Biodiversity and Woodland Ecosystems

A summary of research outputs supported or facilitated by the Environmental Change Programme of the Scottish Government's Portfolio of Strategic Research (2011-16)

Introduction

The context in which we currently view natural and semi-natural ecosystems continues to value biodiversity as a 'cultural ecosystem service', but also considers it to be central to the delivery of other services, notably the 'provisioning services' that represent material products. A major shift in our thinking has been the appreciation of the less obvious environmental benefits connected with biodiversity. These include the environmental 'regulating services' such as maintenance of air and water quality and pollination, and the 'supporting services' that keep the system functioning, such as plant growth, and nutrient and water cycling. For woodlands, three examples of delivery of regulating ecosystem services included in this collection of research summaries are i) the role of woodlands in fixing or sequestration of atmospheric carbon, in order to mitigate emissions of carbon into the atmosphere to meet government emissions targets (Chapter 9), ii) the beneficial services of the greater control of losses of nitrogen and other nutrients from the terrestrial into the aquatic systems (Chapter 8), and iii) the spatial location of woodlands adjacent to watercourses to specifically benefit the water quality of the outflowing aquatic systems (Chapter 7). These outcomes support a range of policies rendering biodiversity of significance to several policies above and beyond the 2020 Challenge for Scotland's Biodiversity. These policies include *inter alia* the Scottish forestry strategy and climate change policies, and the ambitious targets they generated for increasing land cover of woodlands, along with the response to the EU Water Framework Directive respectively.

The threats to woodlands are now rarely due solely to local over-exploitation for timber products. Many of the current challenges posed are large-scale problems, which paradoxically are insidious and less obvious, namely climate change, grazing, and pollution (Chapters 3,4), which interact with emerging pests and diseases (Chapters 1,2,3). Understanding the regulating and supporting roles of the invertebrates and the unseen below-ground components of ecosystems, in decomposition and nutrient cycling is important if we are to have a predictive understanding of how whole ecosystems work, and how they will respond to continued environmental and land management changes (Chapters 5,7). Our tools available for investigation are broadening to include new technological molecular methods to quantify biodiversity (Chapter 5) and detect pathogens (Chapter 1), and our numerical methods that help us to explore patterns and processes are continuously evolving (Chapters 3,8). These analytical methods, augmented by availability of historical data sets (Chapter 4), and large scale experiments (Chapter 6) are increasing our ability to predict and manage the consequences of environmental change in similar systems. Whether the aim of land management is purely for cultural biodiversity benefits (most protected areas) or delivery of an ecosystem service such as carbon sequestration or agricultural production, a theme emerging from these studies (e.g. Chapters 3,7,8,10) is the existence of trade-offs among the benefits of land management decisions. These have to be analysed and appraised across scales ranging from the national policy and regional levels, to the level of the individual decision-making land manager (Chapters 8,9,10). These methods of integration of economic and social factors with biophysical benefits and dis-benefits of land management options represent a significant development in our approach. Outside our protected areas, most woodland is not managed exclusively for biodiversity. Biodiversity outcomes are often the product of management decisions made for other goals including production forestry, agroforestry or landscape management. The enhanced delivery of biodiversity-related ecosystem services is therefore contingent upon a complex set of policy arrangements and their interactions with human agency. These must be considered for cost-effective delivery of multiple benefits from woodlands.

I hope you will enjoy reading these articles, and that they promote consideration and discussion of the many facets of woodland biodiversity and ecosystem function.

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Contents

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Edited by Glenn Iason, The James Hutton Institute,
Craigiebuckler, Aberdeen 24pp.

CHAPTER 1

Phytophthora and other tree diseases: impacts and risks to woodlands

Background and Aims

An increasing number of pests and pathogens are damaging trees and woodland ecosystems in the UK, including *Chalara* dieback of ash trees and *Phytophthora ramorum* on larch, *Rhododendron* and understorey *Vaccinium*. The recent Tree Health and Plant Biosecurity Taskforce report proposed a UK Plant Health Risk Register of known threats, highlighted the importance of 'epidemiological intelligence' and stressed the need for improved biosecurity. In support of these policy recommendations we have been using a molecular diagnostic monitoring approach to study the biology and distribution of *Phytophthora* species in natural ecosystems. Over 120 species have been described but global trade in plants and a changing environment makes it very difficult to assess the risks due to known and, as yet un-described, species. Knowledge of their diversity and spread in nature is an important element of predicting their environmental and economic impact and will inform their management.

We present the design and application of a generic *Phytophthora* diagnostic method that is being used to monitor the species in three upland Scottish Environmental Change Network (ECN) sites and a lowland site to answer the following questions:

- **Which species are prevalent in apparently 'healthy' ecosystems?**
- **How does site and time of year affect Phytophthora range and activity?**
- **How is their activity affected by environmental change?**
- **Can we use the method to guide policy and minimise the risk of future incursions into forest ecosystems?**

Approach

Sampling: Water samples (10 litres) were collected from streams at four sites at 14-day intervals throughout 2012–13. In addition, a stream flowing through a larch plantation infected with *Phytophthora ramorum* was sampled at a single date. In-field processing of the water samples using a knapsack sprayer and an in-line filter holder allowed the efficient capture of motile *Phytophthora* propagules.

Sample processing: Filters were freeze-dried and stored for DNA extraction (Scibetta et al., 2012, Journal of Microbiological Methods 88, 356–368). Nested PCR using Phytophthora-specific primers based on the ITS regions of rDNA was followed by cloning. Eight clones from each Phytophthora-positive sample were sequenced and the data compared to a reference database of previously described species to generate a catalogue of pathogen diversity.

Results

- The sampling and detection system proved a very effective means of monitoring *Phytophthora* diversity in these ecosystems. The primers did not cross react with *Pythium*, a closely related ubiquitous group of less pathogenic oomycetes.
- *Phytophthora ramorum* inoculum was detected in streams flowing near an infected larch plantation highlighting the value of the method in monitoring quarantine forest pathogens.
- At the four main sites a broad range of >25 *Phytophthora* species were detected over six months of sampling. Up to five different species were found in a single 10 litre water sample.
- Eight groups of sequences had no match in public databases and represent *Phytophthora* species not yet known to science.
- *Phytophthora* was active throughout the year, with zoospores detected in midwinter, even in the upland sites. Pathogen species diversity broadly reflected botanical diversity of the sites.

Figure 1: Early infection of *Vaccinium myrtillus* showing a stem lesion and death of lower leaf as a result of infection by *Phytophthora kernoviae*. Sporangia emerge from the stomata of the stem as shown in the photograph on Page 4.

Conclusions

This generic detection technology has the power to track known pathogens such as *Phytophthora ramorum* and provide an insight into the diversity of known, and previously unknown, *Phytophthora* species in apparently 'healthy' ecosystems. Such technology, especially when coupled to high throughput sequencing technology, also offers great potential in monitoring the presence of *Phytophthora* in commercial plant nursery samples and for testing imports in support of UK plant health policy. In combination with our research on wider ecological impacts we are developing robust approaches to assess the nature and risk of environmental impacts of new threats to forest health

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CHAPTER 2

The potential ecological impact of ash dieback in the UK

Courtesy of David Genney, SNH

Background and Aims

Ash (*Fraxinus excelsior*) is a common woodland, hedgerow, park and garden tree throughout the UK. The arrival of the disease 'ash dieback' to the UK, caused by the fungus *Hymenoscyphus pseudoalbidus*, may result in the death of a large proportion of ash trees. **This project assessed the potential ecological impacts of ash dieback in the UK.**

Approach

Using literature review and biological records we collated a list of species associated with ash, and compared the ecological function of ash, with other UK tree species. The impact on ash-associated biodiversity of potential management options that may be implemented as a result of ash dieback was assessed.

Results

- In comparison with other UK tree species ash produces extremely nutrient-rich highly degradable litter that does not form a deep litter layer and which maintains a high soil pH (Table 1).
- In total, 1,058 species were identified as being associated with ash (ash-associated species): 12 birds, 55 mammals, 78 vascular plants, 58 bryophytes, 68 fungi, 239 invertebrates, and 548 lichens.

- Forty-four species have been identified as occurring only on either living or dead ash trees and were termed 'obligate' ash-associated species: 4 lichens, 11 fungi, 29 invertebrates.
- Sixty two species were found to be 'highly associated' with ash (i.e. rarely use tree species other than ash): 19 fungi, 13 lichens, 6 bryophytes (mosses and liverworts) and 24 invertebrates.
- If a large proportion of ash trees die as a result of ash dieback some species that are already of 'conservation concern' may decline further and other species that are currently of 'no conservation concern' may become rare/rarer.
- Twenty-two tree species were assessed for their suitability as replacements for ash. No single tree species is considered able to provide a suitable alternative for all ash-associated species as well as 'matching' ash in terms of ecological function and plant traits. Oak supports 69% of the ash-associated species. A mixture of tree species rather than a single tree species will support a greater variety of ash-associated species.
- Leaving ash (living and dead) within ash woodlands, rather than removing it, is considered to be better for ash-associated biodiversity and will allow a longer time period for ash-associated biodiversity to colonize alternative hosts in the vicinity.

These results are reported in full elsewhere in Mitchell et al (2014), JNCC Report 483: http://jncc.defra.gov.uk/page-6459

Conclusions

Ash has a unique role within UK woodlands in terms of ecosystem function. If mortality due to ash dieback is high, then a single replacement tree species is unlikely to preserve these ecosystem characteristics, and the associated biodiversity. It could cause declines (or possibly even extinctions) in the populations of species that are obligate or highly associated with ash.

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Soil Characteristic or Function	Rank Order
Litter pH, Low C, High Ca and Mg	Ash > Lime = Maple > Beech
Topsoil pH	Ash = Lime > Beech > Norway spruce
Low litter accumulation, High pH, Litter N, Ca, Low lignin	Ash = Wild cherry > Lime = Alder = Oak
Leaf decomposition rate	Ash > Beech Ash > Lime = Hornbean = Sycamore > Beech Ash > Hazel > Oak > Beech
Root decomposition rate	Ash > Beech

Table 1 (above). The results of seven studies comparing ash with other tree species for aspects of ecosystem function and soil characteristics (Mitchell et al 2014).

Figure 2 (right). The bryophyte *Neckera crispa* growing on Ash.

The funders were: Joint Nature Conservation Committee, Defra, Northern Ireland Environment Agency, Forestry Commission, Natural England, Natural Resources Wales and Scottish Natural Heritage.

CHAPTER 3

Climate change, tree disease and the future of woodland diversity

Background and Aims

Biodiversity will respond to an amalgam of environmental drivers in the 21st Century: e.g. climate change, contrasting pollutants, and habitat change including adaptive forest management. Many species in Scotland's woodlands depend on ecosystem stability; for example, lichen and bryophyte epiphytes are often associated with mature and senescent 'veteran' trees (see photograph above) or have a requirement for ancient woodland continuity. To maintain populations of these conservation priority species, management decisions taken today should be robust to long-term uncertainty. The use of 'forecasts' provides a false sense of security when faced with uncertainty; a better option is to explore the consequences of alternative decisions against a range of realistic future 'scenarios'. Options can then be identified which maximise the protection of biodiversity. **The aim of this work is to demonstrate a scenarios tool-kit which allows woodland managers to scope different options in maintaining lichen epiphyte diversity through to the 2080s.**

Approach

Using British Lichen Society data, the response of 382 lichen epiphyte species was modelled as 'environmental suitability' against baseline values for climate, pollution and extent of ancient woodland (for the period 1961-2010). Species environmental suitability was then projected for the 2050s and 2080s, in each case using an ensemble of 11 climate change scenarios which captures inherent uncertainty in the UK's climate models.

Furthermore, the association of each individual epiphyte species was quantified for each of 15 native and naturalised British trees. These associations provided a correction factor, in which a local environmental suitability could be derived by using woodland tree species composition, to weight the response to larger-scale drivers (climate, pollution, ancient woodland). The approach made it possible to compare a baseline with scenarios of environmental change, and to explore woodland management options for epiphyte diversity.

Results

An example of the output is highlighted for an ash wood which is a Special Area of Conservation in the Scottish borders (Figure 1). The position of points along the y-axis (vertical) shows the degree of change in environmental suitability for epiphytes away from a present-day baseline, for four different scenarios along the x-axis (horizontal):

- Assuming woodland structure stays the same, there is a shift in environmental suitability due to the effect of climate change through to the 2050s (including climate model uncertainty as error bars).
- Incorporating a loss of ash from the system (i.e. an ash dieback scenario), generates a statistically significant further shift away from the baseline, relative to the impact of climate change alone.
- Allowing regeneration of 'non-native' sycamore to replace ash, would reduce the difference relative to the baseline, compared to a fourth scenario, a secondary succession of birch.

This approach can be greatly expanded to explore a more comprehensive range of scenarios and management options for this and for other sites.

Conclusions

Scenario analysis provides a heuristic tool for exploring different woodland management options in the face of uncertainty, as demonstrated here for lichen epiphytes. A lichen epiphyte scenarios toolkit is now publically available (http://rbg-web2.rbge.org.uk/lichen/scenarios/index.php), and can be used to explore decisions relating to the impacts of climate change and shifts in tree species composition. The international importance of Scotland's epiphyte flora, which includes globally rare temperate rainforest communities, provides a clear imperative to consider epiphytes within strategic long term management.

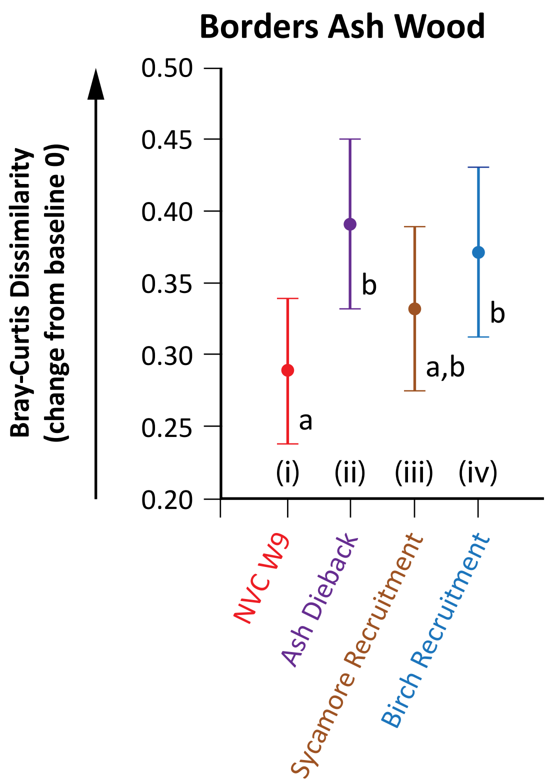

Fig 1: The change in environmental suitability summarised across 382 lichen epiphytes in a Borders ash wood using the Bray-Curtis dissimilarity metric to show (i) the effect of 2050s climate change for a National Vegetation Classification W9 ash wood community (mean and 1 standard deviation for 11 climate runs in an ensemble), (ii) the additional effect of a loss of ash from the system, and the effect of (iii) sycamore recruitment and (iv) succession towards birch. Different letters a,b indicate statistically significant differences among scenarios.

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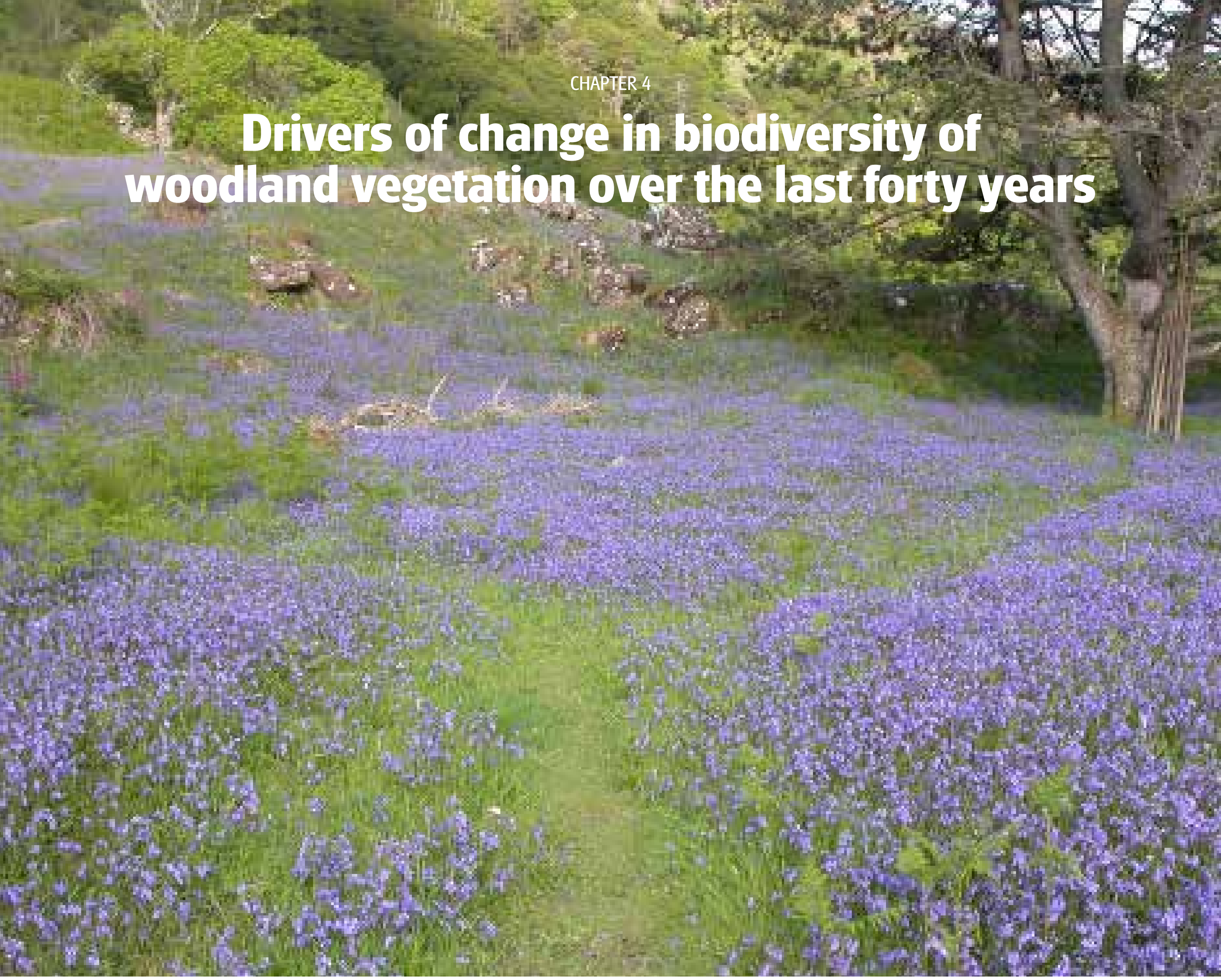
CHAPTER 4

Drivers of change in biodiversity of woodland vegetation over the last forty years



Background and Aims

Natural and semi-natural habitats across the UK have been fundamentally shaped by both natural and human-induced changes, including grazing, pollution and climate. Although some habitat changes may be rapid, many are extremely slow, for example increases in grazing levels can lead to rapid vegetation responses, but recovery from long term grazing can take decades (if at all) where grazing-sensitive species have been lost from the system. Similarly, the benefits of emission control policies for the natural environment can take a long time to be manifested as responses in natural vegetation communities. The effects of climate change may be difficult or impossible to mitigate particularly where species are lost due to changes in climatic conditions. These processes provide an important backdrop against which current biodiversity and other policies are operating.

An understanding of the underlying processes and the impacts of such long-term changes is essential for successful management that addresses the legislative requirements to protect or expand particular habitats, sometimes in the face of powerful drivers in the opposite direction.

In the case of woodlands, the vision of the Scottish Forestry Strategy and its implementation plans (http://www.forestry.gov.uk/sfs) is that by 2050, woodlands will have expanded to around 25% of Scotland's land area with the aim of 35% of trees being of native species. **Here, we summarise some of our findings from analysis of repeat-visit vegetation data, to provide an insight into the drivers of long-term changes in woodland plant communities.**

Approach

The James Hutton Institute (formerly Macaulay Institute) holds a unique historical dataset with >6500 plot-based records of the vegetation and soils of a wide range of Scotland's habitats (Birse & Robertson 1980: Soil Survey of Scotland Bulletin No 4; and unpublished data), giving a snapshot of Scottish vegetation 30-50 years ago. For native woodlands, during the last five years, we resurveyed 264 of the original plots, covering all the main woodland types across Scotland. Analysing these findings together with spatial datasets on climate variables (Met Office), N and S deposition data (CEH Edinburgh), sheep density (EDINA AgCensus) and red deer density (Deer Commission for Scotland, data processed by the James Hutton Institute), we were able to assess the relative importance of these factors in driving changes in our woodlands over the last 30-50 years. As well as analysing overall gains and losses of species and species groups, we have investigated and quantified the magnitude of effects of the three main 'drivers': climate, pollution and grazing by 'variance partitioning'. We present information on the unique and combined effects of climate, grazing and pollution for the 1970s and 2000s for two of our most common woodland types: species-rich oak/birch woodland (NVC W11) and pine forest (NVC W18; Rodwell J.S [ed] 1991. British Plant Communities. Volume 1. Woodlands and scrub. Cambridge University Press).

Results

- For the oak/birch woodlands, pollution had the most important influence of the three 'drivers', particularly in the 1970s – correlating for example with suppression of bryophytes and increases in herbs.
- For pine forests, pollution impacts were not significant in the 1970s but by 2000 they were as important as for the oak/birch woodlands.
- Climate had a significant influence on both woodland types, but a much stronger effect on pine forests than oak/birch in both time periods.
- The effects of grazing impacts by sheep and deer were significant throughout, but again much more so in pine forests than oak/birch.

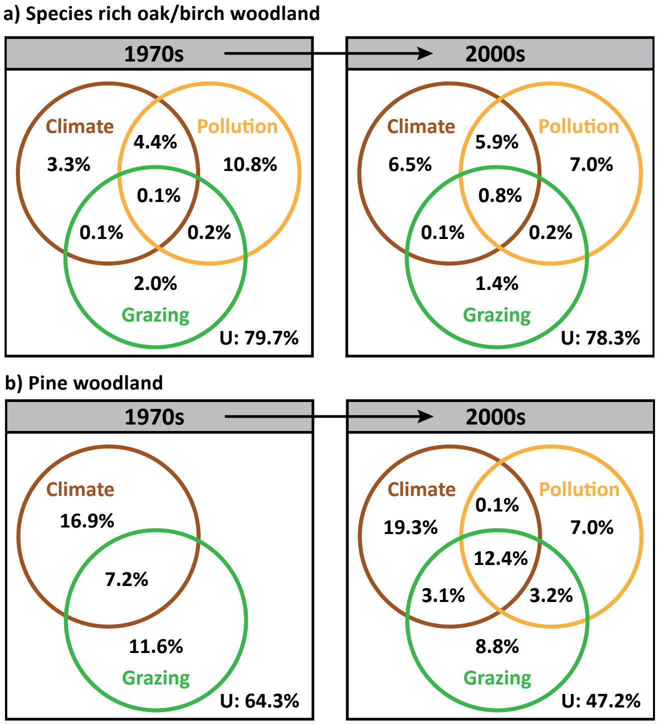


Figure 1: Variance partitioning: %variance in species composition of woodland ground vegetation explained by climate, pollution and grazing for a) Species-rich oak/birch woodland (NVC W11), and b) Pine woodland (NVC W18). All % effects included are statistically significant at P<0.05. U indicates variance not explained by the three 'drivers'.

Conclusion

Unpicking the effects of different drivers of change across all the main Scottish habitats (not just woodlands) is allowing us to identify not only what species have changed, but also to assess the underlying causal factors. For example, changes driven by N-deposition have significantly reduced the characteristic plant biodiversity across many of our semi-natural ecosystems, making them less diverse and more similar. Increases in temperature appear to have already caused shifts of some species 'uphill', with associated declines of some of our arctic-alpine species. Many years of heavy grazing (primarily by sheep and deer) have had strong, long-term impacts on our woodlands, including suppression of tree regeneration, reductions in shrub cover and of other grazing-sensitive species.

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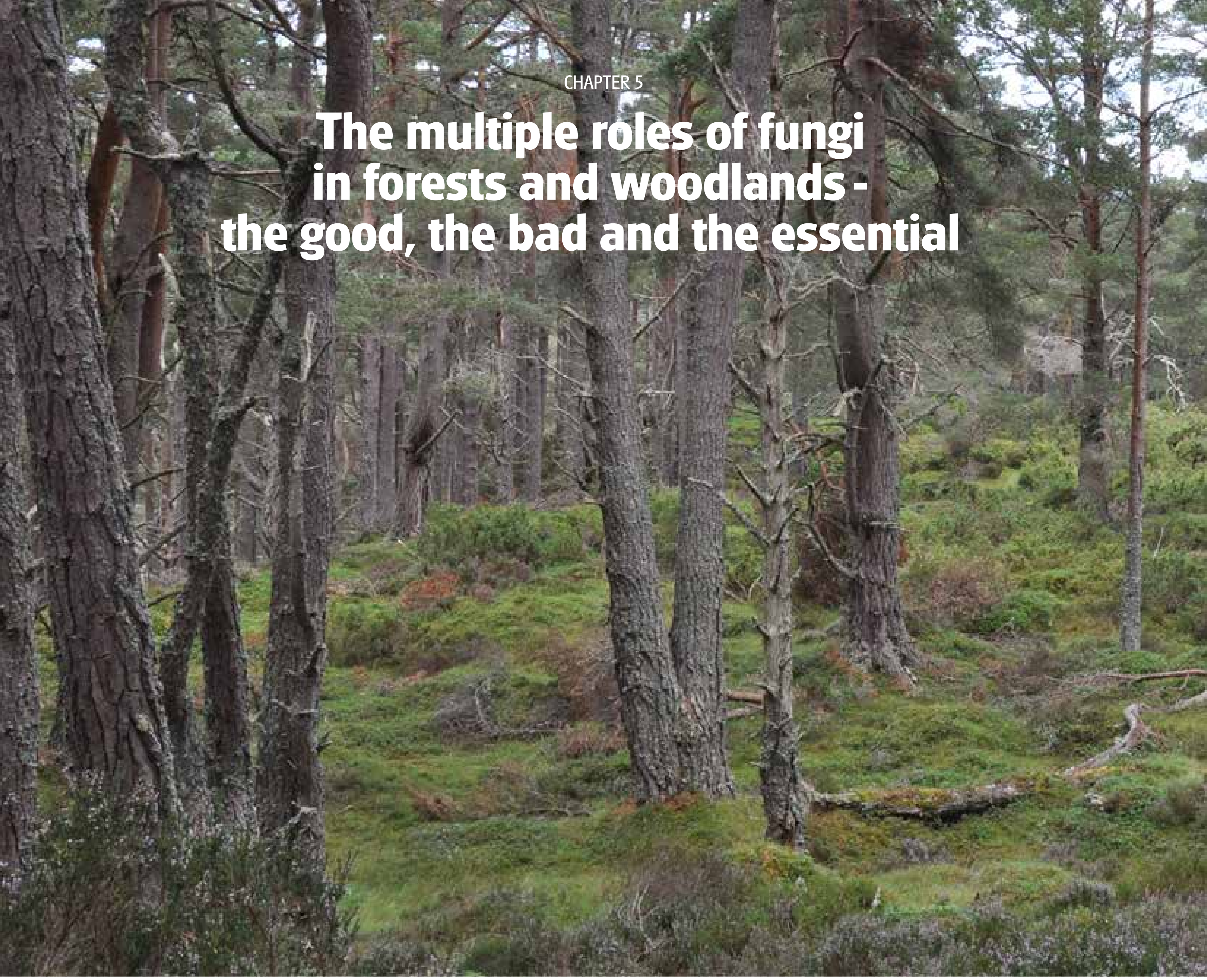
Defra co-funded the pollution-related research



CHAPTER 5

The multiple roles of fungi in forests and woodlands - the good, the bad and the essential

Background and Aims

It is a little known fact that without fungi, Scotland would not have its iconic Caledonian pine woodlands, in which, as in all terrestrial ecosystems, fungi are the essential drivers of nutrient and carbon cycles. Pine trees are intimately associated with fungi throughout their life cycles from germination to death and beyond. The emerging roots of seedlings need to be colonised by beneficial ectomycorrhizal (ECM) fungi, which are ultimately responsible for nutrient and water uptake from the soil and into the growing plant throughout its life. The needles of pine are colonised by a vast array of benign microfungi (endophytes), which influence needle edibility to herbivores. These endophytes then compete with a huge diversity of saprotrophic fungi as the nutrients locked up in the needles are recycled on the forest floor. When a pine tree dies, the decomposition of its wood is entirely dependent on the activity of wood decay fungi.

The 2020 Challenge of Scotland's Biodiversity emphasises the need for healthy, resilient ecosystems, including restoration and expansion of native woodlands. Fungi are fundamental to the health and sustainability of our forest ecosystems but our ability to monitor and manage their diversity and functional roles to achieve the biodiversity aims is currently very limited. **Some of our greatest challenges in achieving these aims are to determine i) which fungi actually occur in Scotland and ii) how these sensitive organisms may be responding to changing environmental conditions, including elevated nitrogen deposition.**

Approach

We have been using traditional and state of the art molecular approaches to address these questions for ectomycorrhizal fungi in native Scots pine woodlands. Root samples have been collected from 15 semi-natural Scots pine stands across Scotland (Figure 1). The DNA from the mycorrhizal fungi on the roots has been extracted and representative regions, Barcodes, have been sequenced to identify which fungi are present. This is done by comparison with a reference dataset. Fruit body occurrence data from pine were also retrieved from the Fungal Records Data Base of Britain and Ireland and above ground surveys of fungal fruiting bodies were carried out.

Results

- Around 460 species of ECM fungi associate with Scots pine in Scotland, but new species are continually being found (Figure 2: *Cortinarius paragaudis*, new to the UK in 2012).
- Fungal communities are strongly influenced by the strong climatic gradients across Scotland with both rainfall and temperature having significant impacts on the abundance of species (Figure 1).
- Analysis of pines on altitudinal gradients demonstrated that species richness of ECM fungal does not decline with altitude but community composition was strongly influenced by changes in soil moisture and temperature.
- Little evidence was found to support any negative impact of nitrogen deposition on ECM fungi.
- The use of species specific molecular markers to detect the soil mycelium of ECM species found that some BAP fungal species may be much more widespread below ground than indicated by the appearance of fruit bodies.

Conclusions

The finding that fungal communities are structured by rainfall and temperature is the first evidence to suggest that the distribution of ECM fungi in Scotland is likely to alter as the climate changes. This could potentially impact patterns of nutrient cycling as these fungi are known to be functionally very diverse. However, all the communities examined were species rich and diverse suggesting that even changing one community for another would have limited impact on tree nutrition. There are many more fungal species present in our woodlands than previously thought – including many species new to science. In addition to understanding the functional changes driven by changing fungal communities, there is a clear need for a reference DNA dataset based on Scottish material for fungal species identification, and a need to develop sampling protocols for detecting rare and endangered species. Future investment in these mycological tools, will ensure that they continue to deliver their beneficial ecosystem services.

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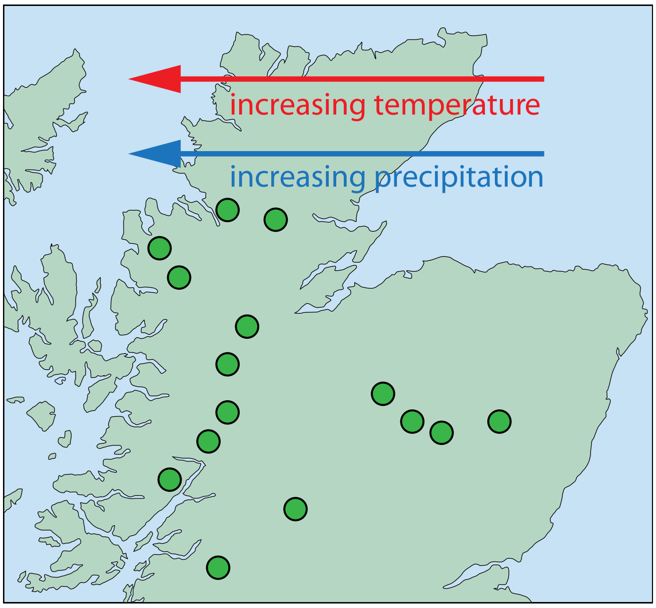
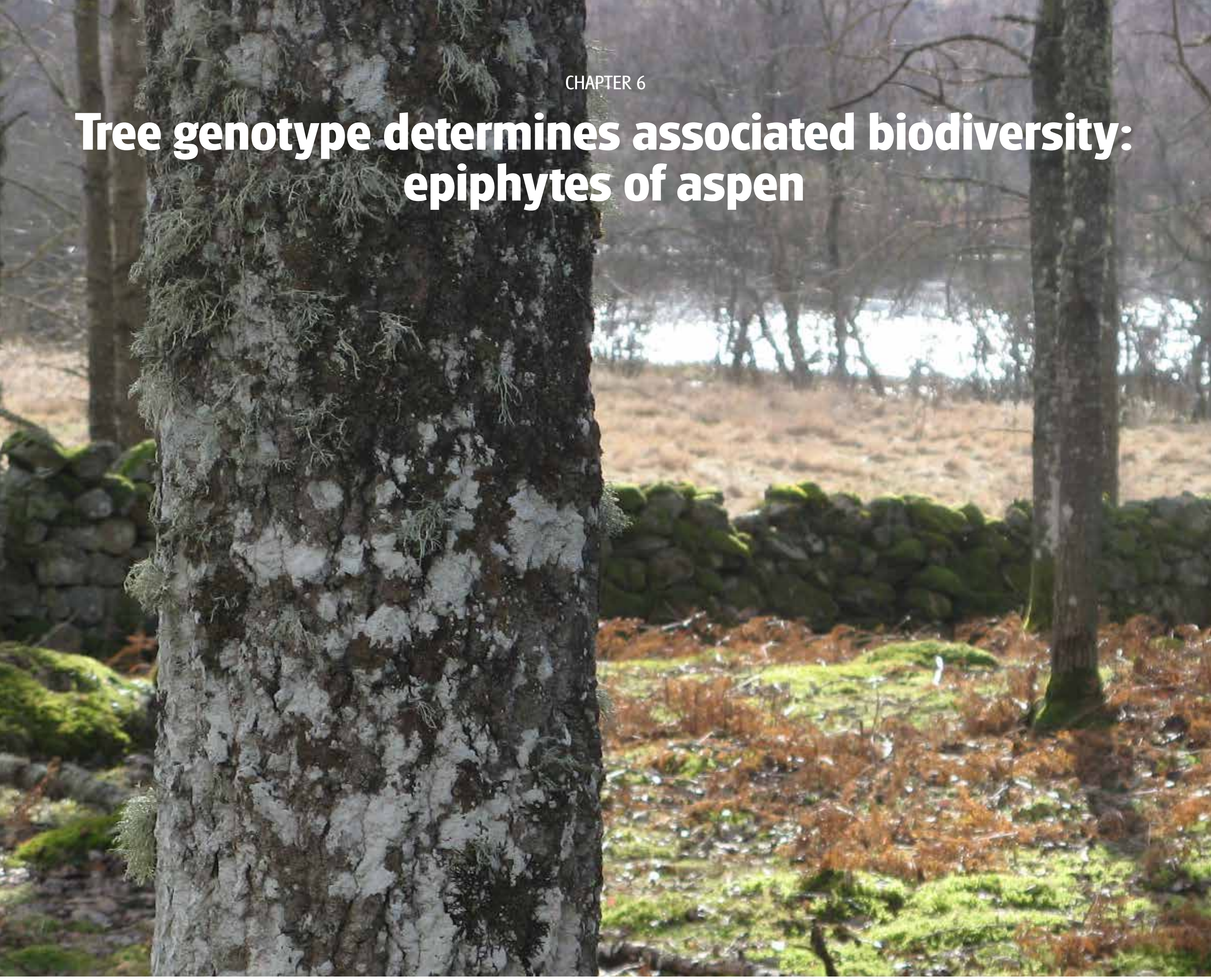


Figure 1. Location of root samples collected across Scotland.

Figure 2. *Cortinarius paragaudis*.



CHAPTER 6

Tree genotype determines associated biodiversity: epiphytes of aspen

Background and Aims

Foundation species define and structure ecosystems through their influences on associated organisms and ecosystem processes. This is particularly true of tree species, which shape the associated biodiversity and ecosystem function of forests and woodlands. Many of the characteristics of trees that influence other organisms are genetically determined, and vary between genotypes and individuals within a species which because of their longevity can influence their local environment over a very long time period. Aspen (*Populus tremula*) in the UK is a fairly widespread but scarce tree species with a fragmented distribution. It has a low frequency of sexual reproduction, but reproduces by prolific suckering, resulting in clumps of trees which may consist of a single or very few clones. In general, there is potential to increase the biodiversity gain or to manipulate the ecosystem function in an area by careful choice of the tree genotypes that we plant. The effect of these decisions could be realised under the increased rates of planting targeted by the Scottish Forestry Strategy (2006) and its implementation plans. Aspen is a foundation species which has numerous specialist insects and >300 species of lichen associated with it in Scotland. It inhabits a broad range of environmental conditions, and we would also expect any differences in biodiversity associated with particular clones to vary with local environmental conditions. **We therefore asked whether structure and biodiversity of the aspen epiphyte assemblage is influenced by the identity of the clone or by local environmental conditions, and which is the most important influence?**

Approach

We measured the epiphyte community on the trunk of aspen in a 15 year old 'common garden' trial established and maintained by Forest Research, comprising replicated and stratified planted clones drawn from 27 source populations around Scotland. The experiment was established near Forres, Moray (cool and dry climate) and near Kilmichael, Argyll (mild and wet climate). The cover of each of the epiphytes (26 species in total) was measured on five (5cm x 25cm) transects on N, S, E & W of each stem of four ramets/clone in each of four (Kilmichael) or five (Moray) randomised blocks. Epiphyte community parameters were calculated (species richness, Shannon species diversity index and %cover), and the community composition was described by detrended correspondence analysis (DCA) scores on two axes, and the difference in scores between clones and the two sites were analysed with analysis of variance.

Results

- Both clone and site explained variation in the epiphyte community parameters, including the community composition (Table 1).
- DCA axis 1 represented a community composition descriptor that varied strongly between sites whereas relatively more of the variation in DCA axis 2 scores was explained by differences among clones (Figure 1).
- The site x clone interaction effects show that the clone-specific characteristics of the epiphyte communities vary between sites.
- The results confirmed that aspect was a key determinant of the characteristics of the epiphyte community on aspen (Table 1).

	Species richness	Shannon index	% Cover	Community composition	
				DCA1	DCA2
Clone	***	***	***	*	***
Site	**	*	NS	***	***
Site x Clone	***	***	***	*	NS
Aspect	***	***	***	-	-

Table 1. The results of the statistical analyses of epiphyte community characteristics in relation to aspen clone, site and aspect. *, ** and * represent statistical probabilities of <0.05. <0.01 and <0.001 respectively. NS: Not significant.**

Figure 2 (right). Aspen common garden experiment.

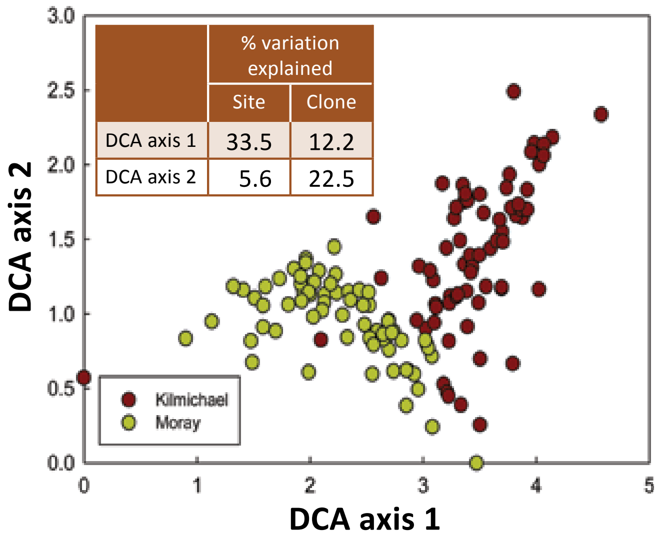


Figure 1. Plots of two DCA descriptors of the epiphyte community composition on the same aspen clones at two sites (Kilmichael and Moray). The table insert shows the percentage of variation in the DCA scores on each axis explained by Site and Clone.

Conclusions

The epiphyte communities associated with aspen are very species-rich, and their species richness, diversity, cover and composition vary between Aspen clones from different origin. This indicates that it is possible to select aspen clones for planting that will maximise the biodiversity of future colonising epiphyte communities. This would represent an innovative use of foundation species for the conservation of biodiversity. Different sites have different characteristic epiphyte communities, presumably due to the different pools of species that favour the conditions at that site, but the relative importance of the effects of site and clone, depend on which parameter is being assessed. The site x clone interaction effects suggest that if planting aspen clones for the future generation of epiphyte biodiversity is a consideration, then different clones are suited to different conditions and should be chosen accordingly.

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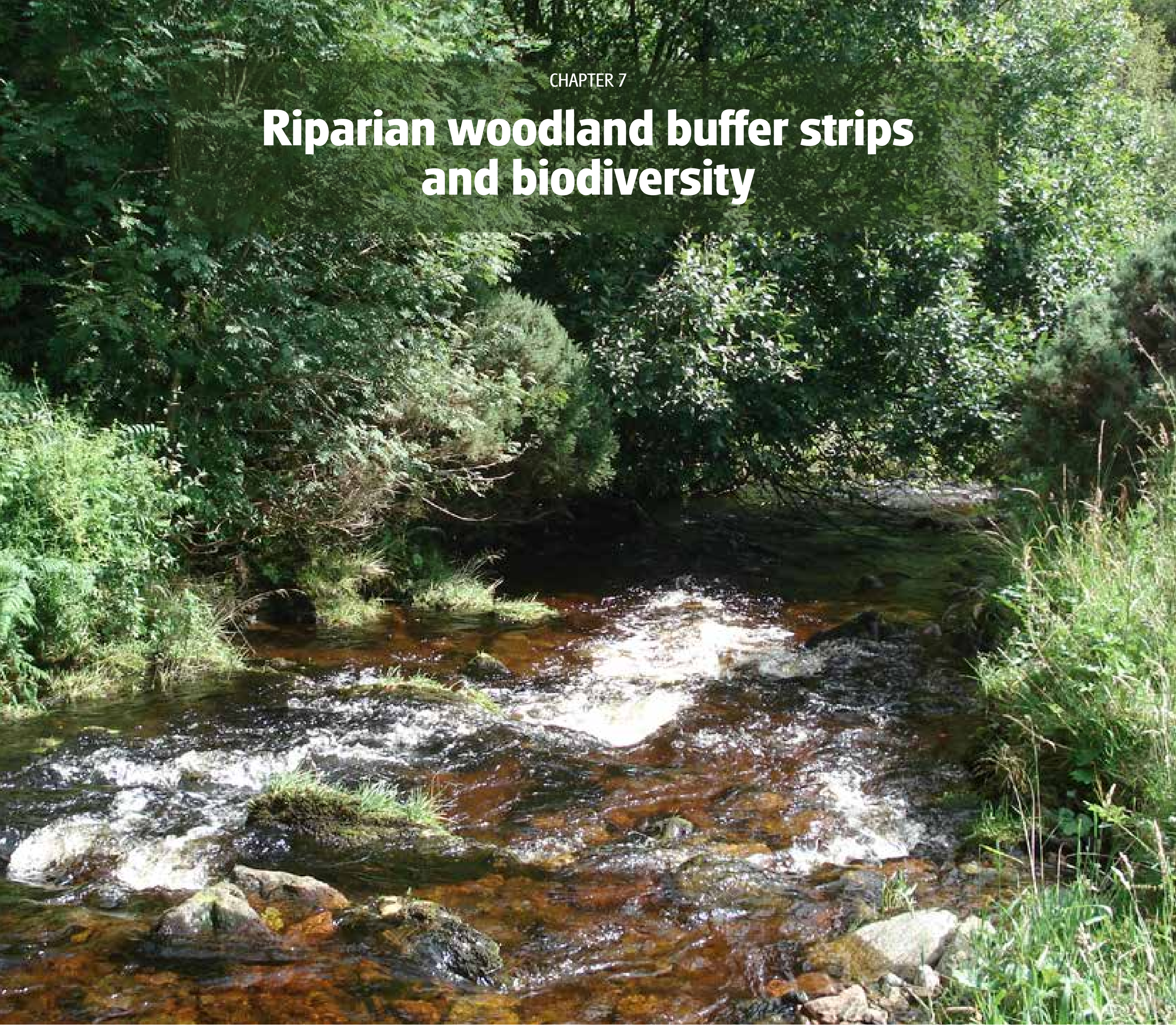

CHAPTER 7

Riparian woodland buffer strips and biodiversity

Background and Aims

The widespread management practice of creating fenced-off buffer strips along rivers and streams, which aims to improve water quality, is likely to have important impacts on riparian biodiversity. One long-term vision is to create riparian woodland either naturally through successional processes, or by planting trees. Wooded margins are likely to provide a number of functions over and above vegetated margins such as increased water holding capacity, shading, and nutrient inputs to the stream ecosystem. However, the effects of buffer strips on biodiversity have yet to be rigorously tested. This is an essential step before they can be generalised and used to generate predictions of biodiversity consequences of management actions to be incorporated into environmental audits and traded off against their other benefits and dis-benefits. Early on in this project we established that fenced-off buffer strips, regardless of their vegetation, are associated with a decline in terrestial taxonomic diversity. **The aim of this part of the study was to investigate what effects vegetated and wooded riparian buffer strips might have on functional diversity.**

Approach

Indices of functional diversity can provide a useful approach to the integration of biodiversity into the broader context of ecosystem processes and functioning. Functional diversity indices consider the abundance and variety of traits which species posess, and therefore the different functional roles they fulfil. We compared these indices for ground beetles (Coleoptera, Carabidae) in three types of riparian margin (unbuffered, vegetated buffered and wooded buffered) across two river catchments in north east Scotland; the Tarland Burn and River Ugie.

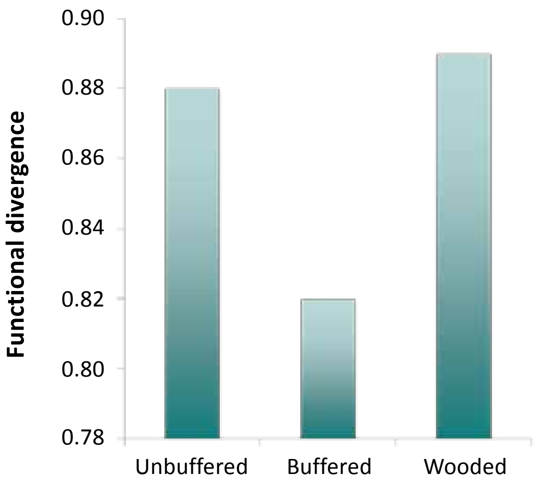

Figure 1. Effect of margin type on functional diversity (divergence). ANOVA F=3.60, P<0.05.

Results

- Wooded margins possessed higher numbers of beetles which were autumn breeding with overwintering larvae, with wider distributions, larger body size and long leg forms.
- Functional diversity (functional divergence) was significantly lower in vegetated buffered margins (Figure 1).
- Community weighted-mean traits differed only between wooded margins and other categories of margins.
- Buffer strip width and age, together with soil and vegetation variables were identified as determinants of trait assemblage structure but there was a strong suggestion that the beetles were responding to soil parameters more than management variables.

Conclusion

Beetle traits associated with wooded margins differ from those of riparian specialists and indicate more stable and undisturbed habitats. Wooded margins help to preserve higher functional diversity than is found in non-wooded buffer strips. Soil was more influential than management in predicting patterns of beetle traits, though buffer strip characteristics, width and age remain important. The narrow, linear nature of riparian habitats may mean they are disproportionately affected by surrounding land use and conditions. Our recommendation is to maintain a mosaic of different successional stages across catchments to help to conserve functional diversity at a landscape scale. This will promote large-scale and long-term ecosystem processes.

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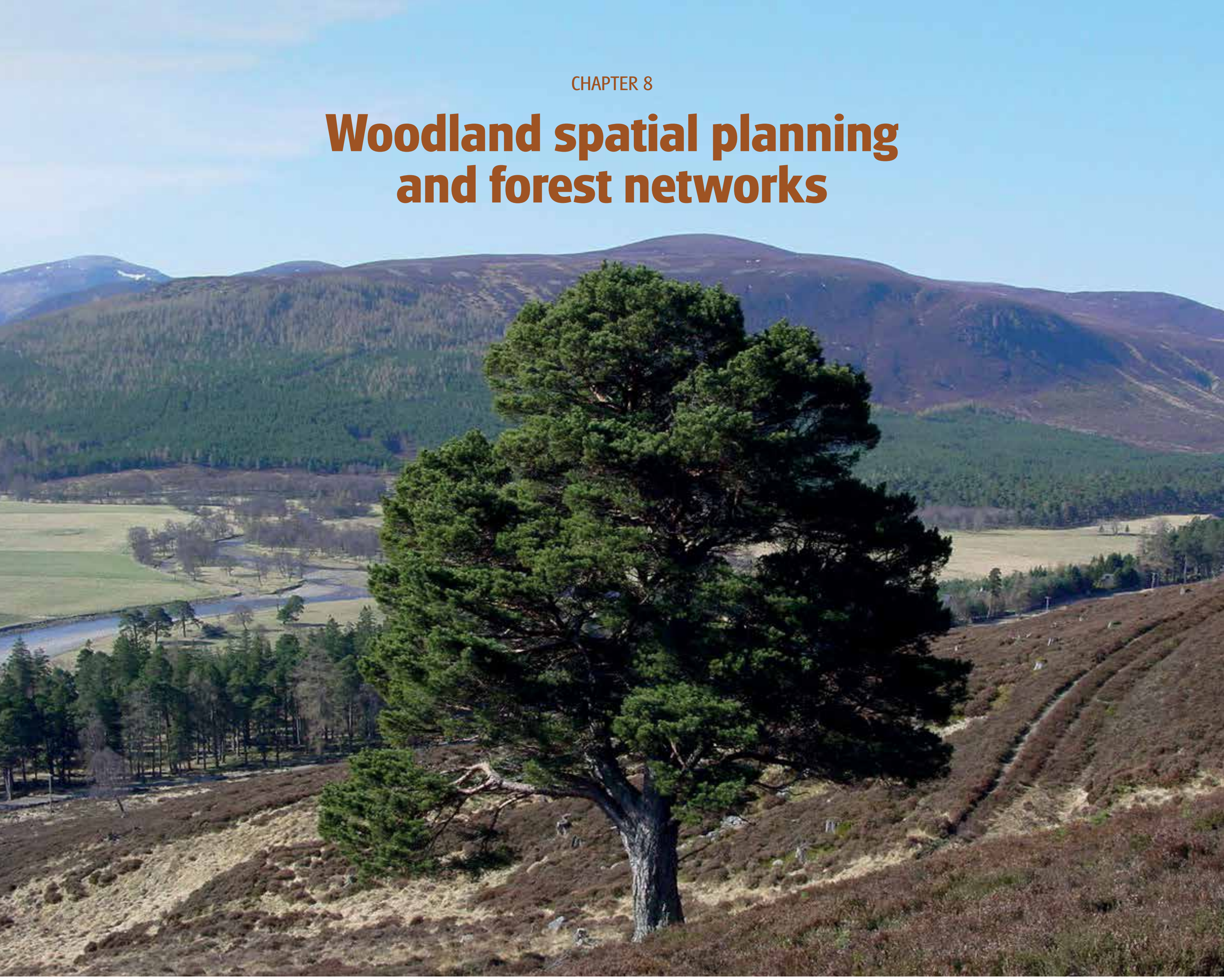
CHAPTER 8

Woodland spatial planning and forest networks



Background and Aims

Landscape adaptation to climate change requires policies that facilitate species dispersal, to counteract the effects of fragmentation and allow tracking of a species' 'climatic niche'. Expanding existing ecological networks is often proposed as a means to maintain functional connectivity for forest species in multi-functional landscapes.

In the next decades, habitat networks and the ability of species to disperse in the landscape are likely to be influenced by climate change. This is not only because of direct effects of climate on their ecology, but also through its indirect effects on land use change. Inter-connected global drivers including climatic, economic and social factors are therefore likely to have an increasing influence on national land use policy.

We aim to evaluate the indirect effects of climate change on habitat networks, mediated by land use change.

Approach

We integrated climate change projections, soil properties, and landscape resistance to species dispersal, to map pathways of dispersal at the national scale. We then used two preliminary but realistic scenarios of land use change to evaluate the vulnerability of broadleaved forest habitat networks and dispersal pathways. The first scenario (Figure1b) refers to expansion of intensive agriculture on future rain-fed prime agricultural land. The second refers to a case where additional land can become 'prime' if irrigated (Figure 1c).

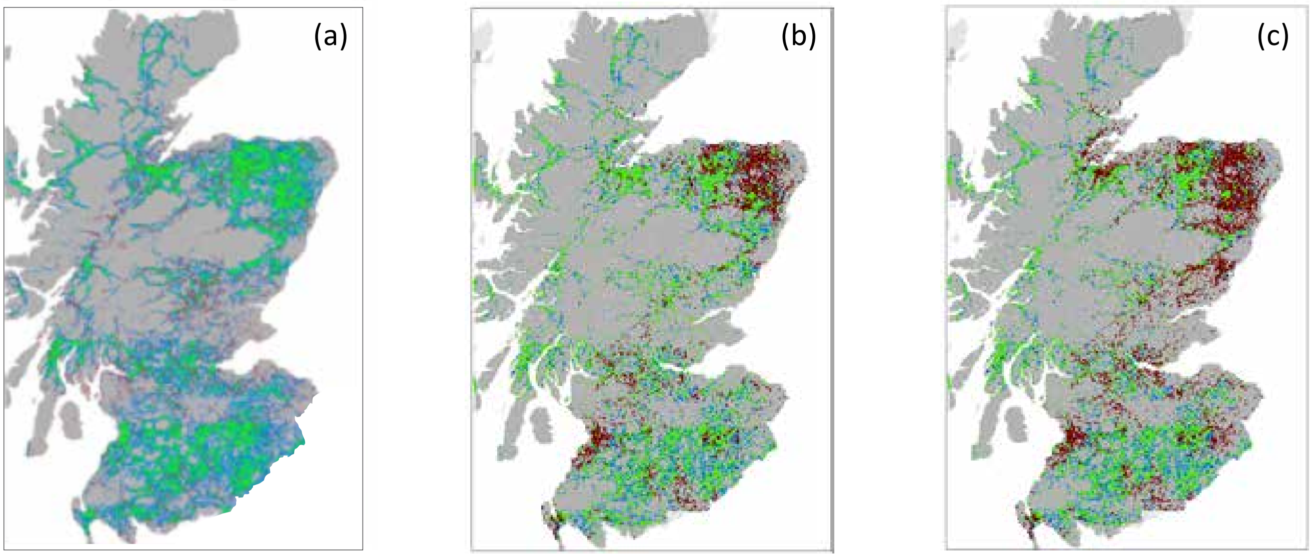


Figure 1. Principal dispersal pathways for a generic woodland species a) at present, and possible future scenarios with an increased cover of prime arable land (shown in brown) which is b) rain-fed and c) with irrigation available. Dispersal pathways are in green and blue (with green more used than blue).

Results

- In Scotland, especially in the East and South, a combination of high international food prices, the imperative for 'food security', and improved land capability for agriculture, could lead to expansion of arable land, loss of woodland cover and therefore to decreased landscape connectivity for woodland species (Figure 1).
- Scenario-based work on the Dee catchment shows the implications of increased forest cover for an ecosystem service. As forest cover increases, so the losses of nitrogen from the terrestrial to the aquatic system are diminished (Figure 2).
- Striking a balance depends also on what accounting framework is adopted. The expansion of prime agricultural land would clearly have positive effects on agricultural production, but also negative impacts on water quality and soil carbon content, and could partly be mitigated through effective buffering of water courses.

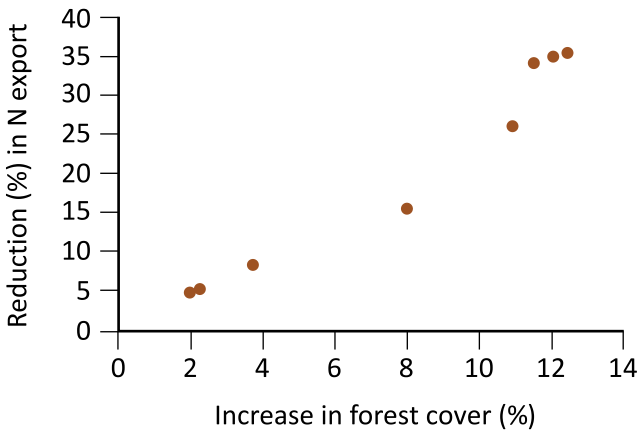


Figure 2. The reduction in Nitrogen exported from the terrestrial to the aquatic system was greater as forest cover in a catchment increased.

Conclusions

Planning of ecological networks needs to account for future potential land use change, while adaptation and mitigation strategies across multiple sectors needs to be reconciled. Landscape connectivity and biodiversity would benefit from the protection of existing semi-natural woodland patches, and the creation of wide-scale dispersal pathways and 'stepping stones' along climatic gradients, (i.e. in the N–S and E–W directions). This could be achieved through the strategic planting of native species and local de-intensification of land use to create pathways.

Policy that favours woodland networks has to balance minimising the creation of new woodlands on future prime agricultural land, with the promotion of landscape connectivity, carbon sinks, and mitigation of nutrients and sediment exports.

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CHAPTER 9

The role of woodlands in meeting Scotland's greenhouse gas emission reduction targets

Background and Aims

The Scottish Government has set itself the aspiration of planting 10,000 ha per year in trees to achieve an increase of 100,000 ha forest cover by 2022 to contribute to meeting net greenhouse gas (GHG) emission reduction targets. The Woodland Expansion Advisory Group (WEAG) was tasked to initiate this work and its Final Report in June 2012 and subsequent discussions with Forestry Commission Scotland identified several research needs.
These included:

(i) identifying what types of land use conversion to different types of woodland are beneficial for reducing net GHG emissions, and
(ii) assessing the impact of woodland expansion on agricultural production, rural livelihoods, and other ecosystem services.

Approach

The project uses complementary approaches: i) literature reviews, ii) modelling GHG emissions and carbon (C) sequestration following land use change to woodland under various scenarios using the ECOSSE soil C model, iii) comparing economic costs and returns of current land uses with those of planting trees under different scenarios, and iv) qualitatively analysing the impact of land use change to woodland on a range of ecosystem services. The potential of agroforestry as an option is also considered.

Results

Preliminary results include the following:

- A review of literature indicated that growing conifer forests, especially in peaty soils and in their first rotation, can decrease soil C stocks by as much as 30%. Following afforestation of unplanted natural grassland with Sitka spruce on a peaty gley soil at Harwood Forest, total C stocks declined significantly during the first 40 year rotation, but then increased to near the unplanted grassland level by the end of the second rotation due to the incorporation of brash during clear felling.
- Although there are few definitive data, afforestation of mineral soils may be expected to lead to long-term increases in soil C, with typical rates of between 0.5–1.7 tCO2 ha^{-1} y^{-1}. For soils with high organic content, such as peaty gleys, evidence from past afforestation suggests that there were substantial soil C losses during the first rotation after afforestation, approximately 5–15 tCO2 ha^{-1} y^{-1}, but then subsequent increases in soil C stock.

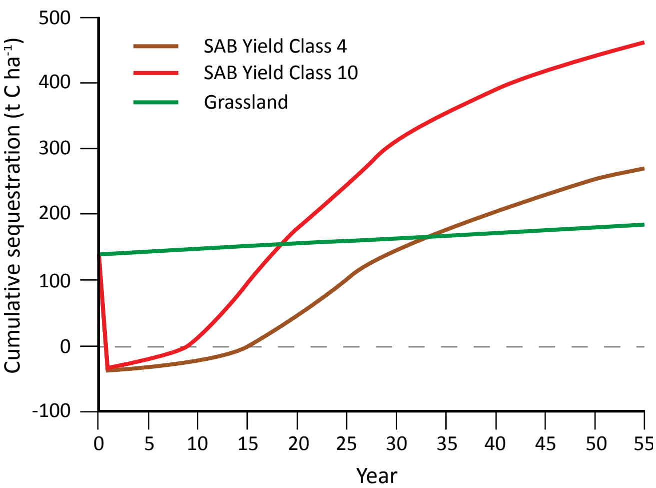

Figure 1. The cumulative carbon sequestration potential of undisturbed improved grassland and conversion of that grassland into two sycamore agroforestry options at different levels of site productivity. Positive values represent a net gain of carbon by the ecosystem, while negative values indicate a net loss. (SAB = Sycamore, Ash and Birch).

- Silvopastoral agroforestry systems have a significant potential in Scotland to contribute to sequestering C as well as maintaining agricultural productivity. Simulations showed that net C sequestration occurs 10-16 years after conversation of pasture to such agroforestry systems (Figure 1). However, changes in the incentive system will be required to encourage uptake of silvopastoral agroforestry.
- There may be a need in the longer term to consider more formal rewards for C-sequestration, backed by some kind of penalty system for heavy C-emitting land uses, ideally associated with tradable emissions reduction to ensure that it takes place in the most cost-effective way.
- Substantial areas of lightly grazed or ungrazed upland on mineral soils, could be afforested at very low opportunity cost in terms of farm output because of minimal stocking, but under current subsidy regimes (e.g. Least Favoured Areas Support Scheme) payments are lost, which militates against farmer engagement with tree planting.

Conclusions

The outputs of the project should help policy makers make more informed decisions on where and how trees should be planted to help meet emission reduction targets, what types of trees should be planted, and the types of incentives that might be required to ensure increased rates of planting by land owners. They will also quantify the net C-benefits of different planting scenarios. There are clearly some areas where additional afforestation would be beneficial in terms of carbon sequestration (above and below ground) and there may be further benefits arising in terms of wood energy substituting for fossil fuels used for space heating.

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CHAPTER 10

Integrating farming and forestry

Background and Aims

Forest and woodland planting is a major policy objective in Scotland, driven primarily by climate change policy objectives but also influenced by biodiversity, landscape and rural development policies. Extending forest and woodland cover has proved problematic, with planting levels falling a long way short of the Scottish Government's aspirations. As those responsible for the dominant land use activity in Scotland, farmers have a key role to play in increasing woodland cover but many farmers have rather negative views of forestry. Some consider that the economics of forestry is a reason for low planting rates; others that attitudinal barriers are the cause. New woodland provides both enterprise and habitat diversification, although the value of habitats created depends *inter alia* on species selection, management regime and connectivity to adjacent woodland. **We explore, through good practice examples, how forest and woodland could be better integrated into farming enterprises and what have been the economic impacts on farm profits. This required examination of motives for planting woodland, amongst which environmental services provided by trees were important. The wider aim of this research was to encourage more farmers to consider planting trees.**

Approach

We interviewed farmers across Scotland who had recently planted farm woodlands to gain a better understanding of their motives for so doing and the impact on farm profits. In association with the Forestry Commission, we identified four types of farm woodland which the case studies should embrace:

1. Production forestry

2. Conservation forestry

3. Agroforestry

4. Shelter belts

Following a case study approach farmers were interviewed either on site or by phone and results were collated. Two-page profiles were written up for each farm.

Results

- Only a minority of farmers are highly motivated by tree planting and woodland management. Motives vary from profit-making management of woodland, to the pursuit of carbon neutrality in land use, biodiversity enhancement of holdings, and most importantly, the enhancement of amenity (for landscape, biodiversity and game). This was often seen by farmers as cost neutral in that it could increase the capital value of their holding.
- Policy structures were seen as less than helpful in that the loss of the Less Favoured Area Support Scheme meant that the forestry grants needed to 'trump' the other policy support. Agroforestry developments have often proved problematic because of losses of farm subsidy. Farmers were concerned about the possible loss of Single Farm Payment in the longer term. Rewarding farmers for carbon sequestration might provide a major future incentive for tree planting.
- Shelter is highly valued by livestock farmers and cropping farmers in exposed locations, but is rarely if ever explicitly valued in monetary terms. Some farmers are also making use of wood pasture systems to provide both wood and livestock outputs from the same area of land. Wood pasture is also often highly valued for biodiversity.
- Some farm woodland has been highly profitable especially where there has been Challenge Fund support for production woodland. Native pinewood planting on poor upland ground has often been more than justified by the grant aid received. The Renewable Heat Incentive is a possible 'game changer', with farmers reporting very short payoff periods for biomass boilers, especially in association with grain drying.

Conclusions

Good practice examples illustrating the woodland planting activities of respected peers in the farming community are more likely to encourage tree planting than hectoring by politicians or foresters. The range of examples investigated in these case studies shows that farmers are motivated differently: for some, profit has been the main driver; in other cases amenity enhancement has been the dominant motive. Mostly poorer farmland has been taken out of production, which has often replaced one extensive land use with another. Overall, profitability impacts vary from positive to neutral. Although landscape and biodiversity factors were not always the main drivers for planting woodland, environmental benefits often accrued, with levels contingent on the type of woodlands and their connectivity.

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The funders were: Forestry Commission Scotland.

This booklet summarises some recent research concerning woodland biodiversity and its relationship with ecosystem function and services. It was undertaken as part of, or under other funded contracts facilitated by the Environmental Change Programme of the Scottish Government's Rural and Environment Science and Analytical Services Division's (RESAS) Portfolio of Strategic Research (2011-16).

This synthesis focuses on a subset of the work on woodland biodiversity and involved researchers from:

The James Hutton Institute

Royal Botanic Garden Edinburgh

Also in collaboration with:

Biomathematics and Statistics Scotland

Forest Research

University of Aberdeen

University of Edinburgh

The Royal Society for the Protection of Birds

and independent experts:

Nick Hodgetts (Independent bryologist)

Roger Polson (Knock Farm, Huntly)

Further information can be found at

www.scotland.gov.uk/Topics/Research/About/EBAR/StrategicResearch/future-research-strategy

www.climatexchange.org.uk

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