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Scottish Native Woodland Adaptation – the potential use of a Flexible Adaptation Pathways (FAP) Framework

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1. Key points

- Although recent Scottish native woodland policy recognises the multifunctionality of this woodland type, the Flexible Adaptation Pathways (FAP) system considered in this study focuses on adaptation planning for protection of woodland biodiversity.
- A FAP monitoring framework would be needed to detect direction and magnitude of change and future threshold exceedance. To support this, it is recommended that a series of 'sentinel sites' is established.
- Further review and research are required to identify thresholds and trigger points for FAP indicators and whether it is reasonable to expect their detection.
- A comprehensive list of options for biodiversity adaptation in Scottish native woodlands has been compiled.

2. Introduction

During 2012 Scottish native woodland adaptation to climate change was identified by policy teams in Scottish Government as an issue that would merit investigation. A scoping paper was published by ClimateXChange following a stakeholder workshop, exploring the issues associated with native woodland adaptation (www.climatexchange.org.uk/adapting-to-climate-change/adaptation-native-woodlands-scotland/). Subsequently, a small CXC working group was established to examine the potential for implementing a Flexible Adaptation Pathways (FAP) approach for native woodland adaptation.

The 'Flexible Adaptation Pathways' approach (FAP) recommends a range of adaptation strategies which might be implemented as the level of risk to some 'asset' (e.g. an ecosystem service) reaches a critical threshold (Figure 1) (Moss and Martin, 2012). Previous examples of successful FAPs are those dealing with relatively simple and clearly defined goals; the Thames barrage providing a case-study which is used to prevent flooding by regulating water flow (Figure 2). In this example, all stakeholders appear to agree that the specific goal of the FAP should be to prevent flooding in order to protect a variety of assets, such as businesses, homes etc. Flooding is itself subject to a relatively simple set of drivers, in that these can be represented through physical laws (phases of the moon, air pressure, wind direction, rainfall within the catchment etc) which can be combined to anticipate the level of risk over time.

In contrast to the single risk example of flooding, UK woodland provides multiple assets (e.g. biodiversity, recreation, ecosystem functions such as carbon storage, economic return), which are valued across a range of different stakeholders. Each of the woodland assets may be subject to its own distinct amalgam of drivers which generate asset-specific risk, while certain of these drivers are highly unpredictable - tree disease providing an obvious example.

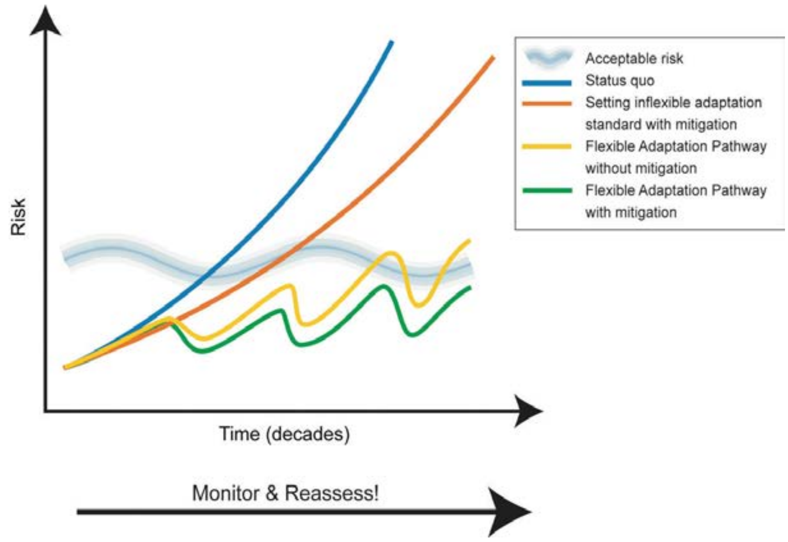

Figure 1 Changing risk in response to a Flexible Adaptation Pathway (adapted from Lowe et al., 2009)

Furthermore, while there is a general consensus that flooding is to be avoided to protect a suite of assets, the prioritisation of different woodland assets by contrasting stakeholders (e.g. ecosystem services: Quine et al. 2011) introduces possible conflicts of interest and trade-offs: (i) the provision of woodland for amenity value, though not necessarily discerning between native and non-native species, (ii) the provision of woodland for native biodiversity, in terms of the trees themselves, and the habitat they provide for multiple other organisms, (iii) the functional role of woodlands in water capture and storage, soil stabilisation, carbon storage etc, or (iv) the potential economic and social value of woodlands, in terms of local management (e.g. wood fuel) to provide a sustainable community resource. **One cannot expect that critical thresholds which define FAPs will occur simultaneously across these competing assets, or that adaptation strategies will necessarily be aligned in protecting them.**

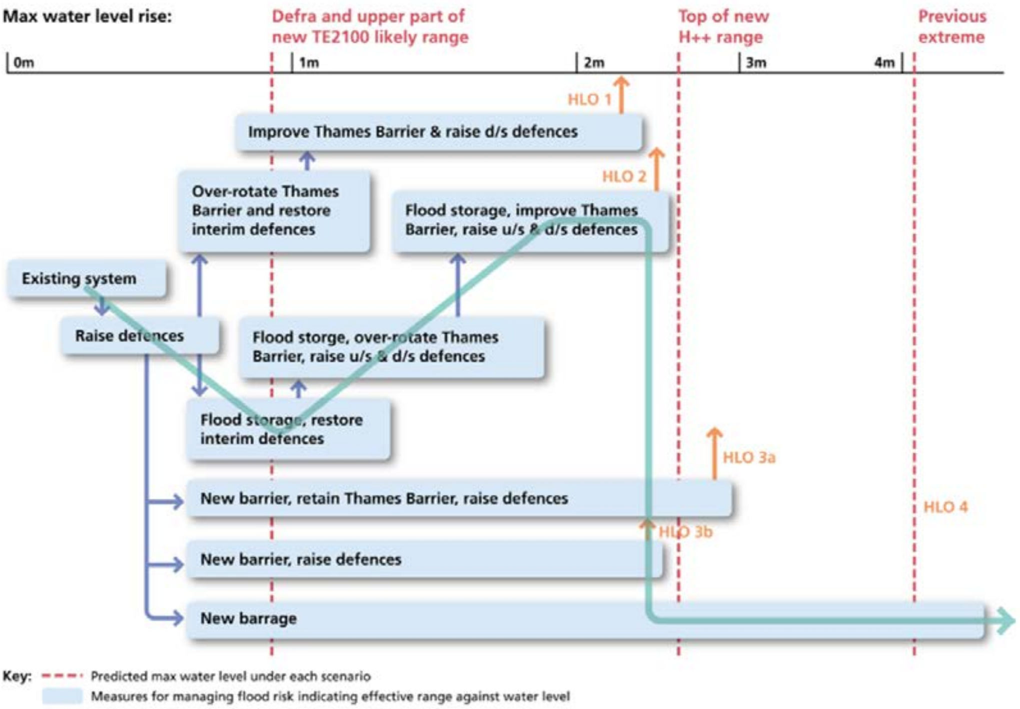

Figure 2 An example of how national level strategies for managing flood risk in London could involve multiple flexible pathways (Reeder and Ranger, 2011).

Nevertheless, in spite of the potential complexity associated with FAPs for woodland systems, the adoption of some kind of FAP framework is attractive for several reasons: (i) such a system acknowledges the *uncertainty* associated with evolving woodland management priorities, imprecision about the likely impacts from climate change, changing policy priorities etc but promotes decision making in this context, (ii) a FAP system would help to identify risk 'pinch-points' where further research should be prioritised, (iii) a FAP system could be used to bring different and contrasting stakeholders to collectively understand how each could deploy adaptation management, (iv) a FAP system demands and encourages a level of purposeful forest monitoring and surveillance, and (v) in the absence of a pragmatic system such as FAP, there is a danger that adaptation will proceed sub optimally in a comparatively random and unplanned manner. Reasoning behind a pathways approach for adaptation has recently been reviewed by Wise et al. (2014). These authors suggest it is important now to move from studies of impact and vulnerability to "enabling decision makers to make the difficult and urgent choices between a range of alternative policy and management options in interconnected social and natural systems".

This report details an exploration of the applicability of a FAP system for native woodland adaptation in Scotland. It was undertaken by members of ClimateXChange at the request of Scottish Natural Heritage (SNH).

3. Policy context

Native woodland policy

Native woodland is highly regarded as an important habitat type in Scotland and one which supports a wide range of important plant and animal species. Native woodland protection has formed an important element of modern forestry policy since the 1980s, and this was further strengthened following the UN Earth Summit at Rio de Janeiro in 1992. Indeed, the UK Programme for Sustainable Forestry (HM Government, 1994b) contained broad policies aimed at forest biodiversity protection and enhancement, and successive high level policy documents, notably the UK Forestry Standard (Forestry Commission, 1998, 2004, 2011) have reinforced this position. In Scotland, the Scottish Forestry Strategy published in 2006 aimed for a long-term programme of expansion, restoration and improvement in the condition of Scottish native woodlands by the middle of the century. Forestry Commission Scotland (FCS) takes the lead in developing policy relevant to native woodlands, in close consultation with other interested parties both within and outside the Scottish Government.

In more recent years, there has been a noticeable injection of multifunctionality into Scottish native woodlands policy, in parallel with a growing ecological understanding of the importance of spatial planning and management at landscape scale. In addition, the ecosystems approach to land-use planning (as exemplified by the UK National Ecosystems Assessment, 2011) has identified the wide range of goods and services that ecosystems, including native woodlands, can supply. So, for example, the Action for Scotland's Native Woods (2008) stipulates that "Managing native woods should provide value to landowners or managers as well as the wider public benefits" and describes the opportunities for timber production, animal shelter, amenity, sporting and other benefits as well as for biodiversity. This multifunctional approach is reinforced in very recent Scottish Government publications, e.g. the 2020 Challenge for Scotland's Biodiversity (Scottish Government, 2013).   Nevertheless, for the study described here, it was assumed that the principal driver for the adoption of a FAP framework for native woodland adaptation was the maintenance of biodiversity.

Biodiversity and climate change
Although UK policy on sustainable development, biodiversity, climate change and forestry all emerged in parallel after the Earth Summit in 1992, **direct links between biodiversity and climate change have developed much later and only relatively recently**. In the past, maintenance and enhancement of biodiversity was seen as important against the pressures of growing populations and land-use change. Although these pressures remain, the certainty of climate change has led to a realisation that it will have serious effects on biodiversity, either directly on sensitive species themselves or indirectly through its effect on habitat (Scottish Government, 2013, 2014). Native woodland is clearly vulnerable to changes in climate too. In broad terms, the Scottish Government Land-Use Strategy (2011) makes it clear that "land-use decisions should be informed by an understanding of the opportunities and threats brought about by the changing climate".

Whilst the need to build resilience in natural vegetation systems to counter or accommodate the impending effects of climate change is promoted, high-level policy guidance is somewhat less specific about how this should be achieved in particular, and whether adaptation guidance is likely to succeed in achieving the aim of protecting valuable and valued species and habitats. Generic actions are advanced, for example promoting the role of ecological pathways and green/habitat networks, and raising awareness about the importance of adaptation. In the context of native woodlands, specific mention is made of the need to improve their condition and encourage natural regeneration (Scottish Government, 2014). More detailed advice considers the role of species diversity and silvicultural management systems (Grant and Worrell et al., 2012). These concepts are also reflected in the recently published SNH Climate Change and Nature in Scotland (2012) guidelines and the FCS Climate Change Programme (2013).

It is in the context of this complex policy environment that a study of the potential of a FAP framework was undertaken - to what extent might a scientifically-rigorous framework for making practical decisions about the type and timing of adaptation options be useful in implementing them.

4. The science of native woodland vulnerability: identification of trigger points or change thresholds

A key challenge in applying FAPs to native woodlands may be in the process of simplification, i.e. (i) defining which woodland assets or services provide a focus of attention, (ii) identifying the key risks to the different woodland assets, (iii) identifying indicators which can be used to measure the risk to each asset, and (iv) mapping FAPs across different woodland assets. Dealing with a single asset at a time, with these accrued across multiple woodland FAPs, avoids complexity. However, care is then needed to ensure that when thresholds are met and adaptation strategies are considered that decisions are taken in cognisance of other valued woodland services.

As was stated in Section 2, **the focus will be on a single asset - biodiversity** - though even this is multifaceted, including the trees themselves, their structure and associated woodland diversity.

Woodland biodiversity
Woodland biodiversity is represented here with three levels of complexity (cf. Ferris and Humphrey, 1999) in terms of: (i) native tree species such as those which occur in British NVC communities (Rodwell, 1991), (ii) the structural complexity of these tree species within woodlands, measured as their species composition and age-structure at a site, and (iii) associated tree dependent species and adopting the assumption that increased woodland structural heterogeneity within the context of a given NVC type will be associated with greater diversity of these associated organisms (Lundholm, 2009). Also, it is

acknowledged that certain niche specialist species of high conservation value will depend on structural components which tend to be rare in the landscape, e.g. post-mature senescent trees, and deadwood.

Native woodland species sensitivity to climate change

Native Tree Species An extensive review accompanied by bioclimatic modelling has indicated the risk of significant impact of climate change on British tree species, in terms of shifts in the suitability of environmental space (Berry et al., 2012) supported where possible by experimental evidence related to species physiology. The findings have important implications for the role of Scotland in prioritising the protection of native tree species, including the gain of suitable climatic space for species such as oak (*Quercus* spp.) and ash (*Fraxinus excelsior*) in Scotland, balancing the risk of a loss of suitable climatic space in England. Results also included increased climatic suitability in Scotland of 'non-native' beech (*Fagus sylvatica*) and sycamore (*Acer pseudoplatanus*), as well as southerly distributed species such as hornbeam (*Carpinus betulus*). Certain coniferous species which are key elements of Scotland's native semi-natural forests are projected to lose suitable bioclimatic space under climate change, including juniper (*Juniperus communis*) and Scots pine (*Pinus sylvestris*), along with other characteristically 'boreal' elements of the woodland flora, such as the birches (*Betula* spp.) and understorey *Vaccinium* species.

Ecologically, the impact of shifting climate space will be realised through community and meta-population processes. Thus: (i) populations of adult trees at a given site may be reduced or extirpated by tree death caused by climate change, including extreme events such as severe drought (as observed for beech: Peterken and Mountford, 1996; Geßler et al., 2007); (ii) this loss may be compensated by the recruitment of new individuals of the same or different species into the canopy and understory. However, in the long-term there is a risk that woodland sites may become unsuitable for extant species, with turnover in woodland composition enabling succession towards a different flora. The process of compositional change is partly dependent on dispersal among fragmented woodland habitats, and dispersal may lag the changing climate (Schwartz, 1992). The result would be a decline in tree species richness, trending towards more widely dispersed generalist species.

Structural Complexity and Associated Biodiversity There is a risk that woodland structural complexity may shift depending on the response of tree species to climate change. In terms of age structure: extensive tree mortality following an extreme event may yield high volumes of deadwood, though because intermediate tree ages are absent from many Scottish woodlands, owing to recent periods of high grazing pressure, there is a danger that mature and old trees could become extremely scarce in the landscape. In terms of woodland composition, if populations of certain tree species in Scotland decline, and these declines are not accompanied by species turnover within woodland sites owing to the colonisation of different bioclimatically adapted species, then tree species richness will decrease.

Recent work focussed on ash dieback has demonstrated that tree-dependent species within a range of different guilds, e.g. epiphytes (lichens and bryophytes) and invertebrates, show divergent associations with different tree species, and trees of different age (Mitchell et al., 2013). Thus, sites with a range of tree species will typically host greater levels of associated diversity, especially for example where trees with different bark characteristics occur intermixed, such as the more acidic bark of birch, juniper and pine, and the sub-neutral bark of ash or aspen. Likewise, a mixed age structure enables the colonisation into woodland of species associated with contrasting microhabitats, including the greater likelihood of dispersal-limited species establishing onto older trees. The consequence of changed structural complexity of woodlands can therefore be profound for associated biodiversity. Evidence suggests this may include a decline in acid-barked birch, pine and juniper, and loss of an older tree cohort from the landscape.

The dilemma of when to act

The potential woodland sensitivities outlined above provide a theoretical perspective on the types of ecological change one might anticipate. However, there is uncertainty as to: (i) the rate and magnitude of climate change, (ii) the sensitivity of woodland tree species composition, structure (e.g. demography) and associated biodiversity to climate as a driver, and (iii) the degree to which nature will respond to this climatic sensitivity in a manner that maintains woodland ecosystem services and goods (i.e. inherent resilience of biodiversity assets). All these pose significant difficulties for decisions designed to manage such risks, exacerbating uncertainties relating to, for example, the extent to which human intervention will be required, and when. These uncertainties thus create a dilemma (Figure 3).

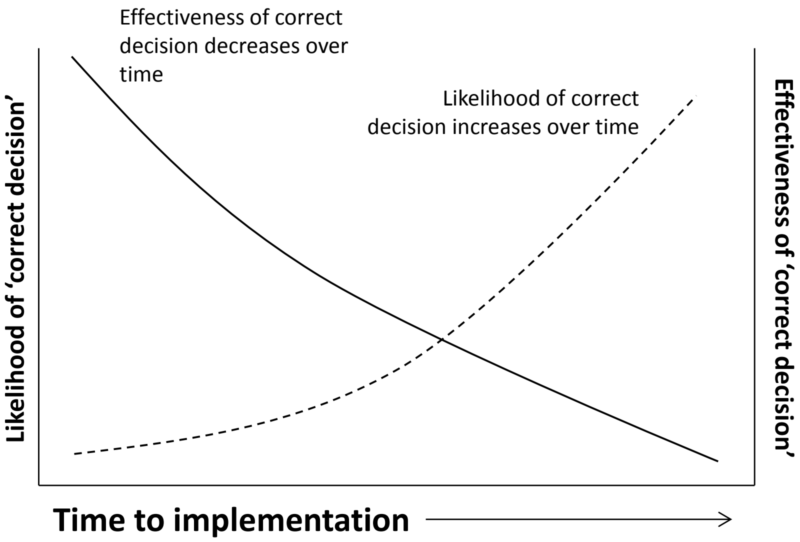

Figure 3 A woodland biodiversity paradox identified through discussion with stakeholders. The likelihood of making a correct adaptation decision improves the longer the time over which knowledge accumulates, though the likelihood of that decision being effective in protecting biodiversity declines the longer one waits to take action.

Over time, it will be possible to generate more complete knowledge of the woodland biodiversity response to climate change, shifting from predictive modelling (Berry et al., 2012), through to a directly observed response with field-sampled data. This improving knowledge base increases the likelihood of identifying a 'correct decision' in terms of strategic adaptation to protect woodland biodiversity assets. However, **the effectiveness of implementing a 'correct decision' declines over time**, because there is an inevitable lag phase between an adaptation action, and its effectiveness in protecting woodland biodiversity. Take as a cursory example the projection of declining environmental suitability for Scots pine based on predictive models (e.g. Ray et al., 2010). The evidence at present is too insecure to justify a radical option such as the gradual replacement of pine by a more warm adapted 'substitute species'; however, by the time evidence might become available to make such a decision palatable, i.e. a massive decline in native pine woods, it may be too late to implement an effective response. This is because many associated pinewood faunal and floral species depend critically on the continuity of old trees and/or mature woodland for their survival. There would therefore be a temporal gap between the loss of suitable habitat (old pine trees) and its restoration within the landscape, which could take centuries.

Options available for Flexible Adaptation Pathways

The dilemma of when to act indicates a staged approach may offer the best option, in terms of creating a framework with sufficient flexibility for the delivery of Flexible Adaptation Pathways (FAP).

Firstly, it is recognised that policy levers which are currently available, such as reducing air pollution, extending the size and reducing the isolation of native woodlands, and best practice in terms of grazer management and tree regeneration, will improve the starting point for woodland resilience to climate change. These actions do not require detailed knowledge of climate sensitivity to justify implementation, and are expected to be effective in improving biodiversity resilience.

Secondly, the starting point of a FAP would seek to build a consensus around thresholds that indicate risk to a woodland biodiversity asset and then consider the strategic response should these indicators approach a threshold. For example, given the death of 'x percent' of tree 'species a' following an extreme event, assisted colonisation of substitute 'species z' into native woodland becomes necessary. These thresholds might be defined at and form a response at a local level, with the accompanying challenge of scaling local adaptation actions into a coherent national response.

Third, the synthesis of existing data, and modifications in their collection, are necessary to create a robust observational network (e.g. Site Condition Monitoring). This forms the basis for knowing when to act. An improved monitoring system might be combined with experimental 'sentinel' sites, which could help define how to act, to increase the likelihood of making a 'correct decision'. In an experimental framework, regenerating woodland sites might incorporate multiple experimental scenarios (Hoegh-Guldberg et al., 2008; Thomas, 2011) which provide the opportunity for recurrent learning. For example, these might include (i) reference plots representative of standard NVC communities, (ii) mixing native NVC communities with insurance plantings, including 'non-native' southerly-distributed and warm-adapted trees, (iii) establishing entirely new woodlands of non-native tree species which are aligned to contrasting climate change projections. Each of these three scenarios may incorporate different levels of standing genetic diversity, representing opportunities for genetic rescue effects and evolutionary adaptation (Aitkin et al., 2008).

Recommendations for woodland biodiversity indicators in a FAP system
Preliminary identification of suitable indicators on which to judge the appropriateness of following a particular adaptation pathway has been undertaken. Such indicators include: (i) **tree health and mortality**, (ii) **successful recruitment of juvenile trees** (same or different species) into the canopy and understory, (iii) **tree-related microhabitat diversity** (contrasts and complementarity, e.g. among tree species and their age structures), (iv) **population viability of dispersal-limited, niche-specialist species**, such as 'ancient woodland indicators'.

5. Monitoring and evaluating flexible adaptation: potential native woodland indicator data for Scotland

The nature of both biodiversity and adaptation policy means that only sites with designated status (e.g. SSSIs, 'Natura' sites established under the EC Habitats and Birds Directives (1992 and 2009), National Nature Reserves (NNRs), and habitats on the Scottish Biodiversity List) are liable to be monitored and scrutinised specifically for their provision of biodiversity 'services' in the face of climate and other drivers of change. SNH has the primary responsibility for surveillance of these sites and reports on their quality every six years. However, **for the vast majority of native woodland in Scotland there is currently no legal or authorized responsibility for monitoring quality or other aspects of their status and/or ecosystem delivery**.

Nevertheless, the central importance of monitoring to support a Flexible Adaptation Pathway decision framework is clear and has already been emphasised in Sections 2 and 4. Monitoring needs to provide the evidence that climate change is having an impact on Scottish native woodlands such that management decisions can be taken and different adaptation pathways chosen as necessary.

Measurements are focussed on the indicators chosen to track change in responses (see Section 4). Annex 1 identifies a large number of potential datasets/data tools which are currently available or under development. These cover both broad scale national level indicators as well as data at sub-compartment level for individual forest stands, providing the potential to examine response to management at both national policy, regional and forest stand levels.

The list in Annex 1 is comparatively long, but initial exploration suggests that only a few entries seem suitable as the primary means of supporting a Flexible Adaptation Pathway framework. And inevitably, as yet, there has been no consideration about the realistic opportunity to access relevant data (collected for different purposes) and to build a suitable FAP-dedicated data management system from which to base adaptation decision making. **The National Forest Inventory is probably the most established platform with sufficient flexibility to deliver information** on many of the primary indicators identified in Section 4.

As well as providing details of monitoring networks where measurements are made on indicators relevant to native woodland biodiversity, Annex 1 also provides examples of modelling projects which could be used to generate spatial predictive data. These data could be used within a FAP framework to inform decisions on adaptation pathways. In the absence of an ability to use actual data reflecting native woodland response to climate change, **it is recommended that consideration be given to formally bringing modelled outputs into an adaptation decision support system**.

6. Adaptation options to support a Flexible Adaptation Pathway framework for native woodland in Scotland

The scientific literature provides a large array of possible adaptation options for managing native woodland and forests, and Moffat et al. (2013) reviewed some of these recently. Annex 2 provides a more thorough synthesis, but also takes the opportunity to offer expert opinion on 'likelihood of success' and 'barriers to success' as well as linking each possible measure to current policy statements. Previous workshops on options have revealed the comparative lack of knowledge for many of them, and outcomes from their uptake are therefore quite uncertain in many cases. This does not invalidate their inclusion in the list of possible options because it is improbable that we will know all we would like to before having to choose some of them. But it should be recognised that some options, whilst scientifically plausible, will be extremely challenging, expensive or both to implement in practice. It is likely that we are now in a position where most of the possible options have been identified (though innovative new solutions may still be possible). However, despite a need for greater understanding in respect of several of these **it is recommended that a systematic review be undertaken soon in order to prioritise options in order of sustainable delivery and policy tractability**. In the short term, the greatest confidence should be placed on the more conventional options such as reducing external stress from browsing animals and abiotic drivers. Some options, although mooted in current policy guidance on native woodland adaptation, seem almost totally unsupported in terms of policy instruments and 'SMART' objective-led outcomes.

7. Conclusions

Policy environment

The review of the current legal and policy environments at the beginning of this study leads to several conclusions regarding the development and implementation of a FAP approach to native woodland adaptation. Firstly, although laws (notably the Nature Conservation (Scotland) Act 2004) and policies identify the necessity of preserving important habitats and species, it remains to be seen how risks will be identified, registered and effectively managed. There is seemingly no provision in law and no precise identification of risk thresholds beyond which remedial measures could be put in place. Loss of designated features (species or habitats) of Sites of Special Scientific Interest might be reasonably put forward as a strong indication of lack of effective adaptation. Reports to this effect are likely to generate debate, but it is not clear whether inevitable losses are likely to be considered a matter of significant political concern.

Secondly, there is no requirement for monitoring of native woodland except that which is classified as SSSIs, Natura sites or other sites of designated importance. Other monitoring may take place, e.g. as part of the Forestry Commission National Forest Inventory, but these activities are not bound by law and have an uncertain future. It will need to be explored whether native woodland which falls within sites legally bound to be periodically monitored will be representative of the whole – i.e. whether such surveillance will serve the purpose of a FAP system, or whether further monitoring will be needed. Certainly, an FAP approach to adaptation is heavily reliant upon monitoring support, but this is currently poorly established legally.

Thirdly, the new focus on the importance of a range of ecosystem goods and services delivered by native woodlands means that a simple 'biodiversity' focus, e.g. on designated species of importance, may not always be the optimal way to define adaptation success or failure. For example, recent interest in studying functional traits may point to a more practical and pragmatic approach to a focus on taxonomic units, and this may mean less expenditure of effort in preserving individual species. In addition, appropriate adaptation intervention measures to support some native woodland goods and services may, in some cases be antagonistic for biodiversity and could lead to a loss of some species to preserve others, e.g. timber producing trees. A greater understanding of possible trade-offs from different adaptation pathways is required.

Finally, a focus on the ‘nuts and bolts’ of adaptation for a particular ecosystem, namely native woodland, and the desirability for advancing a pragmatic framework for adaptation decision-making, brings the need for effective policy instruments into sharp relief. If a FAP approach is to have credibility and to offer the prospect of facilitating effective decision making, then, in parallel, **policy makers and advisors will need to address how the various options identified in such a framework can be made to work in practice**. So far, various options have been explored from a scientific perspective (e.g. Berry et al., 2012; Annex 2) but it is essential to see how they can or can’t be made to work in practice. Similar sentiments to the above have recently been put forward by the Adaptation Sub-Committee (2013). This report also identifies the need to strengthen the implementation of current regulations to facilitate adaptation, particularly those contained in the Conservation (Natural Habitats, &c.) Regulations 1994. In addition, it points to the need to further incentivise financially the creation and restoration of habitats such as native woodland.

Scientific environment

Inevitably, this review has identified a range of issues where further research could be undertaken to strengthen the application of a FAP framework for native woodland. Such gaps in knowledge should be judged as either fundamental to, or merely supportive of an early roll-out of such a framework. In the former category, it would seem that decisions regarding the most appropriate adaptation path to follow rely upon an understanding of adaptation thresholds (see p. 7), and these have yet to be articulated. In the first instance, it is highly likely that most of these will need to generated by expert elicitation or empirical modelling - more scientifically-founded thresholds could take years or decades of research. In other respects, most of the other research identified in this report is capable of being undertaken as part of a FAP programme. The suggestion of a need to set up a range of 'sentinel' sites where some of the more radical options for adaptation (e.g. importing non-native species, or genetic material, from more southerly climates) are tested in 'real time' is challenging but certainly worthy of further discussion. The biggest technical challenge for the project as a whole is to build a data management and information communication system around FAP components (e.g. monitoring systems built for other purposes, GIS information on extent and location of native woodland) and to build confidence amongst native woodland stakeholders that the FAP decision support system generates adaptation options that are optimal for their woodlands. A financial evaluation module would also seem to be an essential component of a future FAP system if support for one was forthcoming. Last but not least, the social dimension must be explored further - to what extent are native woodland stakeholders willing to support a FAP system, and to respond to its guidance. Indeed, the exploration of how a FAP framework might be developed has raised again issues around why and how adaptation of native woodland should be considered. As the effects of climate and other changes are felt over the coming decades, such attitudes are likely to change, and a FAP framework would need to be flexible in order to accommodate them.

Alternatives to a FAP approach

Our review to date has identified that development of a FAP system for native woodland adaptation will be comparatively **challenging - though** certainly not beyond current, or realisable, boundaries of knowledge and technology. However, further work to develop such a system would require commitment from relevant funders and stakeholders over at least a two year period. So it is worth considering what other approaches might be taken in the absence of a system as robust as that discussed in this report.

The process of scoping a FAP system has revealed some significant gaps between theoretical knowledge and policy and practice which if left uncontested could contribute additional risk to native woodland health and viability. Indeed, many of the components for a FAP system have value if developed in their own right. Perhaps one of the most important current gaps in the evidence base is good *ground-based evidence* that Scottish native woodlands are at risk of significant change, indeed that change may already be occurring. It is possible that there are sites in native woodland where current monitoring (for whatever reason) might provide relevant information, and these should be explored. In addition, further discussion should establish whether there is sufficient interest and resources for an experimental approach to test adaptation options, e.g. via the formation of a series of 'sentinel' sites.

If nothing else, it is hoped that the review has identified some issues that need addressing, whether a FAP system is taken forward or not. It seems evident that projects which deliberately work at the science:policy interface are effective in identifying directions for both decision makers and scientists to travel. The study has also reinforced several of the conclusions from the recent review by Wise et al. (2014) - that it is important to take account of organisational, political and social circumstances in developing a pathways framework, but despite the complexity it remains a very valid response to the challenges and the need for appropriate adaptation.

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Annex 1. Monitoring and evaluating flexible adaptation: potential native woodland indicator data for Scotland

Dataset	Description	Organisation	Frequency	Coverage
Biodiversity and ecosystem indices				
Biodiversity (2010) indicators[1]	Track the state of Scotland's biodiversity and the level of engagement of people with biodiversity. Based on the UK indicators with additional ones that reflect Scotland's distinct environment. Indicators cover: habitat extent; habitat condition; trends in the status of priority habitats and species; wildlife indicators; action for biodiversity	SNH	Annual (?)	National scale
Index of Abundance for Scottish Terrestrial Breeding Birds[2]	Terrestrial breeding birds are monitored primarily through the BTO/JNCC/RSPB Breeding Bird Survey (BBS). Randomly located 1 km survey squares which are representative of the three main terrestrial habitats throughout Scotland (farmland, woodland and upland) are visited twice in the breeding season.	BTO/SNH	Annual	National
Ecosystem health Indicators	A measure of the quality (condition and function) of ecosystems at a range of different geographical scales being developed as part of Scotland's Biodiversity Strategy[3].	SNH	Unknown-Under development	
Ecosystem Services	These indicators are being developed through the Ecosystem Assessment Working Group led by JHI as part of the Ecosystem Services Theme[4] of the RESAS Programme 2011-2016.	JHI	Unknown-Under development	
Natural Capital Asset Index[5]	Natural capital is the stock of natural systems, or 'ecosystems', which yields a flow of valuable services into the future. Initial prototype worked up by SNH, currently being developed by a partnership between SNH and James Hutton Institute.	SNH/JHI	Unknown-Under development	

1 http://www.snh.gov.uk/publications-data-and-research/our-changing-environment/scotlands-indicators/biodiversity-indicators/
2 http://www.scotland.gov.uk/About/Performance/scotPerforms/indicator/biodiversity
3 http://www.scotland.gov.uk/Resource/0042/00425276.pdf
4 http://www.scotland.gov.uk/Topics/Research/About/EBAR/StrategicResearch/future-research-strategy/Themes/Theme1
5 http://www.snh.gov.uk/docs/B814140.pdf

Dataset	Description	Organisation	Frequency	Coverage
Threats to biodiversity				
Invasive Non-Native Species	To be developed.	SEPA/CEH/BTCB/ Highland Invasives Forum	Unknown- Under development	
Wild deer	The purpose of these indicators is to describe in total the progress towards the vision and the three outcomes set out in Wild Deer a National Approach[6].	The Deer Commission for Scotland/SNH	Unknown- Under development	
Site condition monitoring[7]	The purpose of Site Condition Monitoring is to determine the condition of the designated natural feature within a site. This is to establish whether the natural feature is likely to maintain itself in the medium to longer term under the current management regime and wider environmental or other influences. There are in excess of 5000 individual natural features of special interest hosted on designated sites which are monitored on a rolling programme through Site Condition Monitoring.	SNH	Monitoring frequency is based on sensitivity- ranging from 6-24 years frequency	Covers all notifiable features in Scotland
Tree Health Diagnostic & Advisory Service[8]	Currently information on the distribution and impact of pests and pathogens is rather disparate. The Advisory service in FR builds a record of advisory requests, but there is no central depository for all information relating to pests and pathogens. It is planned that this will become a central repository for pest and disease data.	Forest Research	Data collection is on-going but no formal indicators are created	
ObservaTREE[9]	Database of observations of tree pests and diseases primarily collected through 'citizen science'	Forest Research		

[6] http://www.snh.gov.uk/land-and-sea/managing-wildlife/managing-deer/wdna/
[7] http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/site-condition-monitoring/
[8] http://www.forestry.gov.uk/fr/ddas
[9] http://www.forestry.gov.uk/fr/observatree

Dataset	Description	Organisation	Frequency	Coverage
Woodland extent and composition				
National Forest Inventory (NFI)[10]	The National Forest Inventory provides a record of the size and distribution of forests and woodlands in Great Britain and information on key forest attributes. The location and extent of all forests and woodlands are being mapped. Measurements collected from field survey will be linked to area data derived from the maps in order to generate quantitative and bounded estimates of woodland structure, composition and size.	Forestry Commission	5-year cycle starting in 2009	Great Britain
Native Woodland Survey of Scotland[11]	The survey is creating a woodland map linked to a spatial dataset which describes the type, extent, composition and condition of all native woods in Scotland over 0.5 ha in area. Planted woods on ancient woodland sites (PAWS) will also be surveyed, even where they are not mainly native in species composition, in order to provide information to help maintain or restore their remaining biodiversity value. Baseline for monitoring change in individual woods.	Forestry Commission Scotland	Currently being completed- likely full coverage by end of 2013. No plans for future re-survey.	Scotland
Potential Native Woodland Network[12]	Potential native woodland network maps for Scotland have been created based on modelling analyses by Forest Research. The maps include core woodland areas expected to have high conservation value, together with two potential expansion zones. These zones represent the distances over which woodland species of slow or moderate colonising ability might be expected to disperse and to establish themselves in new native woods created near to the core areas, within a period of approx. 50-100 years.	Forestry Commission Scotland	No update planned (?)	

[10] http://www.forestry.gov.uk/inventory
[11] http://www.forestry.gov.uk/nwss
[12] http://www.forestry.gov.uk/forestry/infd-7x7d9w

Dataset	Description	Organisation	Frequency	Coverage
Updated connectivity of native woodland	This will utilise the new NWSS to create a functional connectivity index across Scotland	Forest Research	Under development	
Habitat connectivity indicator	This will provide a functional connectivity index for all BAP habitats	SNH	Under development	
Ecological Site Classification[13]	Assessing species suitability: ESC is a PC-based Decision Support System for British Forests. The model is designed to match key site factors with the ecological requirements of different tree species and woodland communities, as defined in the National Vegetation Classification for Great Britain.	Forest Research		Intended to be presented at several scales from national to local. Detailed data based on a representative sample of 15,000 1ha plots
Native Woodland Model[14]	The Native Woodland Model identifies the potential-natural extent of native woodland cover. Used at a broader scale than ESC to give an indication of the potential woodland types at the regional level.	JHI(?)		Data from NWSS can be used in many ways and at national, regional, and local or woodland scales.
FES Sub-compartment database (SCDB)[15]	The SCDB is the Forestry Commission's authoritative dataset, giving information for recording, monitoring, analysis and reporting across the entire FC estate. It helps to provide a definitive measure of trends in extent, structure, composition, health, status, use and management of all FC land holdings.	Forestry Commission	Annual (sub-annual?)	Scotland wide coverage to be used as a guide at local scale in conjunction with finer resolution detail.
FES component visualisation database	This contains more detail than the sub-component database, including detail on planted material (providence etc) and management	Forestry Commission	Annual (sub-annual?)	

[13] http://www.forestry.gov.uk/esc
[14] http://www.snh.org.uk/pdfs/publications/heritagemanagement/nativewoodland.pdf
[15] http://www.forestry.gov.uk/pdf/FCSOASSCDB.pdf/$file/FCSOASSCDB.pdf

Dataset	Description	Organisation	Frequency	Coverage
Management				
Wildlife Management	To support the Wildlife Management Programme and the Wildlife Management Framework developed by SNH. These indicators will assess the impact and progress of wildlife management projects and initiatives and provide feedback to inform future work through the SNH Wildlife Management Programme.	SNH	Unknown- Under development	Analysis can be done at an individual stand scale. Data layers have national coverage
Scottish Forestry Strategy Progress Indicators[16]	Fifty four indicators that cover a range of FCS activities. Topics covered are: Climate Change; Timber; Business Development; Community Development; Access and Health; Environmental Quality and Biodiversity. Biodiversity section includes specific indicators related to native woodland condition, restoration and expansion	FCS	Annual	The model covers upland Scotland. Suitable for use at scales above 1: 50 000

[16] http://www.forestry.gov.uk/sfs

Annex 2. Adaptation options to support a Flexible Adaptation Pathway framework for native woodland in Scotland. Coded from green (current practice), through orange (possible option) to red (radical option).

Option	Aim	Description	Likelihood of success	Barriers to success	Reference	Current policy / guidance
No (or minimal) management Unassisted biological adaptation	Allow (unmanaged or limited management) woodlands to adapt through phenotypic plasticity, evolution and unassisted migration.	No (or minimal) intervention - uncontrolled adaptation. Rely on 'natural' adaptation	Low: Likely to lose species with small populations, distributions and/or narrow genetic variation. Woodland type / structure likely to change dramatically or decline. Expect decline in ecosystem services.	Limits to latitudinal migration, Limits to altitudinal migration, Limited opportunity for inland migration, Physical barriers to dispersal e.g. sea, urban areas, roads, Small population numbers, Low genetic diversity, Over-grazing by deer, Regeneration limited in dense under-managed woodland, Competition from invasive species.	Berry et al. 2012	☒ SG 2013. "improve habitat management where it ...could improve resilience to climate change through increased habitat diversity"
Reduce external stresses	Improve resilience by reducing threats and stresses.	Reduce air pollution, over harvesting, habitat conversion, invasive species, deer pressure.	Good, if these are controllable. However, many well be beyond control of woodland manager, some requiring significant investment.	Air pollution levels difficult to influence. Deer control requires cooperation of other land owners and deer numbers are a major constraint in Scotland. Invasive species expensive to control (e.g. rhododendron).	Kirby et al. 2009, Lawton et al. 2010, Berry et al. 2012 SNH 2012	☑SG, 2013 "Reduce adverse pressures on ecosystems, habitats and species".
Increase habitat heterogeneity	Maintain or improve ecosystem functioning by creating new habitats within woodland area and increasing genetic and species diversity.	Increase available space for a wider range of species, and improve migration potential.	Good if site, climate and habitats are well understood.	Potential loss of current woodland type. New habitats may fail if small or not managed adequately. Risk of increased ease of movement of pest and pathogens. Will require sufficient scientific consensus to produce workable guidance and incentives to change management practices	Berry et al. 2012, Lawton et al. 2010	☑SG, 2013 "Improve habitat management where it is the cause of decline in species diversity or where it could improve resilience to climate change through increased habitat diversity on farms, in forests and elsewhere in the landscape".
Habitat restoration / improvement	Restore degraded habitats, and restore native woodland to sites previously converted to plantation forest / other land use (e.g. ongoing restoration of 'PAWS' planted ancient woodland sites).	Remove plantations and replace with native species through planting or by encouraging natural regeneration.	Good if site, climate, ecology well understood, and if carefully managed.	Problems of establishment due to weeds, regeneration of previous plantation species, deer browsing, insects, wind. Will require willingness to accept trade-offs with traditional ecosystem services (e.g. timber), and probable long-term incentivisation – high cost.	Lawton et al. 2010, Berry et al. 2012 Pryor et al. 2002 Case studies: FCS – PAWS?	☑SG, 2013. "Woodland expansion and habitat restoration will benefit biodiversity while serving important social and economic objectives".

Option	Aim	Description	Likelihood of success	Barriers to success	Reference	Current policy / guidance
Increase number and size of habitats	Increase **connectivity**, landscape permeability.	Options of expanding / increasing with or without improving genetic / species diversity.	Good: Resilience likely to be higher in larger or connected woodlands. Enabling species movement reduces pressure on protected sites. Success depends on site conditions, climate, ecology, silviculture and establishment.	Risk of enhanced movement of invasive species, pests and pathogens. Requires good scientific understanding, co-ordinated spatial planning and strong policy leadership.	Hampson and Peterken 1998 Kirby et al. 2009, FCS 2013, Lawton et al. 2010, Berry et al. 2012 Case studies: FCS?	☑SNH, 2012 "Strengthen habitat networks, especially where habitats are highly fragmented" ☑SG, 2013. "Enhance species dispersal and genetic adaptation through improving connectivity and habitat availability"; "Restoring the quality, or increasing the area, of some habitats….is an important way of trying to recover ecosystem health
Assisted biological adaptation	Increase regeneration rate to allow more potential for selective pressures to work, and/or provide greater genetic diversity to assist natural selection.	Encouraging rate of natural regeneration (e.g. by thinning, soil disturbance). Introducing wider genetic diversity through planting within or adjacent to native woodlands.	May succeed if system and genetics well understood, and if carefully managed. Control of deer and invasive species will be important.	May require relaxation of guidelines designed to protect and maintain populations, e.g. Caledonian pine origin zones. Introduced trees may be 'maladapted' for local climate. Adaptation may not be fast enough to cope with changing climate and pressures. Will need significant incentives to change management approach in managed woodlands. A trade off with important other ecosystem goods and services, e.g. timber production, may need managing.	Kirby et al. 2009, Ennos et al. 1998.	
Species reintroduction	Maintain populations in refugia and reintroduce when appropriate (e.g. when problem pests and diseases are controllable).	Maintain ecosystem as far as possible and re-establish dominant or component species when threat removed	Possible, but likely to be difficult / in practice. Only likely for designated sites with significant available resources for management	Problems maintaining genetic diversity elsewhere, and difficulties re-establishing due to new competition in woodland.	Berry et al. 2012, Lawton et al. 2010	☑SG, 2013. "Develop a strategic programme for re-establishing species lost locally or nationally, or threatened by climate change and other pressures".
Reclassify planted forest	Expand area of 'native woodland', by reclassifying existing plantations of native species grown for timber, as 'native woodlands'. [Note: this assumes that these plantations are not already classed as native woodlands.]	Change management and objectives of plantations of native species (and often of non-native origin), for example Scots pine originally planted for timber, to accelerate development of 'old growth' features, size distribution.	Likely to succeed if carefully managed over long time period, and sufficient commitment and resources are deployed.	Slow process to reproduce age structure of mature native woodlands. Biodiversity will be different to old growth woodland. Difficult to persuade owners to take forest out of production. These plantations are often composed of non-native stock even though the species is 'native', so 'native woodland' may need to be redefined.	Mason 2000 See FC 2003 for definition of 'native pine woods'.	

Option	Aim	Description	Likelihood of success	Barriers to success	Reference	Current policy / guidance
Adjust woodland structure	Increase resilience to abiotic threats such as wind and drought by altering structure.	Managing structure to reduce risks, for example by coppicing woodland, to increase resilience to drought.	Likely to succeed if well planned and managed. Requires skilled practitioners.	High cost. Risk of unplanned impacts on other species from changed woodland structure. Will require sufficient scientific consensus to produce workable guidance and incentivisation to change management practices	Stokes and Kerr 2009, Ray et al. 2010. Case studies: FCS?	☒FC, 1994. Although most upland oakwoods were coppiced, restoration of coppicing is not generally recommended.
Allow colonisation by non-native naturalised species	Maintain ecosystem services by accepting diversity / maintained structure provided by invasive naturalised species. (However, it may not be possible to preserve all aspects of biodiversity as an ecosystem service.)	Accept naturalised species, such as beech and sycamore, in mixed woodlands.	Likely to be successful in some woodlands, but see above.	Will change ecosystem services provided by the woodland. Requires local seed source, right establishment conditions. May increase pressure on remaining native species. Requires that 'native woodland' is redefined and that invasions and extinctions are seen (and accepted) as natural processes.	Brown 1997, Ray 2008	☒ SNH, 2012 "Reduce other pressures on nature, including invasive non-native species" ☒Scottish Government, 2013. "Restore terrestrial ecosystems degraded by invasive species"; "The damage to our environment, .. from invasive non-native species will be greatly reduced, and contingency plans will be in place to guard against future invasions".
Change to more suitable woodland type	Replace declining native woodland with most suitable woodland type.	Remove declining woodland and replace by establishing new woodland based on assessment of species, woodland type suitability for site conditions and current / future climate. Take ecosystems approach in planning replacement woodland	Slow transition may prove successful in some cases. But unlikely to provide similar ecosystem services, nor may these be desirable.	UK only has small number of native tree species to choose from. Unlikely that change of native woodland type will be successful on many sites due to differing soil, site, climate requirements of species. Thus, may require rethinking of what constitutes 'native woodland' in the future, and to what extent 'new natives' are acceptable.	Berry et al. 2012 Ray 2008 Kirby 2009	☒CBD, 2010. and JNC/Defra 2012. "By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero"
Introduce new species to maintain existing / similar woodland structure	Maintain ecosystem services by replacing species, or increasing number of species that occupy same functional space, to maintain structure. (However, it may not be possible to preserve all aspects of biodiversity as an ecosystem service.)	Replace or add to threatened or failing species using other species with similar traits.	Gradual change of dominant species can be successful and still provide similar ecosystem function, though individual faunal and floral species may succeed or fail depending on relationship with failing tree species. Their fate may alter perception of the woodland and its status	UK has lack of native tree species so little opportunity to change (unless non-natives are used).	Kirby et al. 2009, Berry et al. 2012 SNH 2012 Kirby 2009	☒SG, 2013. "Use the Wildlife Management Framework to identify priorities for tackling species conflicts, species conservation issues, reintroductions and sustainable management of wildlife resources. Develop a strategic programme for re-establishing species lost locally or nationally, or threatened by climate change and other pressure