Woodland Biodiversity

A summary of research outputs from the Scottish Government's "Environment – Land Use and Rural Stewardship" research programme

Contents

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Introduction

Scotland's relatively treeless landscape was formerly more heavily wooded, with many of the woodlands having been fragmented or removed in relatively recent times to facilitate grazing livestock. We are currently reversing this trend and are poised to accelerate natural regeneration and planting of new woodlands, under the Scottish Government's target to increase woodland cover from 17% of the land area to 25% by 2050. It is aimed for native species to comprise 35% of the woodlands. A main driver of this move towards increased woodland cover is the aim to increase sequestration of atmospheric carbon in order to ameliorate climate change[1]. New woodlands can also form an integral component of an ecosystem approach to sustainable management of water and soil resources, as well as delivery of wood products, landscape enhancement, and community, recreational, wildlife and tourism benefits. Our conservation obligations for native woodlands derive from Annex 1 of the EC Habitats Directive (Scots pine) and the UK Biodiversity Action Plan in which several other woodland types, including upland birch and oak woods, are Priority Habitats. Here we introduce some of the components of the Scottish Government's "Environment – Land Use and Rural Stewardship" research programme relating to Woodland Biodiversity, and describe some recently emerging results.

In our current position, at the cusp of a rapid expansion of woodland regeneration and planting, it is important to be able to maximise the biodiversity and other benefits and services obtainable from this investment. The chapters presented here span a wide range of ecological levels from the autecology of single woodland species through to community diversity and processes of successional vegetation change, ecosystem function, large scale landscape and genetic variation across Scotland.

Innovative molecular techniques have been developed and applied as conservation tools to study genetic variation in woodland herbs and a dominant tree species. There can be large knock-on effects for other organisms of the characteristics and responses to environmental change of some dominant or foundation species, and their diseases. For example the chemical variation among individual Scots pine trees is a determinant of crown invertebrate populations and their exploitation by wood ants, which are themselves ecosystem engineers. The colonisation of moorland by birch represents a natural woodland expansion which influences the biodiversity and function of all other components of the system, and this process is sensitive to both the intensity and seasonal timing of browsing by large herbivores which we simulated in a long-term experiment. This is highly relevant given the reductions in grazing livestock now occurring in the uplands under current agri-environmental policies. Similarly, the large populations of sheep ticks in woodlands, and their positive response to current climate change has strong implications for the interactions between host animal populations (including man) and tick-borne disease.

Our woodland research also guides us in planning future woodlands for different biodiversity and landscape goals. Here we provide strategic management advice for re-establishment of communities of epiphytic lichens, which are a determinant of Scotland's status as an international biodiversity hot-spot for crypotogamic plants. A mapping approach for spatial woodland planning at the landscape scale is based on maximising a range of benefits from multi-functional woodlands, and the basis of zones for seed collection from Scots pine, to maintain local genetic conservation, is revisited.

These scientific contributions will not only progress our understanding but will also help us to enjoy and benefit in many other ways from our future woodlands.

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[1]Scotland's Climate Change Adaptation Framework (2009)

Cover photos: Joan Beaton

Clonal diversity and distribution of *Pyrola media* in Scotland

Background

Intermediate wintergereen (*Pyrola media*) is an evergreen perennial herb which occurs in heathlands and woodlands in Scotland. It has shown a marked decline in recent decades, leading to its inclusion in Scottish Natural Heritage's 'Species Action Framework'.

However, establishing its current conservation status is hampered by two key factors. Firstly, when not in flower *Pyrola media* is difficult to distinguish from the closely related species *Pyrola minor* (Common wintergreen) (Photo 1).

Photo 1: Pyrola media (left) and Pyrola minor (right) [Photos Jane Squirrell]

Photo 2: A patch of Pyrola. How many genetically distinct individuals? [Photo Jane Squirrell]

This is a common problem as failure to flower is a frequent occurrence. Secondly, as these species occur in patches (rather than as individual plants) it is difficult to know exactly how many genetically distinct individuals and are present (Photo 2). ***To clarify the distribution and abundance of* Pyrola media *we have used genetic tools to (a) assess the extent of clonal growth (b) to distinguish between* Pyrola media *and* Pyrola minor.**

Approach

Assessments of clonal diversity of the two *Pyrola* species were undertaken using two different DNA fingerprinting techniques (amplified fragment length polymorphisms (AFLPs) and Simple Sequence Repeats (SSRs)). If clonal growth is the sole means of reproduction, all individual plants in a given place should have identical DNA profiles. If there is no clonal growth, all individuals should have distinct DNA profiles. To develop a diagnostic assay to distinguish *Pyrola media* from *Pyrola minor*, we examined the DNA sequence of several DNA regions using well identified reference material of either species. We searched for DNA differences which could tell the two species apart, and which would also enable us to develop a simple test for screening on larger sample sizes.

Results

Clonal diversity:

- Clonal diversity differed among patches: the largest clone occupied approximately 20m^2. More commonly patches this size consist of 2–3 clones, and even small patches (e.g. 1m x 1m) may contain multiple clones.
- Similar patterns of clonal diversity were detected in Pyrola minor.

Distinguishing between species:

- In the region of the Internal Transcribed Spacers of nuclear ribosomal DNA (nrITS), we detected consistent DNA sequence differences between *Pyrola media* and *P. minor*.
- These differences enabled the design of a simple assay in which we fragmented the DNA region to give a diagnostic 'banding pattern' (Photo 3).

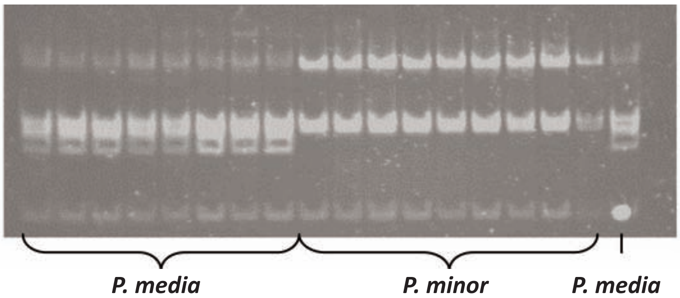

Photo 3: DNA based-assay which distinguishes Pyrola media from *Pyrola minor*. Each 'column' represents a different sampled individual. All individuals of *Pryola media* have one type of banding pattern, all individuals of *Pryola minor* have another

- This cost- and time-effective assay was then used to obtain identifications for samples of unknown identity (e.g. non-flowering individuals).

Conclusions

Clonal growth is important, but not the sole means of local reproduction for this species. Adjacent plants often represent genetically different individual but seed production and recruitment is also important for this species.

The development of a simple diagnostic assay has enabled us to clarify the fine scale distribution of *Pyrola media* by establishing which non-flowering patches belong to this species, and which belong to the more common *Pyrola minor*. This enhanced understanding of the species distribution and genetic structure makes it more straightforward to assess conservation threats and design conservation strategies.

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Conserving Woodland Biodiversity in a Changing World – Lichen Epiphytes

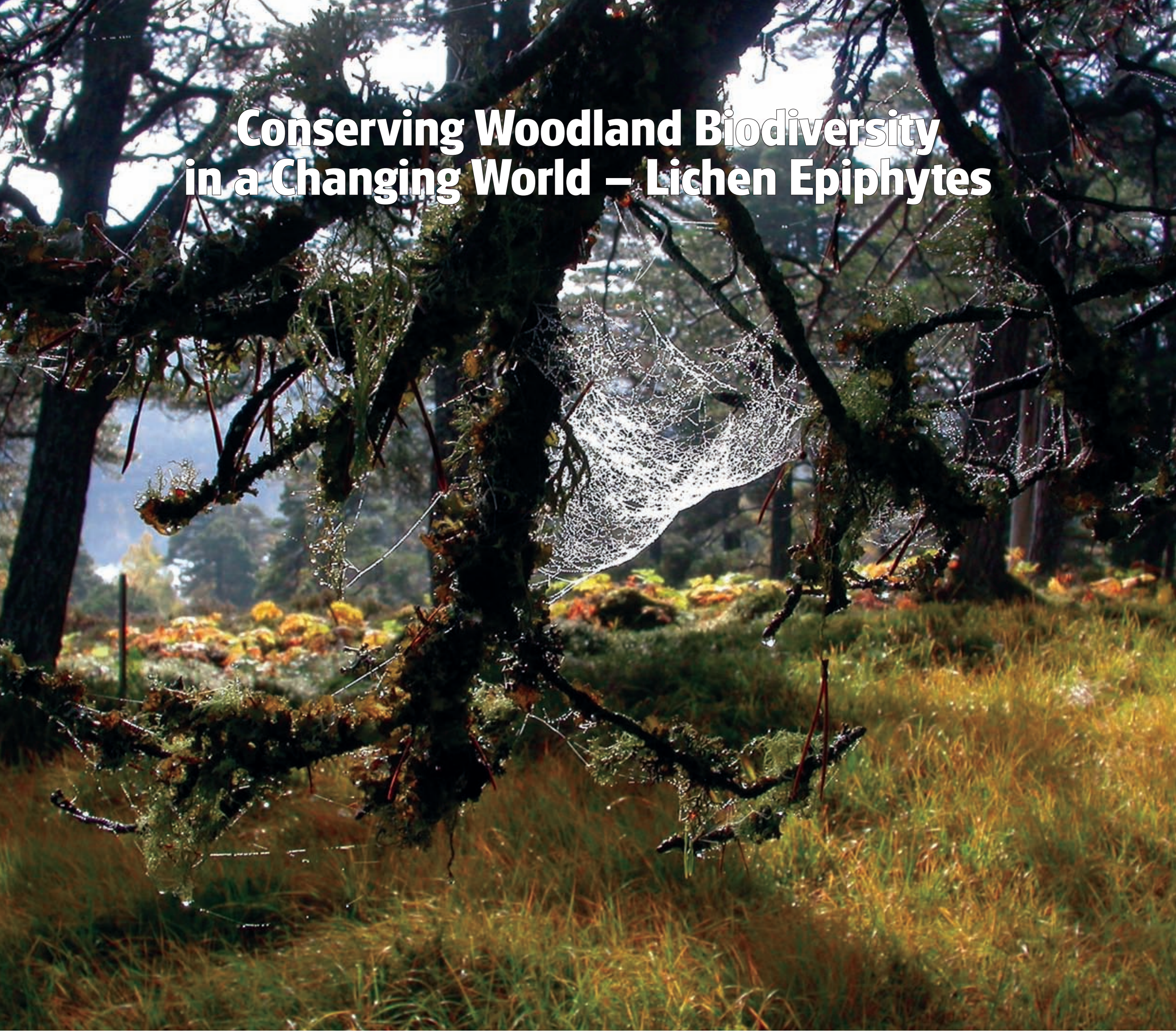

Photo 1: A single pine twig laden with epiphytic lichens

Background

Scotland has world-renowned epiphyte communities, especially those characterising the 'Celtic Rainforest' of the Scottish west coast (Photos 1 & 2). In Scottish woodland, the species richness of lichen epiphytes (hundreds of species) may be an order of magnitude higher than the trees on which they grow (5–10 species). The microhabitat provided by epiphytes has important consequences across the forest food-web: e.g. increasing the biomass and diversity of invertebrates. However, this diversity hangs in the balance. Lichen epiphytes have been impacted by deforestation in Scotland, and more recently, through intensification of woodland management. Additionally, lichen epiphytes are extremely sensitive to long-range air pollutants, are responding to global warming, and have been developed as high resolution bioindicators for woodland ecosystem structure and biodiversity.

The conflicting demands we place on Scotland's landscapes, coupled with large-scale emerging threats such as climate change and transboundary pollution, mean that we require a conservation strategy that is adaptive at a local scale in order to counter these large-scale threats. ***RBGE research uses epiphytes as a model system, demonstrating how local woodland management might offset the negative effect of climate change on biodiversity.***

Photos: Chris Ellis

Photo 2: *Sphaerophorus globosus* – a fruticose lichen which occurs on old trees along Scotland's west coast

Approach

Our inventory work generated field-sampled species lists for habitats of high conservation status, focussing on Scotland's native aspen stands (*Populus tremula* L.) and juniper scrub (*Juniperus communis* L.). These data were supplemented by c. 250,000 geolocated lichen records, edited by RBGE staff, and uploaded onto the National Biodiversity Network (www.nbn.org.uk).

Scotland's Extinction Debt

- Lichen species richness sampled from the modern landscape was explained by 19th century woodland extent and fragmentation, and not by the present-day extent and fragmentation of woodland.
- Therefore the impact of 20th century forest management is not yet expressed by current lichen communities.

It may be a mistake to conserve areas of high species richness by assuming that current conditions (extent and isolation of woodland) provide adequate protection. Rather, we should target reforestation of native trees in buffer zones around species-rich woodland remnants, in order to secure their future lichen biodiversity.

Cross-Scale Interactions and Biodiversity Protection

- 'Habitat specificity' of lichen epiphytes changes along climatic gradients.
- Under *optimal* climatic conditions a suite of lichen epiphytes occur in a wide variety of woodland, whereas under sub-optimal climatic regimes, the same lichen epiphytes become more restricted in their occurrence e.g. only occurring in 'ancient' woodland.

Local woodland habitat might be managed to provide a small scale solution to offset large scale negative climate impacts: i.e. the possible shift with global warming from an *optimum* to a *sub-optimum* climate (Fig. 1). Our findings fully support a Government commitment to expansion of native woodlands. However, our work also indicates that in order to benefit epiphyte diversity, this process of forest regeneration cannot be *ad hoc*, and must be carefully targeted, by maximising habitat heterogeneity, as well as buffering existing sites with high species richness.

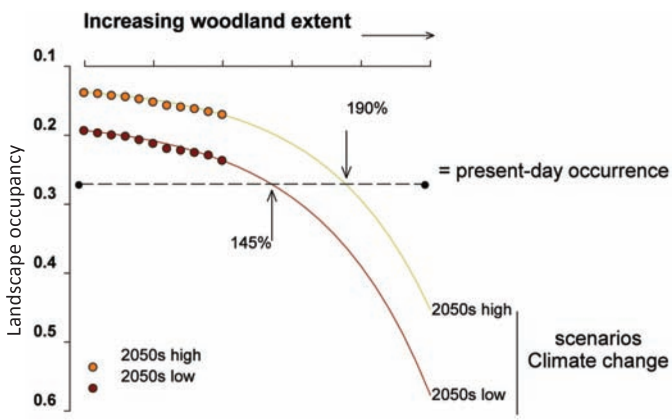

Fig. 1: Comparison of the occurrence of Scotland's oceanic epiphytes in the present-day landscape (horizontal dashed line) with their occurrence under two climate change scenarios (2050s high and low greenhouse gas emissions), though including the positive effects of increasing woodland cover (curved dotted lines). Where the lines intersect, increasing woodland cover offsets negative climate impacts, maintaining the occurrence of species. See Ellis et al. (2009) *Journal of Biogeography*, 36, 302-313.

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Wood ants and tree chemistry determine the population of crown invertebrates in Scots pine

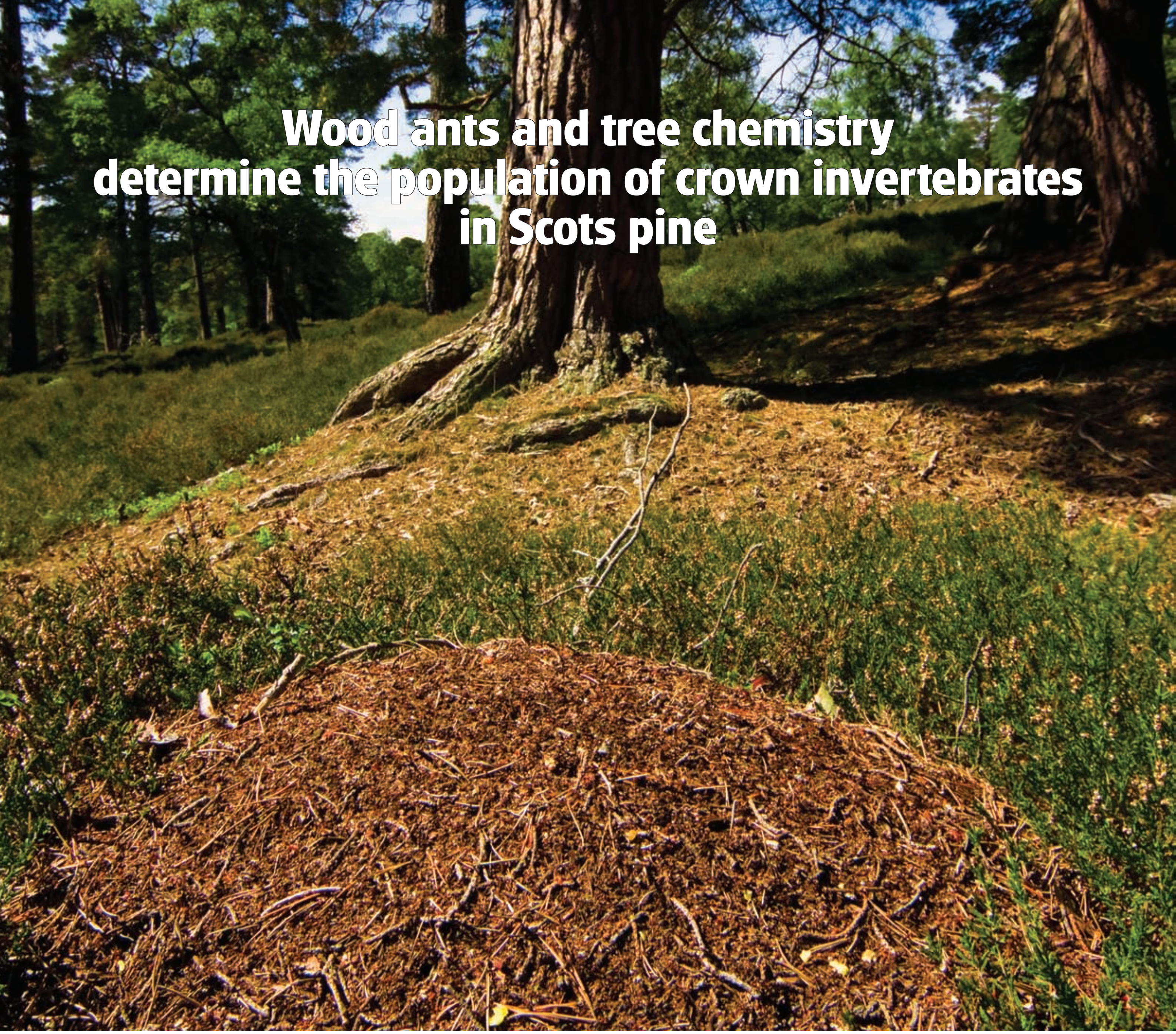

Photo 1: Ants have a large impact on the ecology of forest ecosystems

Background

Wood ants are an integral component of native boreal pinewoods (*Pinus syvlestris*). One of the most important and enduring interactions is between the wood ants and the trees themselves. Wood ants show strong allegiance to particular foraging routes into tree canopies, where they collect honeydew from tended aphids, and predate other invertebrates, including defoliators, as sources of protein. They thereby have a large impact on biodiversity. Tree choice by wood ants is not well understood. Within pinewoods, there is considerable genetically-based variation between individual trees including in the chemical composition of monoterpenes in particular: some trees contain δ^3-carene in their needles whilst other trees contain none. These volatile compounds give pine trees their characteristic smell and mediate its interactions with herbivorous invertebrates, which may influence the foraging potential of a particular tree for wood ants. ***We investigated whether there was any relationship between tree choice by wood ants and pine tree monoterpenes, and how these factors influenced the populations of crown invertebrates.***

Approach

The two true wood ant species occurring in Scotland are the Scottish wood ant, *Formica aquilonia*, and the hairy wood ant, *Formica lugubris*. The foraging behaviour of these two

Photos: Gabor Pozsgai

Photo 2 : The Scottish wood ant *Formica aquilonia*

ants was studied within Ballochbuie native pinewood in north-east Scotland. A large number of trees were analysed for their monoterpene composition and a representative sub-group of 45 were selected for further study of their ecology. Over two years these trees were visited monthly, and ant foraging activity monitored. Ant and non-ant trees were identified. The crown invertebrate community was quantified by experimentally enclosing branches in insect proof nets on trees used by ants as compared with trees not used by ants.

Ant foraging patterns

- 56% of our trees were foraged by ants.
- The average distance between nest and tree was 13m with a maximum of 44m.
- Average ant territory size was estimated to be 590m^2.
- Honeydew dominated the diet throughout the year constituting 94–99% of loads.
- Aphids, Diptera larvae, and Lepidoptera larvae dominated among prey items.
- Ants foraged more in trees with lower concentrations of the monoterpene δ^3-carene in their needles.
- Trees with zero δ^3-carene contain higher populations of crown (non-aphid) invertebrates than trees that contain δ^3-carene in their needles, but this effect is only evident when ants do not forage in the tree (Fig. 1).

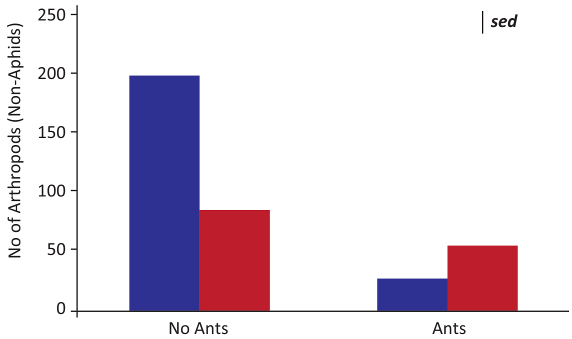

Fig. 1: The number on non-aphid arthropods on Scots pine trees in relation to whtehr the trees were foraged by ants, and whether the trees' needles contained δ3-carene (red bars) or no δ^3-carene (blue bars). SED : standard error of difference.

Conclusions

Ants have a profound influence on the invertebrate population of Scots pine trees and the influence of a single ant colony spreads widely within the forest. The size of crown invertebrate populations (of non-aphids) in Scots pine trees is greatest in trees containing no δ^3-carene, but the greater ant predation here leads to fewer invertebrates in these trees.
The contrasting positive effects of ants on aphid populations are being investigated. These results demonstrate the complex interactive effects of tree chemistry and the presence of ants on crown invertebrate populations. As ecosystem engineers wood-ants have strong effects not only on forest ecosystem function, but also on biodiversity which should be considered in the genetic planning of forests to maximise biodiversity.

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Impacts of woodland expansion and management on ticks and tick-borne diseases

Photo 1: An engorged female adult tick

Background

Scotland has a heterogeneous landscape with a mosaic of habitats such as grasslands, moorlands and woodlands. Our diverse woodlands are managed for recreation, commercial timber, biofuels, and conservation purposes, and each type has a different community of organisms, including ticks (*Ixodes ricinus*), tick-borne pathogens and their vertebrate hosts. Reported incidence of tick-borne disease (such as Lyme disease) has been increasing alarmingly over the last decade in Scotland. The Scottish Government aims to increase woodland cover in Scotland from 17% to 25% over the next 40 years. How will this affect disease risk?

We aimed to determine (a) the role of woodlands as habitats for ticks and (b) how woodland management such as fencing and culling deer can help control tick populations.

Approach

To determine the role of woodlands as habitats for ticks, and the effect of culling deer, we surveyed 77 sites throughout Scotland. We counted ticks by dragging blankets and used deer dung as a proxy for deer abundance. To determine the effect of woodland fencing on ticks, we surveyed ticks in 18 forests: nine fenced to exclude deer and nine unfenced.

Results

- Ticks were most abundant in woodlands compared to open habitats such as heather moorland and grasslands (Fig. 1). This is because woodlands tend to have more tick hosts than open habitats, and the woodland canopy creates a favourable, mild micro-climate that aids tick survival and host-seeking behaviour. A related project found more ticks infected with the Lyme disease pathogen in semi-natural deciduous/mixed woodland compared to coniferous woodland. Semi-natural woodlands tend to have more small mammals and birds that are hosts to the pathogen of Lyme disease.

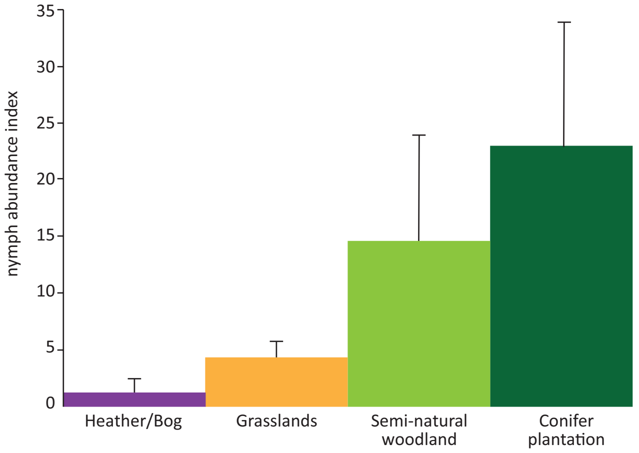

Fig. 1: More ticks were counted in woodlands than in open habitats

- Ticks increased with increasing deer numbers (Fig. 2), implying that managing deer numbers for woodland protection would also be beneficial in reducing ticks and tick-borne disease risk.

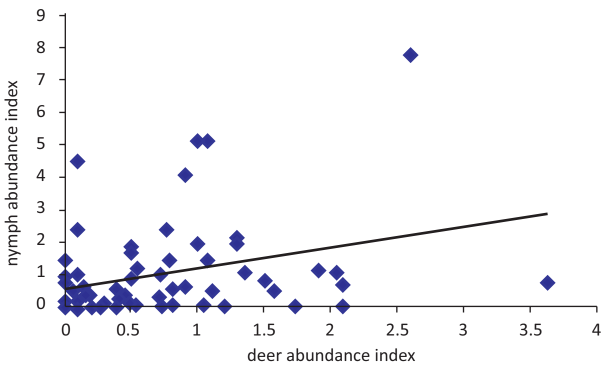

Figure 2: Fewer ticks were counted in areas with fewer deer. The large variation is due to differences in habitat and alternative hosts

- Woodlands that were protected from deer damage by use of deer-proof fencing contained far fewer ticks than similar, adjacent, woodlands that allowed access by deer (Fig. 3).

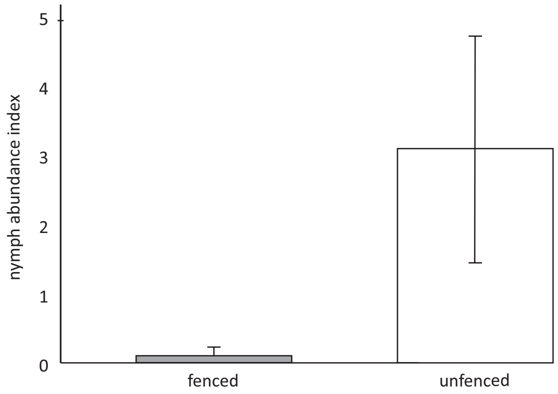

Fig. 3: Forests that were fenced to exclude deer contained fewer ticks

Conclusions

- Woodland expansion is likely to increase tick abundance. Therefore, we might predict that risk of Lyme disease will increase as woodland cover increases. This will depend on woodland type, and trade-offs will need to be assessed between the cost of increased risk of Lyme disease and the benefits of increased biodiversity.
- However, standard woodland management techniques could help mitigate this risk. Excluding deer using deer-proof fencing or culling is likely to reduce tick abundance and Lyme disease prevalence in the woodland.
- It is important to carefully consider all the issues relating to deer reduction and fencing, in terms of wider biodiversity impacts, social and cultural impacts, and economics.

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Photo: Richard Hewison

Effects of long-term browsing on regenerating birch

Photo 1: Corrimony plot 1, August 2001 compare to photo 2

Background

Within the Scottish highlands, where downy birch (*Betula pubescens*) is prevalent, free-ranging sheep and deer have open access to many areas of semi-natural woodland. Government targets to increase the area of native woodland (including birch) depend on management of browsing herbivores to allow successful regeneration. Wild deer numbers are controlled mainly by shooting and fencing but for domestic sheep, numbers and timing of grazing can both be easily manipulated. Thus, for sheep there is potential to devise a range of seasonal management options to secure regeneration of birch whilst still allowing grazing for agricultural benefits. ***We therefore designed an experiment to examine: how birch saplings respond to different timing and severity of browsing damage?***

Approach

We established an experiment in 2000 at two sites with large numbers of regenerating birch (*Betula pubescens*) saplings within heather-dominated vegetation: Drynachan in the north-east; Corrimony in the western highlands. Three replicate plots were fenced at each site and the following browsing treatments were applied every year: factorial combinations of severity (0 (control), 33% and 66% shoot removal) x timing (clipped during dormancy, at budburst, or late summer). Each treatment combination was applied to 60 different saplings per site. Clipping was used to simulate browsing, to enable complete control of severity and timing of damage. All saplings at the start of the experiment were within 10cm of vegetation height as this is considered the stage of greatest vulnerability to browsing. Growth and size of all saplings was measured every year at the end of the growing season (Photo 3), for a total of 10 years (Photos 1 and 2).

Photo 2: August 2010

Photo 3: Measuring birches in midge-heaven!

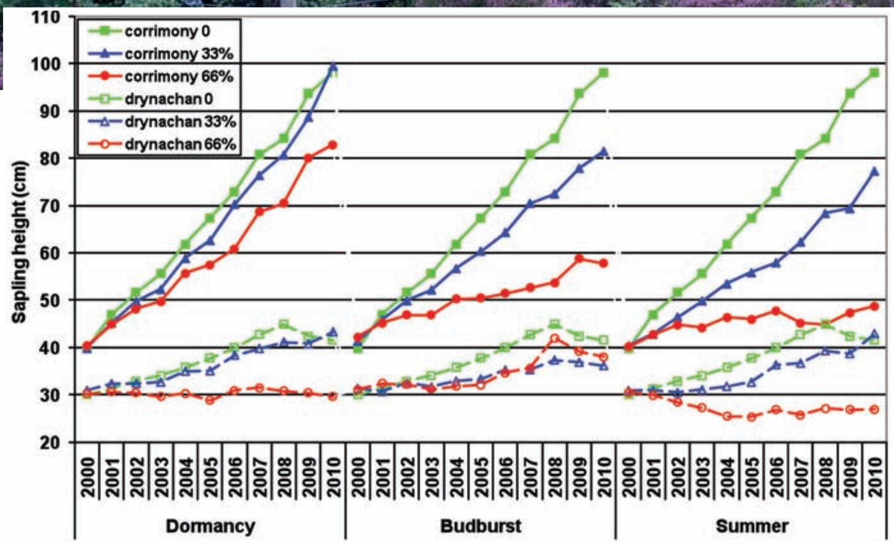

Fig. 1: Changes in birch sapling height over 10 years.

Photos: Alison Hester

Results

Timing and severity of browsing both had strong significant effects on all growth parameters (Fig. 1) as follows:

- As expected, heavier browsing had more detrimental effects on growth.
- Browsing in late summer was more detrimental to saplings than browsing in winter or spring.
- Sapling mortality increased dramatically after about 5 years of browsing treatments: mortality was highest for heavily late-summer-browsed saplings.
- The two sites showed the same direction of impacts but growth rates were very different: at Corrimony 38% of unbrowsed saplings had grown above 1m height after 10 years (Photo 2), whereas none of the heavily late summer-browsed saplings grew above 1m. At Drynachan <1% of saplings had grown above 1m high in any treatment.

Conclusions

Timing of browsing is clearly important, not just its severity. Therefore management to reduce sheep stocking in late summer could improve the likelihood of birch regeneration escaping the reach of browsing herbivores, to form new woodland. The length of time needed clearly depends on the birch growth rates, which can differ greatly between sites, as shown here. However, our findings must be considered together with information on browse preferences and the availability of other forage at different times of year before designing browsing management plans: a site with an abundance of better quality forage in late summer, for example, may remove pressure from birch, resulting in little or no browsing at this time of year.

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Woodland expansion onto moorland: impacts on biodiversity and ecosystem services

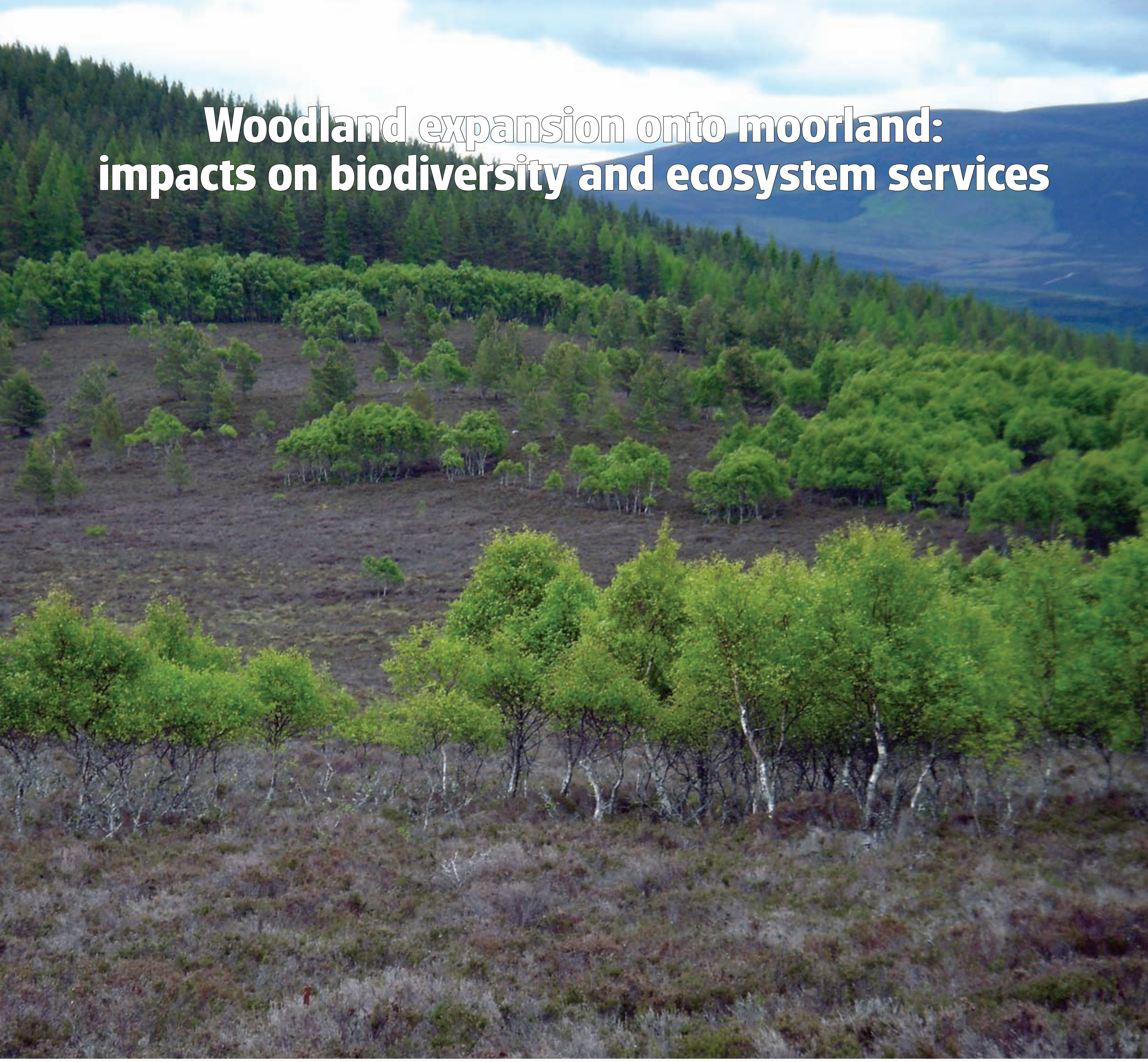

Photo 1: Birch woodland colonising adjacent moorland

Background

Scotland is currently only sparsely wooded with woodland covering about 17% of the land area. The Scottish Government aims to increase this to 25% by 2050 and woodland expansion onto moorland is one way to achieve this target. Pine and birch woodlands are the two native types of woodland that most readily establish on moorlands (Photo 1). Caledonian pinewoods are included within Annex 1 of the EC Habitats Directive and both Caledonian pinewoods and upland birch woodlands are Priority Habitats within the UK Biodiversity Action Plan. Both woodland types together make up the majority of the remaining fragments of native woodland in Scotland today and will readily expand, given the right conditions.

The long-term research described below addresses the question: ***How does woodland expansion onto moorland affect biodiversity and ecosystem services?***

Approach

Three different experiments have been used in this work to date:

1. In the 1970's a series of sites (chronosequences) were identified where birch woodland had naturally colonised moorland; changes at these sites and their neighbouring moorland have now been studied for 40 years.
2. In 1980 three new sites were established each with a series of plots; half were planted with birch and half were left as open moorland.
3. In 2005 a new experiment was established where both birch and pine trees were planted on moorland, with and without exclusion of large grazing herbivores.

Using these long-term experiments we are examining how woodland colonisation on moorland drives changes in above- and below-ground biodiversity and ecosystem function, using a combination of field data and controlled experimental data.

When birch colonises moorland the following changes occur:

Changes in biodiversity

- The vegetation changes from heather-dominated to grass- and herb-dominated understorey.
- The number and diversity of soil mites, collembola (spring tails) and earthworms increase (Fig. 1).
- The soil microbial community changes from being fungal-dominated to bacteria-dominated.
- The species of fungi change.

Changes in soil properties

- Soil acidity decreases.
- Soil phosphorus and bulk density increase.
- Total soil carbon and depth of organic matter decrease.
- Soil moisture decreases.

Changes in ecosystem services

- Rates of litter decomposition increase (Fig. 1).
- Increased rate of nitrogen mineralisation.
- Less carbon is stored in vegetation and litter in some 20 year old birch woodland vegetation than in moorland vegetation.
- Less carbon is stored in the soil under 20 year old birch trees, planted on moorland, than in the moorland soil.

Summary

Colonisation of moorland by birch woodland drives changes in above- and below-ground biodiversity: this leads to changes in soil chemical properties and ecosystem services such carbon storage, decomposition and nutrient cycling.

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Photo: Alison Hester

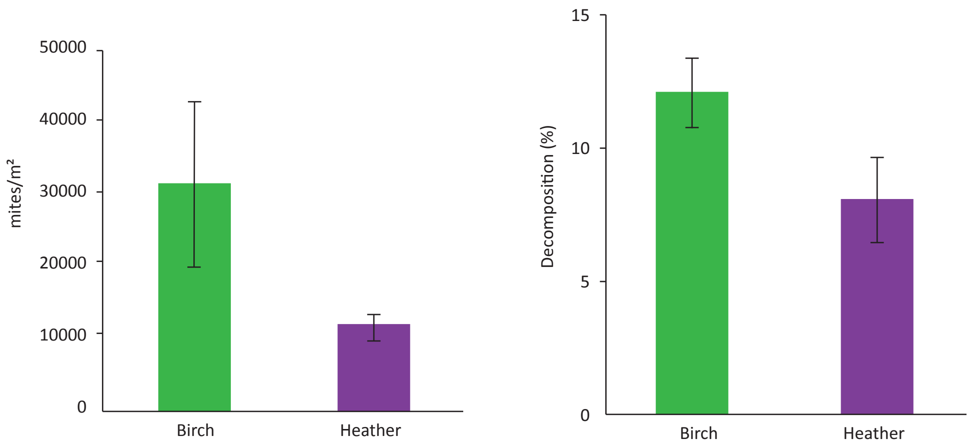

Fig. 1: The succession to birch from heather results in a) greater abundance of soil mites and b) higher rates of decomposition

Multifunctional woodlands in the landscape

Background

Numerous conservation and restoration efforts in developed countries, including woodlands, are now based on the premise of recognising and stimulating the creation of landscapes that can provide multiple and diverse benefits, including ecological, social and economic. The incorporation of multi-functional woodlands into sustainable landscapes requires policy and analytical tools at the landscape level.

We have concentrated our study of multi-functionality on small woodlands in the lowlands, where they can provide multiple benefits. For example, the simplified landscapes associated with the introduction of intensive agriculture, have led to a reduction in biodiversity. At the same time, opportunity for recreation in such landscapes has declined along with their visual amenity. The notion of multi-functionality is therefore at the heart of efforts to link ecological concepts of biological functions with the economic concept of total economic value and ecosystem services. ***We have explored opportunities to describe the geographic heterogeneity of biodiversity, visual amenity and recreation potential of woodlands across the landscape of the NE of Scotland in search of potential 'multiple win locations' which we called 'multifunctional hotspots'.***

Approach

We have developed a method to identify and map areas where such coincidence of multiple functions is realised, in order to identify suitable target areas for the creation of small multifunctional woodlands.

Potential for biodiversity: This approach is based on 16 important species identified by the NE Biodiversity Action Plan. We mapped the importance for biodiversity in the landscape based on the habitat suitability for each of these species.

Potential for visual amenity: This was based on the viewing population (using traffic data and travel distance from urban areas) and accounting for the general preference of the public for the amount of woodland they like to see in the landscape, the amount of woodland already visible in the local landscape and the actual visibility of grid cells in the landscape from (public) points of observation.

Potential for recreation: This was based on estimates of the expected number of visitors at any location which was inversely related to distance by road to where people live. The map also takes account of substitute sites of woodland recreation, i.e. people living in an area with little woodland cover are assumed to be willing to travel relatively longer distances for the purpose of woodland recreation.

Results

Combining all three maps found that despite giving precedence to each of the three criteria in turn, there is a 'win-win-win' area that is independent of which criterion is given precedence (Fig. 1). The yellow and red areas are those most suited for the planting of new woodlands because these new woodlands would deliver all of the three benefits above.

Conclusion

This approach can be used to find multiple win areas and areas where there might be trade-offs between a high number of criteria that could be preferred by the public.

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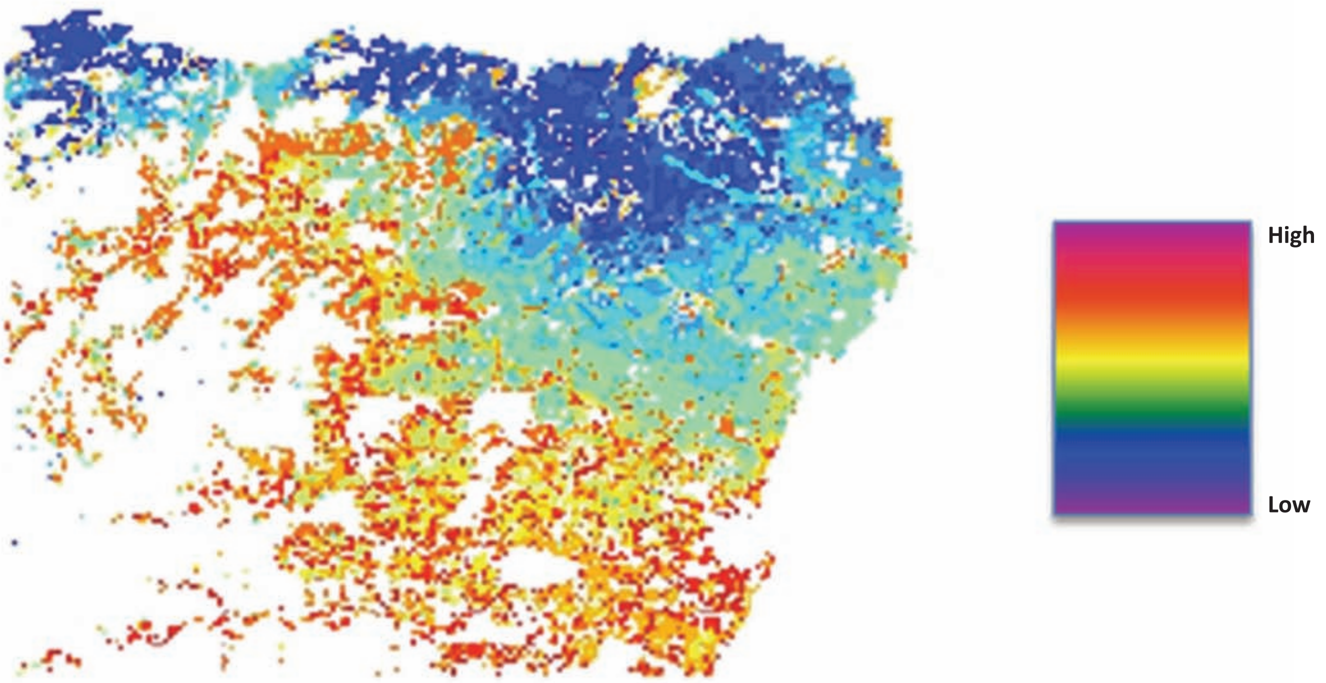


Figure 1: Multifunctional areas in the NE of Scotland agricultural landscape

Reappraisal of our zones of genetic conservation of Caledonian Scots pinewood

Photo 1: The Caledonian pinewood at Coille Coire Chulic

Background

Caledonian Scots pine (*Pinus sylvestris*) woods cover less than 1% of their previous extent and are protected under the EC Habitats Directive. Scotland has 100% of the UK Caledonian pinewoods, which persist in 84 small fragments, the core areas of which range from 1-2500ha (Photo 1). Current guidelines for the conservation of British tree species recommend that any planting stock should be derived from local seed sources, assuming that it is best suited to that particular local environment.

For Scots pine, seven 'origin zones' have been identified based upon the relatively small proportion of variation between populations in the monoterpenes, a group of genetically heritable volatile plant secondary metabolites, previously commonly used as pseudo-genetic markers (Fig. 1). Since the delineation of the Scots pine origin zones in the 1980s there have been considerable advances in analysis of both these chemicals and of genetic material (DNA) that permits direct identification of the genotypes of Scots pines. ***We re-examined the basis of the current seed zones for Scots pine.***

Current Origin Zones

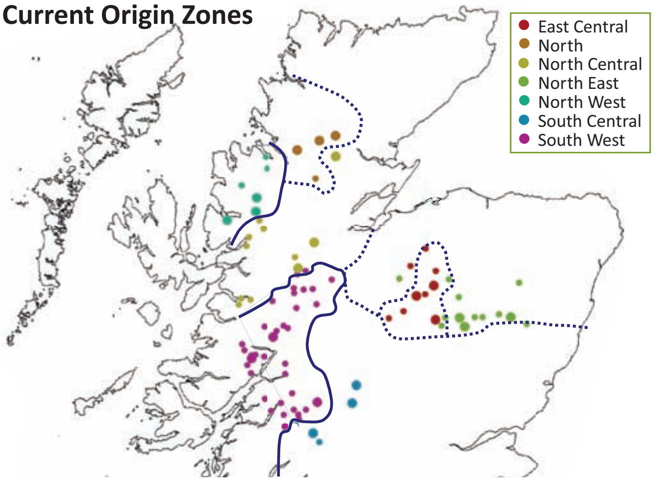


Fig. 1: Map showing the seven current origin zones for Scots pine. Larger dots show the 21 study populations, three in each zone

Approach

We collected and analysed pine needle samples from 30 trees in each of 21 of our original native Caledonian pinewoods (three populations in each of the seven current origin zones). We applied principal components and hierarchical cluster analysis to identify the variation between the Scots pine populations after using the latest techniques for the analysis of monoterpenes and newly developed Simple Sequence Repeat DNA markers.

Results

- The biochemical analysis identified two zones that are distinct from the remainder – 1) in the North-West of Scotland and 2) another group comprising the Abernethy and Rothimurchus populations (Fig. 2a).
- For molecular DNA markers only the Shieldaig population in North-West Scotland appears to be different from the others (Fig. 2b).

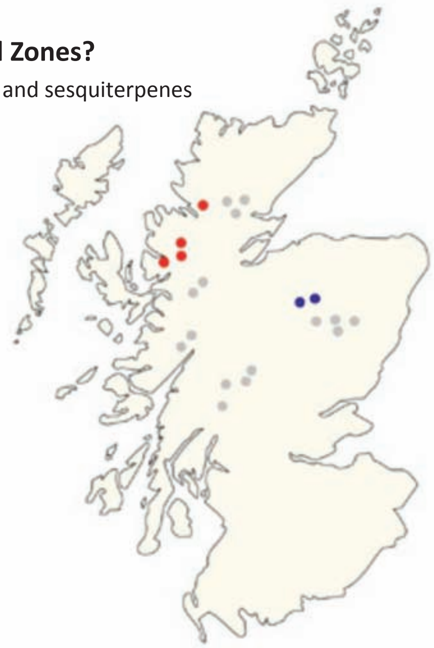
Conclusions

The molecular markers (DNA) do not necessarily represent characteristics of the trees that may affect their survival or reproduction. Neither chemical nor molecular markers show the population level differentiation needed to inform a comprehensive conservation strategy. As an alternative we should consider whether characteristics of trees, such as growth or the timing of bud burst, form a better basis to investigate and classify differences between our Scots pine populations. Further research work is needed to quantify the tolerance of Scots pine from different origins to different climatic conditions in order to ensure the long-term persistence of regenerating populations under changing climatic regimes.

Photo: Ben Moore

Revised Zones?

2a Mono and sesquiterpenes



2b Neutral DNA markers

Figure 2: Maps showing which of the 21 study populations were distinct from the others, based on revised analysis of a) pine needle mono- and sesquiterpenes. Two groups of populations were identified (red dots:Shieldaig, Ben Eighe and Loch Clair and Rhiddoroch); and Abernethy and Rothiemurchus (blue dots) and b) neutral genetic markers; only Shieldaig was distinct from the others.

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Biomathematics and Statistics Scotland
Macaulay Land Use Research Institute
Royal Botanic Garden Edinburgh
Scottish Agricultural College
Scottish Crop Research Institute

Further information can be found at
http://www.programme3.net/

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