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A national-scale assessment of climate change impacts on species: Assessing the balance of risks and opportunities for multiple taxa

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ABSTRACT

It is important for conservationists to be able to assess the risks that climate change poses to species, in order to inform decision making. Using standardised and repeatable methods, we present a national-scale assessment of the risks of range loss and opportunities for range expansion that climate change could pose for over 3000 plants and animals. Species were selected by their occurrence in England, the primary focus of the study, but climate change impacts were assessed across Great Britain, widening their geographical relevance. A basic risk assessment that compared projected future changes in potential range with recently observed changes classified 21% of species as being at high risk and 6% at medium risk of range loss under a B1 climate change scenario. A greater number of species were classified as having a medium (16%) or high (38%) opportunity to potentially expand their distribution. A more comprehensive assessment, incorporating additional ecological information, including potentially confounding and exacerbating factors (e.g. dispersal, habitat availability and other constraints), was applied to 402 species, of which 35% were at risk of range loss and 42% may expand their range extent. This study covers a temperate region with a significant proportion of species at their poleward range limit; the balance of risks and opportunities from climate change may be different elsewhere. The outcome of both risk assessments varied between taxonomic groups, with bryophytes and vascular plants containing the greatest proportion of species at risk from climate change. Upland habitats contained more species at risk than other habitats. Whilst the overall pattern was clear, confidence was generally low for individual assessments, with the exception of well-studied taxa such as birds. In response to climate change, nature conservation needs to plan for changing species distributions and an uncertain future.

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1. Introduction

To make the best use of conservation resources, it is necessary to prioritise species for action, for example according to their current status and the threats that they face. Globally, the most widely adopted framework for this is the IUCN Red List which quantifies extinction risk using information on the population size and range extent of a species, and the rate of change in those parameters (Mace et al., 2008; IUCN, 2016). Anthropogenic climate change is likely to exacerbate the extinction risk of many species over the course of this century (Thomas et al., 2004; Bellard et al., 2012; Warren et al., 2013; Foden et al., 2013). A number of approaches have been developed to assess the potential impact of climate change on species' future status (Akçakaya et al., 2015). One common approach uses species distribution models (widely termed bioclimatic-envelope or climate-envelope models) to link distribution to climate variables and project the likely future impact of climate change on species' distributions (e.g. Thomas et al., 2004; Huntley et al., 2007; Walmsley et al., 2007; Warren et al., 2013). An alternative approach is to undertake vulnerability assessments which may combine a measure of future projected climate change (exposure) with ecological traits to identify the sorts of species most likely to be both sensitive to and lack the capacity to adapt to climate change (e.g. Gardali et al., 2012; Foden et al., 2013).

Vulnerability assessments have often been applied to single taxonomic groups within particular regions or countries (e.g. Heikkinen et al., 2010; Barbet-Massin et al., 2012) or, less commonly across a global scale (Jetz et al., 2007; Foden et al., 2013). Relatively few vulnerability assessments have covered the full range of biodiversity present within a particular geographical area, despite the fact that a comprehensive assessment of as many taxa as possible would assist governments and conservation organisations plan and adapt to climate change. Achieving such wide coverage is challenging because many assessments require taxon-specific information or use approaches that have limited applicability to other taxa (e.g. Heikkinen et al., 2010; Gardali et al., 2012; Moyle et al., 2013). To date, it has been difficult to develop an approach which works across a range of taxa due to the different nature of ecological traits across contrasting taxonomic groups, and the variable availability of data (e.g. of species distributions, trends and traits). The strong tradition of biological recording in Britain across a wide range of taxa provides a rare opportunity to tackle this challenge.

Thomas et al. (2011) developed a framework to assess the threats and potential benefits of climate change that is applicable to a wide range of taxa. It uses bioclimatic-envelope models, combined with information on recent trends and additional ecological information, to identify the likelihood of species' range expansion and contraction, and has so far been applied to UK butterflies and some exemplar species from other taxa (Thomas et al., 2011). Here, we use a modification of this approach to undertake a climate change vulnerability assessment of > 3000 terrestrial and wetland species, (and in a minority of cases, species aggregates and distinctive subspecies or varieties, hereafter all termed 'species' for brevity; see methods) across 17 taxonomic groups in Britain (Table 1). This provides the first opportunity to examine how an important aspect of vulnerability to climate change varies between taxonomic groups, and between species associated with specific habitat types, for as complete a biological assemblage as currently feasible.

This study was developed as part of a wider initiative of Natural England, the government conservation agency in England, to support decision making on adaptation (Natural England, 2014) and inform an adaptation plan (Natural England, 2015). It therefore focuses on species in England, the largest of the component countries within the United Kingdom (UK), but assesses the vulnerability of those species across Great Britain (GB), the single land mass within which England is located. This ensures that the outputs are also highly relevant for Wales and Scotland, for UK organisations, and more widely.

2. Materials and methods

The vulnerability assessment involved a number of steps (Fig. 1) outlined below:

1. Distribution data for over 5000 species were collated for a wide range of taxa that occur in England (Table 1).
2. Statistical models linking species' distributions to climate were used to assess the likely impacts of future climate change upon species' potential distributions.
3. Information from these projections was compared with observed changes in species distribution. By assessing recently observed changes in the context of projected future trends, a *simplified risk assessment* could be undertaken rapidly across all species.
4. For a representative subset of 402 species, additional ecological information enabled the application of the full Thomas et al. (2011) framework. By considering the potential for non-climatic factors and ecological constraints to affect species' responses to climate change, this framework produces a more comprehensive assessment (the *full risk assessment*).

Whilst the term 'risk assessment' can have specific meanings in different contexts, we follow Thomas et al. (2011) and use it to describe our methodology for assessing the potential risks of species decline and extirpation in parts of its current range, and opportunities that the same species may expand its distribution into other regions, both as a result of climate change. By using a combination of observed and modelled responses to climate change, the methodology deals with the long timescales over which species' responses to climate change are likely to occur.

2.1. Species distribution data

Species distribution data for GB were available from a range of biological recording schemes for a total of seventeen taxonomic groups (Table 1) at a hectad (10 km square) resolution. For inclusion, species had to be present in England and recorded from > 5 hectads (the minimum required for modelling; Hickling et al., 2006). Even with this threshold the climate envelope models (described below) failed to converge for 10% of the most sparsely distributed species, giving a total of 4540 species for which modelling was possible.

We used data from 1970 to 89 to represent baseline distributions prior to recent climate change, in order to minimise the risk of species' distributions being unsynchronised with the climate due to recent range shifts (Mason et al., 2015). For plants we used the period 1970–86; the time period (Braithwaite and Walker, 2012) that most closely matched the data for other taxa. For birds the period 1988–91 was used, which coincided with a national atlas (Gibbons et al., 1993). Cells for which climate data were not available were excluded from analyses. To aid model convergence, small islands, with little data, were also excluded for all taxa apart from birds, leaving 2561 hectads, or 2670 for birds.

Recording effort varied between taxa, with the highest coverage for groups with well-developed and popular volunteer recording schemes such as vascular plants and birds. To avoid species' distribution models being biased as a result of limited recording effort, we used the program FRESCALO (Hill, 2012) to estimate taxon-specific recorder effort in each 10 km square (see below).

2.2. Species distribution modelling

We used the climate envelope modelling approach of Beale et al. (2014) across all taxa (Appendix 1). The approach was devised to address the problem of spatial autocorrelation in large-scale species' distribution data, and applies a Bayesian, spatially explicit (Conditional Autoregressive) Generalised Additive Model (GAM) to species'