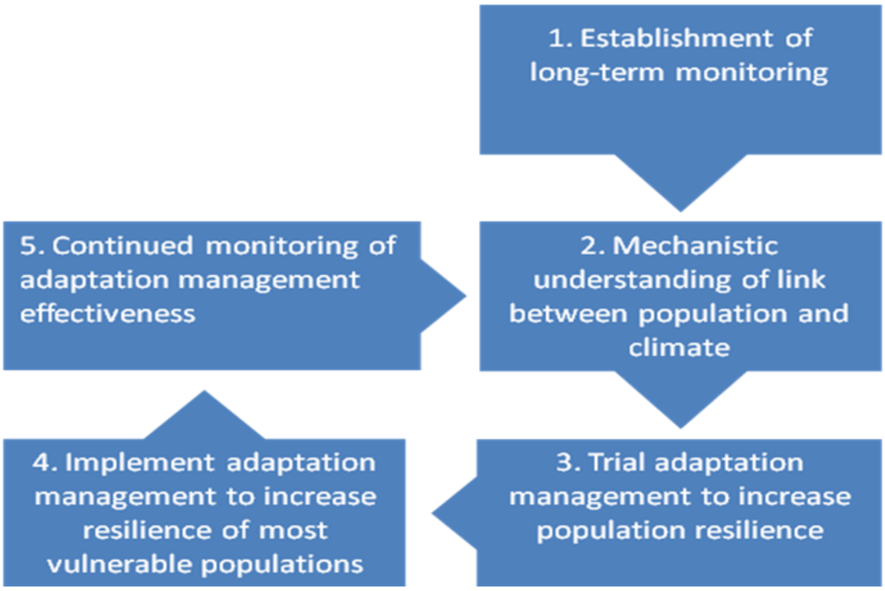

Figure 1: Schematic diagram outlining a potential approach to site-based adaptation management. Adapted from Pearce-Higgins (2011b)

Based on the information provided in this report, the UK Biodiversity Partnership adaptation principles (Hopkins *et al.* 2007), and the England Biodiversity Strategy (Smithers *et al.* 2008) several recommendations can be made;

1. Existing PAs should be retained. PAs protect large percentages of most important semi-natural habitats, without this protection the land might be used for activities harmful to biodiversity (Lawton *et al.* 2010).

2. Management within PAs could help to reduce sources of harm not linked to climate change, for example (Pearce-Higgins 2011a) by decreasing predation rates and increasing available prey resources for birds. The effectiveness of these management interventions in decreasing vulnerability to climate change should be monitored and conservation priorities regularly reviewed to ensure resources are used efficiently (e.g. Pearce-Higgins 2011a, 2011b, see figure 1).

3. Maintaining heterogeneity within landscapes should increase the chances that species will be able to spread locally into newly favourable habitat (Hodgson *et al.* 2009, Carroll *et al.* 2010).

4. Creating new habitat (Hodgson *et al.* 2011), restoring degraded habitat, or reducing the intensity of management of the landscape between existing habitats should facilitate species' movements between PAs. The RSPB aims to double the area it currently manages for nature conservation by 2030 (RSPB 2007).

5. When reviewing management plans, the likely future impacts of climate change should be considered and appropriate changes made (Monzón *et al.* 2011, Pearce-Higgins 2011b, see figure 1). This approach has been taken by the RSPB in their futurescapes campaign (Dodd *et al.* 2010, RSPB 2010).

6. Intertidal habitat should be re-created and protected through managed realignment, to compensate for losses predicted by coastal squeeze (DEFRA 2011). This should be done as soon as possible, since compensatory sites can take some time to become suitable for their target species (Gilbert *et al.* 2010) and may not achieve the same plant communities as natural sites (Mossman *et al.* 2012).

7. The needs of species currently resident in PAs for which climate will become less suitable should be balanced against the needs of species of conservation concern that colonise these sites during range expansions. The optimal balance will depend on the location of each reserve within the UK, and the importance of the site to the species it protects on an international level. Many birds associated with upland and montane habitats in the UK are of international conservation importance (Pearce-Higgins *et al.* 2011), so care should be taken not to disadvantage these species through habitat management.

8. The habitat requirements of species that might colonise new areas should be identified from the north of their current climatic range. This is because species often show variation in habitat use across their full geographic range (e.g. Suggitt *et al.* 2012) and the requirements towards the north of their current range are likely to be the most similar to areas that become climatically suitable.

Knowledge Gaps

The effectiveness of PAs in conserving biodiversity under climate change is an emerging field of study, and as such there are a large number of knowledge gaps that should be considered priorities for research.

- Likely changes in abundance within PAs in taxa other than birds are unknown, but if models were generated these could be compared to monitoring data to determine whether numbers observed are as expected by models.

- The impact of changes in habitat extent and quality on abundance is unknown for most species, along with the likely interactions of these impacts with climate change.

- There is a lack of population monitoring of most taxa, even birds listed on the Birds Directive (Pearce-Higgins *et al.* 2011), from non-PA land, which makes it difficult to quantify the effectiveness of PAs.

- The area requirements and habitat preferences of species that might colonise the UK are often unknown in their current ranges, and filling this knowledge gap would help inform future habitat creation in the UK.

- The likely effectiveness of PA management in retaining viable populations of species predicted to do badly under climate change is largely unknown, and the results of management actions should therefore be closely monitored.

- Little is understood about the genetic components of biodiversity, and how to protect genetic diversity using PAs (Gaston *et al.* 2006).

- Likely future changes in land use in the matrix surrounding PAs is difficult to predict, and how these changes will affect species' ability to colonise areas that become climatically suitable is therefore unknown.

- The ability of species to track climate change to colonise all newly suitable PAs is largely unknown, as dispersal distances are not well understood for most species (e.g. Jaeschke *et al.* 2012). This limits our ability to project the future utilisation of PAs by potential colonisers.

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