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Adaptive Forest Management and Climate Change – A New Toolkit for Scotland's Epiphytes

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1. Key points

- Scotland benefits from outstanding natural capital, including an internationally important diversity of cryptogams: e.g. bryophytes (mosses and liverworts) and fungi, including lichens. These small but important organisms are responsible for ecosystem services such as peat formation (*Sphagnum* mosses) and nutrient cycling (soil fungi), they are indicative of clean and healthy air (lichens), and they provide wild character to the landscape, e.g. on Scotland's tundra-like mountain summits, or as epiphytes growing on veteran trees in ancient woodlands.
- Scotland's lichen epiphytes are particularly species-rich and functionally important in forest ecosystems. Scotland has among the best remaining examples of intact epiphyte communities in Europe; in particular (i) lichen epiphytes characterise the globally rare and remnant temperate rainforest which occurs along Scotland's Atlantic coast, while (ii) epiphyte communities in the upland straths of Speyside and Deeside include outlying examples of Scandinavian-boreal species.
- Lichen epiphytes are sensitive to climate change, and because they are highly dependent on trees as their habitat, they can also provide a signature in the response of biodiversity to woodland succession, including tree disease impacts.
- This project has developed a publicly-available online scenarios toolkit, which uses Scotland's epiphytes to test different woodland management options across a range of climatic and tree disease scenarios. This scenarios type approach does not aim to accurately predict the future, but offers a platform for biodiversity decision-making under uncertainty, and the means to scope alternative adaptation options.

2. Biodiversity, Climate Change and Strategic Adaptation

Climate change adaptation seeks to reduce the risk to a valued asset through a strategic, managed response. Biodiversity is a valued asset; it is the planet's natural resource generated over 3.8 billion years of evolution, and effectively irreplaceable on human time-scales. There are compelling ethical and aesthetic reasons for biodiversity conservation (Ehrenfeld, 1988). Biodiversity also has utilitarian value as a stock of natural capital, resulting in functioning ecosystems as an emergent property, from which humanity benefits in a supply of services and goods (MEA, 2005). Biodiversity is widely acknowledged to be threatened by climate change, particularly in combination with accompanying pressures such as habitat loss, fragmentation and degradation.

Predictive models have demonstrated the potential for species range shifts in order to track suitable climate space (Walmsley et al., 2007), with mobile species already showing distributional shifts that are explained by climate warming. This biodiversity response to climate change requires adaptation in policy and practice. For example, biodiversity within protected sites may undergo a dynamic change, requiring conservation mechanisms that are appropriately flexible. Species for which the climate is expected to be less suitable in the future may be priorities for monitoring, and/or remedial action to increase population resilience through direct habitat intervention. Alternatively, the climate at a site may become suitable for nationally important species which are not currently present but which are threatened elsewhere, and if these species are limited in their dispersal capacity they may form a target for translocation (assisted migration) across fragmented landscapes (Thomas, 2011).

3. Dealing with Uncertainty

The prioritisation of different options – such as investment in monitoring/protection for target species, or translocation of threatened species – is complicated by a degree of uncertainty in the direction and magnitude of climate change. It is impossible to precisely forecast for a given time and place the future climate, say in 2050. The Met Office's Hadley Centre has provided under the UKCP09 programme (http://ukclimateprojections.metoffice.gov.uk/) a probabilistic range of future climates based on multiple runs of computer simulations, to generate a spread of possible climate outcomes. This makes it possible to incorporate inherent climatic and model uncertainty into decision-making.

Nevertheless, uncertainty further affects decision-making through non-climatic factors. Tree disease provides an excellent example, where a disease outbreak is difficult to forecast but could completely alter ecological parameters. Trees are 'foundation species' which define structurally and functionally the woodland ecosystems on which a vast multitude of other organisms depend. However, given the life-span of trees, coupled with long-term processes occurring at a stand-scale, any strategic response to tree disease in the present-day must be climate change resilient through and beyond the 21st Century.

This layering of uncertainty across multiple drivers (i.e. climate change, tree disease) represents one of the greatest challenges in managing biodiversity, but it can be tackled through the use of a scenarios approach to decision-making. This report provides examples of the scenarios approach, focussing on the conservation of lichen epiphytes, and drawing on the publicly-available Lichen Epiphyte Scenarios toolkit: http://rbg-web2.rbge.org.uk/lichen/scenarios/index.php.

4. Lichen Epiphytes

Lichens are among Britain's most important contributions to International biodiversity. There are c. 2000 lichen species in Britain (c. 45% of European diversity), and lichens are the taxonomic group with the third most species on the UK's Priority conservation list. As one moves northwards out of the tropics and into temperate and boreal zones, lichens and bryophytes (mosses and liverworts) dominate the epiphytic biomass and richness of forests and woodlands (**Fig. 1A**). Approximately 800 species of lichen occur as epiphytes in Britain, and they play an important role in water and nutrient capture from the atmosphere, and in providing food and shelter for invertebrates with consequences that cascade across trophic levels. Epiphytic lichens also characterise some of Britain's most evocative ecosystems, e.g. in western Scotland where an oceanic climate, relatively clean air, and ancient traditional or non-intensively managed woodland coincide, epiphytes contribute to some of the best remaining examples of European cool-temperate rainforest (**Fig. 1B**).

Bioclimatic modelling and shifts in observed distributions (Ellis, 2013) suggest that lichen epiphytes are sensitive to and indicators of climate change. Lichen epiphytes also provide an excellent example of woodland biodiversity that is totally dependent on trees, and are therefore indicators for the ecosystem consequences of tree disease. This is because trees with contrasting physical or chemical bark characteristics have different associated lichen epiphyte species, while trees with more similar bark characters will tend to overlap in their types of epiphyte community. Thus, the loss of a given tree from a woodland stand will have a signature effect on lichen epiphytes that can usefully capture the biodiversity impact of tree disease.

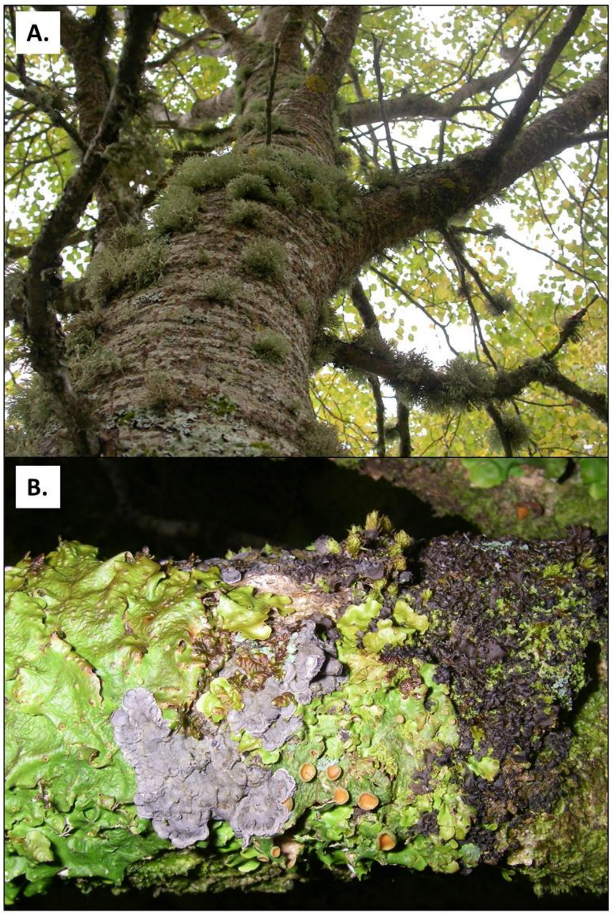

Figure 1. A. Lichen epiphytes on the trunk and in the canopy of an aspen tree; B. A community of oceanic lichen epiphytes, including fungal species which are associated with cyanobacteria as their symbiotic partner, and which fix nitrogen directly from the atmosphere.

5. Lichen Epiphyte Scenarios

The Lichen Epiphyte Scenarios toolkit uses British Lichen Society data (http://www.thebls.org.uk/) in a system which allows practitioners to explore and optimise conservation decisions, via scenarios incorporating lichen epiphytes as an indicator of biodiversity, and considering climate change, woodland structure (e.g. tree disease) and Britain's changing pollution regime. The user inputs a grid-reference for a site of interest, and then compares the environmental suitability (scored between 0 and 1) for epiphytes at a present-day baseline, with that of future climates: (i) a 2050s medium greenhouse gas emissions scenario, and (ii) a 2080s high greenhouse gas emissions scenario. These future scenarios include a lowered SO_2 pollution environment, to allow species range-filling as distributions achieve equilibrium in a lower pollution environment (given significant uncertainty in future trends, levels of nitrogen pollution are held constant). Additionally, environmental suitability values based on the larger-scale climate and pollution regime can be modified by woodland tree composition, by selecting frequency values for 15 native and naturalised British trees on a scale of 1-5, equivalent to National Vegetation Classification 'constancy' classes. This makes it possible to explore the combined effect of climate change, and changed woodland structure.

The Lichen Epiphyte Scenarios toolkit is used here to demonstrate four increasingly complex decision-making scenarios. Each case is focussed on Scotland, which is the region for which the toolkit was designed. Each case also follows a standard procedure in which several management options are tested, and selecting that which provides the best outcome across plausible future climates.

5.1 Population Monitoring

It is becoming a priority to address the threat of climate change for species within a reserve, through population monitoring and targeted habitat management. The Lichen Epiphyte Scenarios toolkit can be used to project a shift in a species' environmental suitability while allowing for inherent uncertainty in climate modelling. Demonstrated here for the Abernethy RSPB reserve (north-east Scotland), it is shown that for different species there can be a consistent decline or increase in their environmental suitability across the range of plausible climate futures, while for other species there is uncertain risk, with outcomes dependent on the future pathway of climate change (**Fig. 2**). Monitoring could therefore be deployed to investigate this variability in projected response.

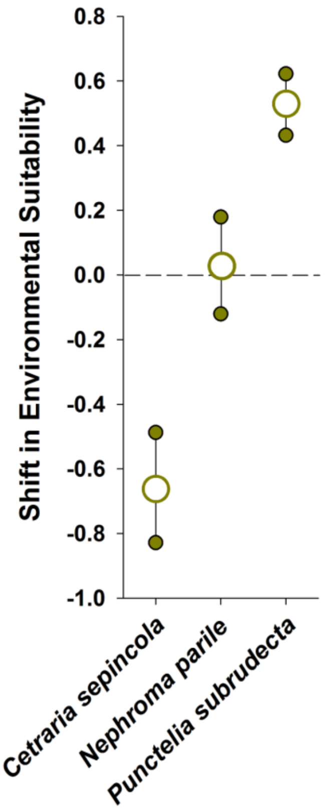

Figure 2. Projected shift in environmental suitability values, comparing the baseline with a 2080s climate change scenario for Abernethy (NJ01). Bars show the 95% confidence intervals in shifted response, calculated across different UKCP09 climate model runs. Epiphytes for monitoring can be ascribed different levels of expected risk, e.g. *Cetraria sepincola* = negative shift consistent across climate model runs, *Nephroma parile* = positive or negative depending on climate pathway, and *Punctelia subrudecta* = positive shift across climate model runs.

5.2 Forest Regeneration

Britain has active programmes of reforestation; in Scotland this includes an ambition for up to 25% of land forested by 2050, c. 35% of which should be targeted to native woodland (Forestry Commission Scotland, 2009). We imagine a scenario in a site such as Glen Affric (**Fig. 3A**), with forest regeneration seeking to recreate native upland pinewood. One might adopt National Vegetation Classification stand structure as a guide (Rodwell, 1991), e.g. for type W18 *Pinus sylvestris-Hylocomium spendens* woodland. However, given recent interest in aspen as the host to a specialist epiphyte flora (Street and Street, 2002), one might also explore the added benefit of introducing aspen into the stand structure. This simple option can be applied in the Lichen Epiphyte Scenarios toolkit to test the implications for epiphytes, e.g. focussing on species that have been classified as having an IUCN threat status (Woods and Coppins, 2012).

The results show that under the baseline, 2050s medium and 2080s high greenhouse gas emissions scenarios (2050sM and 2080sH), the introduction of aspen into the regenerated woodland increases estimates of environmental suitability for threatened species (**Fig. 3B**). Values of environmental suitability can be loosely interpreted on a relative scale, with the threatened species on average 3-5 times more likely to occur within the pine-aspen mix, than within a W18 woodland stand without aspen. Planting aspen is a potentially valuable conservation investment that is robust across the range of plausible climate futures.

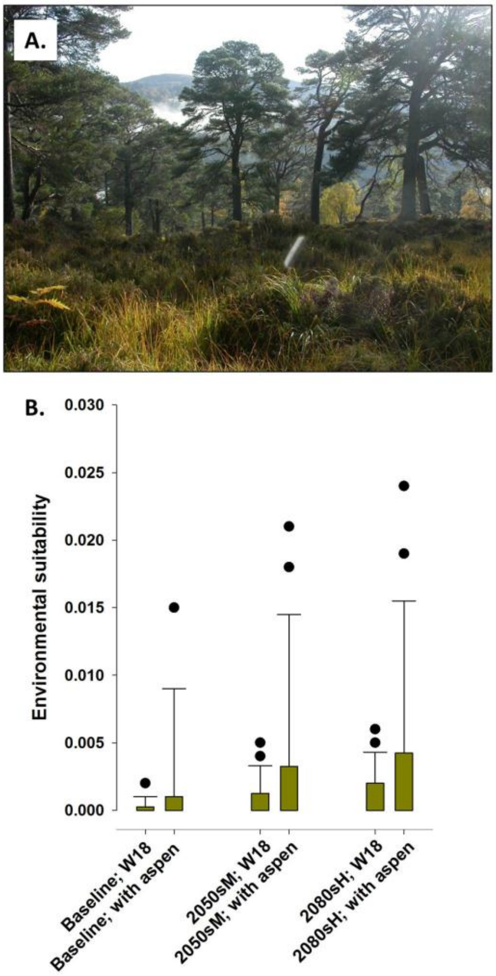

Figure 3. A. Glen Affric, an ancient pinewood site, rich in epiphytic lichens; B. Environmental suitability values plotted for IUCN-category threatened epiphytes, and compared between a 'standard' W18 pinewood, and a pinewood with aspen: for the baseline environment, and two climate change scenarios, the 2050s medium emissions (2050sM) and 2080s high emissions (2080sH). Across each of the three different climate regimes, environmental suitability values are consistently higher for the stands with aspen.

5.3 Translocation into Previously Polluted Woodlands

Large areas of Britain are recovering from formerly high levels of SO_2 pollution, the legacy effects of which continue to affect lichen distributions. In areas such as the Loch Lomond Woods SSSI/SAC, the epiphyte flora was denuded by pollution from industrial Glasgow. It may be desirable to accelerate the recovery of epiphytes into such woodlands via the translocation of material from donor sites; however, it may also be interesting to know how the choice of epiphytes for translocation alters when considering pathways of climate change in the mid-term. Using tree frequency values for a stand of 'old sessile oakwood', and focussing on lichen epiphytes that are considered the UK's 'International Responsibility' species (Woods and Coppins, 2012), a suitability ranking of species for active recovery into the Loch Lomond woodlands can be generated for the present-day environment, and under a 2050s medium greenhouse gas emissions scenario.

The results **(Fig. 4)** show a difference between (i) increasing environmental suitability for two pollution sensitive *Lobaria* species, contrasted with (ii) decreasing climatic suitability for two *Hypotrachyna* species. As these two genera tend to occupy locally different microhabitats, there should be opportunity to encourage both the recovery of *Lobaria* species and bolster existing populations for the more acid-bark tolerant *Hypotrachyna*s. However, there is a large increase in environmental suitability for *Enterographa sorediata*, which is distributed to the south of England in ancient woodlands; more radically, species recovery around Loch Lomond could be coupled to translocation experiments (assisted migration of *E. sorediata*) under climate change.

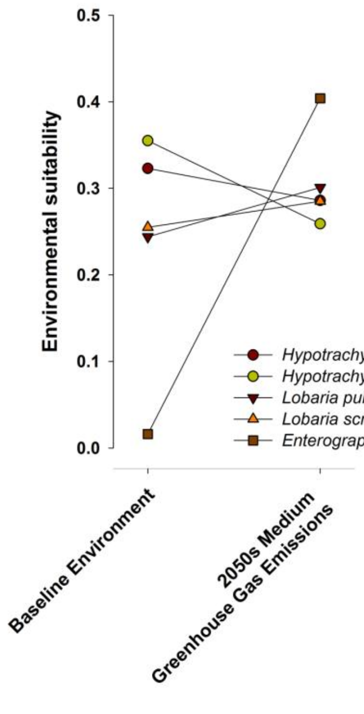

Figure 4. Environmental suitability values in the Loch Lomond oakwoods, for five 'International Responsibility' lichen epiphyte species, calculated for the present-day environment, and for a 2050s medium emissions climate change scenario.

5.4 A Strategic Response to Tree Disease

The final example acknowledges that management decisions to recover woodlands from tree disease in the present-day will be affected over the long-term by climate change, with ash dieback as an example, and focussing on an 'upland mixed ashwood' in the borders region of Scotland which qualifies as a SSSI/SAC.

Alternative management scenarios are considered in this example, with environmental suitability values calculated for 'all epiphytes' (382 modelled species) to develop a generic understanding of climate and tree disease risk for the 'epiphyte guild'. First, the baseline is compared to a 2080s high greenhouse gas emissions scenario. A metric of Bray-Curtis dissimilarity is used to compare environmental suitability values at the baseline with those for the 2080s scenario, thus estimating the potential for a changed epiphyte community under the influence of climate change alone (0 = no change, 1 = complete change). In the following six additional scenarios, any change beyond this initial Bray-Curtis value represents the additional effect of ash dieback on top of the consequences of climate change. Second, Bray-Curtis values are calculated under the 2080s climate change scenario but given a complete loss of ash; third, for the 2080s scenario but replacing ash with birch; fourth, replacing ash with lime; fifth, replacing ash with oak; sixth, replacing ash with a mix of lime and oak; and seventh replacing ash with sycamore.

The results (**Fig. 5**) demonstrate the additive effect of ash dieback in shifting the epiphyte assemblage beyond the effect of climate change alone (shift A., in **Fig. 5**). In terms of alternative recovery options to achieve equilibrium with projected climate change (shift B. dropping to the dashed line in **Fig. 5**): 1. Succession to birch represents the least favourable option, while 2. Recovery to lime is less favourable than recovery to oak, which is in turn less favourable than a mix of lime and oak. The mixture of lime and oak has the added advantage of climate resilience, because the environment of northern Britain may become increasingly suitable for lime (Berry et al., 2012). 3. The

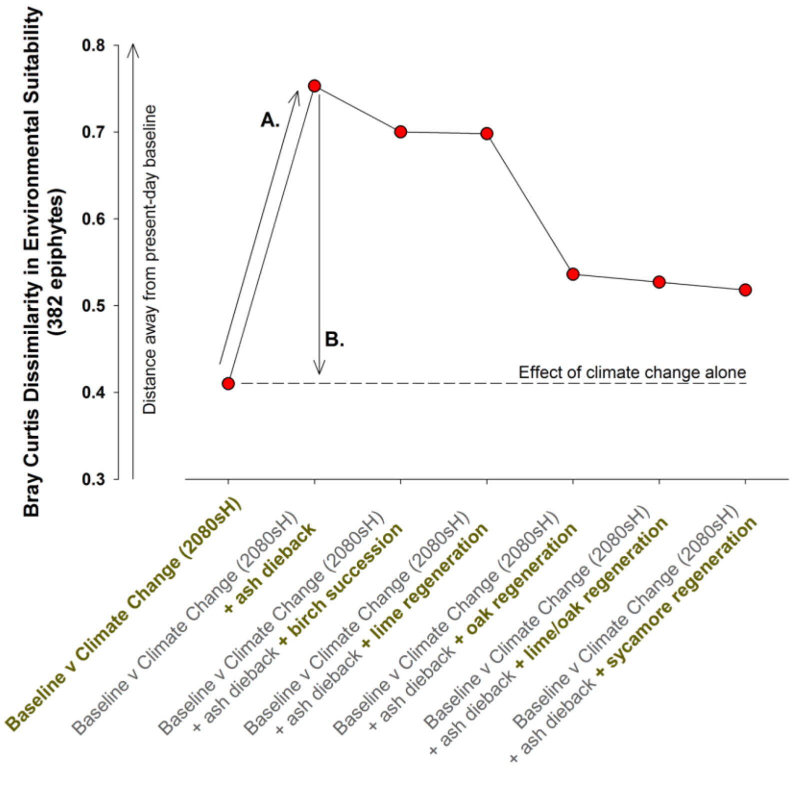

Figure 5. An estimate of potential epiphyte community change (Bray-Curtis dissimilarity) for seven scenarios. First, the comparison between the baseline present-day environment and 2080s high emissions scenario defines the potential shift in community structure under climate change alone (dashed line). Second, the effect of ash dieback can be calculated as an additional shift beyond the climate change response (shift A.). Third, recovery options in terms of woodland management can be explored as the degree of return (shift B.) towards a point that is equivalent to the expected climate change impact (dashed line).

overall best option is recovery to sycamore, a tree for which the climate in northern Britain is also expected to become more suitable (Berry et al., 2012), though with only a marginal gain over oak that needs to be balanced against the policy implications of encouraging a 'non-native' species.

6. Using the Lichen Epiphyte Scenarios

As demonstrated here, the Lichen Epiphyte Scenarios toolkit can be used in various ways to explore the effects of climate change on woodland biodiversity (specifically epiphytes), alongside the effects of changing tree composition. Parameters can be manipulated to suite a variety of different questions. The toolkit provides a useful instrument within certain constraints; in particular it provides a guide to the generality of decision-making, though there are many instances where lichen conservation will need to be coupled with a more detailed understanding of local microhabitats. For example, certain epiphytes may be particularly strongly associated with oak, and planting oak can be identified as a good option; but in detail a lichen species may be associated with wound tracks on old oaks in open structured gladed woodlands, and establishing these local microhabitat conditions adds another level of understanding in achieving long-term goals. The toolkit also represents the best available knowledge at the current time, though as species distribution records improve, and with more accurate interpolated environmental data and projected models, the evidence base for future planning will become better.

Notwithstanding these limitations, the toolkit improves access to information for a diverse and important group in Scottish conservation – lichen epiphytes – which can be representative of shifts in forest/woodland biodiversity in response to climate change and woodland succession (including disease impacts). We hope the toolkit will be used to more broadly incorporate epiphyte diversity into landscape planning. We are fully open to questions and comments on the toolkit, and are particularly interested in details of how it is being used, to help guide future improvements. To provide any feedback, please communicate with the main author at: c.ellis@rbge.org.uk.

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