Delivering Resilient Forests

A summary of research

Ian Willoughby and **Suzanne Peace** review the latest research commissioned by the Forestry Commission to address resilience.

The UK Forestry Standard and country forestry policies for England, Scotland and Wales all acknowledge that resilient forests are important if our trees are to cope better with changing environmental conditions, and current and emerging pest and disease threats. There are however gaps in understanding what exactly this means and how it may be achieved in practice. Recognising this challenge, a major emphasis of the 2014 Science and Innovation Strategy for Forestry in Great Britain (Forestry Commission, 2014) was how to better understand and assess resilience, as well as develop practical solutions to assist land managers to create more resilient forests.

The GB Forestry Commission (FC) commissioned seven research programmes to help deliver the challenges identified in the Science and Innovation Strategy. The 'Delivering Resilient Forests' programme has been carried out by Forest Research in collaboration with numerous partners, and involved scientists from a broad range of disciplines. Its purpose has been to produce evidence that guides decision-making around four central challenges, developed from the Science and Innovation Strategy:

1. How can we maintain ecosystem services and biodiversity whilst achieving resilience?
2. What are the properties of trees we are likely to grow for increased resilience?
3. How do we design, cultivate and manage adaptive, resilient and productive woodlands?
4. What is the impact of pests and diseases on the creation and retention of forests?

In this article we summarise some of the research that took place between April 2015 and March 2019, and signpost the tools and publications that contain further information on this research.

How can we maintain ecosystem services and biodiversity whilst achieving resilience?

This challenge is concerned with understanding the impacts of changes to forest management practices, carried out to increase resilience, on biodiversity and wider ecosystem services.

To address this challenge, in collaboration with forest managers in Scotland, England and Wales, researchers developed a method to simulate how ecosystem services provided by forests would differ under climate change, both with and without the presence of disease, and under varying forest management scenarios. The information from this research has been used to inform forest design plans in Scotland, England and Wales (Bellamy et al., 2018; Ray et al., 2017). For example, in the study of the National Forest Estate in Scotland it was found that introducing more broadleaved species into planting schemes would improve the standing biomass and biodiversity, albeit with slightly reduced timber volume.

Another significant work cluster focussed on forest planning to protect biodiversity against environmental change. Forest managers are faced with a considerable challenge when seeking to manage areas of habitat for rare and threatened species as reliable data on the occurrence of these species tends to be sparse. The 'Niches for Species' model was developed to help overcome this difficulty by predicting the occurrence of woodland species based on the ecological characteristics of an area. Uses for the tool include comparing the likely benefits to biodiversity of different woodland expansion scenarios, visualising the configuration of species-rich and species-poor woodland, and predicting the likely presence of a particular woodland species at a site. The tool is described in more detail in an FC Research Note (Broome et al., 2018).

Further support for biodiversity through forest

management has been provided in a number of FC Research Notes that explored how to avoid disturbance to woodland birds, provision of conifer seed for woodland bird species, and conifer management for breeding birds (Broome, 2016; Broome et al., 2017; Calladine et al., 2016). A further Research Note (Broome and Mitchell, 2017) discusses the ecological implications of Chalara ash dieback, summarising recent research on the ecological value of ash, what tree and shrub species could be considered as alternatives to ash, and what this could mean for woodland management.

To better understand the benefits and risks of forestry on soil and water services work has continued on a number of medium to long-term studies across Great Britain. These have included an analysis of the effects of peatland restoration by deforestation on water quality at Flanders Moss in mid Scotland (http://bit.ly/2TB7kCi) and at Halladale in north Scotland. In the New Forest stream water temperature monitoring is continuing to investigate the important role of riparian woodland shade for protecting salmonids from climate warming (http://bit.ly/2FaUcRe). Results from these studies have informed a forthcoming FC Practice Guide on managing forest operations to protect the water environment.

Afforestation benefits and impacts on mineral and organo-mineral soil long-term carbon balance and nutrient sustainability have been studied in Scotland, England and Wales using detailed chronosequence studies (Vanguelova et al., 2017a), and long-term monitoring networks (Figure 1). Long-term impacts of additional forest biomass removal and fertilisation on forest and soil carbon and on nutrient balances have been studied at long-term experimental sites in Bala, Kielder, Ae and Teindland. This work will inform a planned FC Practice Guide on managing the impacts of whole-tree, brash and stump harvesting.

What are the properties of trees we are likely to grow for increased resilience?

The current portfolio of trees grown within Britain may be less suitable in the long term given the threats from climate change and pests and diseases. This challenge is concerned with understanding the potential of new species or provenances that might help increase the future resilience of our forests and woodlands.

In response to this challenge, in April 2016 funding for long-term research was initiated to help identify alternative tree species and their silvicultural characteristics that might be used to improve the resilience of forests in Great Britain.

Figure 1. Three-year-old maritime pine in a species trial involving large-scale forest plots established in collaboration with Forestry England; most trees are over 2m tall. (Photo: ©Forest Research)

In collaboration with Forestry England and Forest and Land Scotland eight species trials, involving 20 emerging species on large-scale forest plots, have been established (Figure 1). These include comparisons of conventionally used species, and also explore differences between plantings made on clearfell and underplanting sites.

Running in parallel across Britain are a further series of eight trials; five Forest Research emerging species trials and three linked to a wider European project (REINFORCE) looking at the survival of a number of tree species along the Atlantic Coast from the Azores to the Isle of Mull, Scotland. Over 40 species with a range of provenances are being trialled to see the effect of different climatic conditions on tree survival and growth. Some of these are known forestry species but for which we lack extensive knowledge of their silvicultural requirements in the UK. Others are new and untried species in the UK but established forestry species in other countries. Drawing on existing evidence, a series of alternative species profiles have also been developed and published (http://bit.ly/2E5BB8K).

As with many strands of research mentioned here, silvicultural trials by their nature take many years to produce definitive results, and ongoing, long-term funding will be required to maximise the benefits from this important investment. In the future new evidence generated from this work will be integrated into the Forest Research tree species database at http://bit.ly/2A7flaT.

Another significant piece of work addressing this challenge has been the Living Ash Project (https://livingashproject.org.uk), co-funded by Defra and coordinated by Earth Trust. The project has established new genetic trials of ash to investigate the variation and heritability of tolerance to infection by the pathogen *Hymenoscyphus fraxineus*, which is responsible for Chalara ash dieback. Tissue culture techniques have been developed to enable the production of large numbers of any ash dieback tolerant trees for use in future tree planting. Data from the Continent suggest relatively high heritability, which means selecting tolerant trees in woodlands will lead to a general increase in the number of tolerant trees in the landscape. We need to find out if this is also true in Britain, and although it is very early to reach definitive conclusions, this work marks a starting point against which future progress can be measured.

The implications of species choice in urban areas have been considered with a series of FC Research Reports (Hand et al., 2019a & b) and in a forthcoming FC Research Note. The results indicate that, relative to small and medium stature species, large species provide greater quantities of ecosystem services both annually and over the lifetimes of the trees. The information generated is intended to guide species selection of trees for planting in urban areas.

How do we design, cultivate and manage adaptive, resilient and productive woodlands?

This challenge is about developing practical management solutions to help deliver resilient forests and woodlands today and in the future.

In response, an FC Practice Guide on the adaptation of forests to climate change is being developed to draw together findings from new and previous research, and guide forest managers on how to design, cultivate and manage resilient woodlands. The Guide will describe the potential impact of climate change and the changing risks to woodlands, discuss the evidence behind various adaptation options, such as species and provenance choice and structural diversification, and illustrate case studies of adaptation actions by woodland managers in a range of situations.

Complementary research has provided an improved awareness of the differences in forest managers' understandings of resilience and how this links with their management behaviours. This gives us an important insight in how best to influence their practice (Ambrose-Oji et al., 2018; 2019). The research found that key factors affecting resilience behaviours include managers' knowledge and understanding of forest resilience, how these ideas relate to their own woodland and forestry objectives, their perceptions of actual risks to their own forest and their belief in their capacity to take effective actions to manage risks. The findings stress the importance of characterising land managers so that information and advice can be communicated in ways that are tailored to specific interests.

The long-term experiments of Forest Research (http://bit.ly/2CivcE3) also provide a rich source of data helpful to delivering resilient forests. A thorough review of these experiments has been carried out and around 350 of the most useful experiments have been selected for retention. They cover topics including mixtures, nutrition, ground preparation, stability and exposure, timber quality, spacing, thinning, native woodlands and natural regeneration. They also include species and provenance trials. Data from the experiments has been used to address

research questions on issues such as provenance selection of silver fir and hybrid spruce for our current and future climate (Stokes et al., 2018), and on the long-term effects of vegetation management on timber yield and carbon sequestration (Stokes and Willoughby, 2014).

The forest management techniques associated with continuous cover forestry (CCF) and the use of pesticides and alternatives for integrated pest, weed and disease management have been investigated. Practical guidance on CCF includes information on the management of mixed-species forest stands to support diversification of forests and an FC guide on under-planting (Kerr and Haufe, 2016). After 54 years of its application, there has also been an analysis of the pioneering Bradford-Hutt system of CCF (Kerr, 2017). Alternative approaches to woodland regeneration, such as practical guidance on direct seeding for the conversion of low productivity conifer plantations to native woodlands (Willoughby et al., in press) (Figure 2), and the initiation of research into the use of sacrificial nurse species to help improve the establishment of shade tolerant novel / emerging tree species have also been explored, as well as the early enrichment of Sitka spruce plantations with emerging species to increase diversity and long-term resilience.

A number of experiments on integrated forest vegetation management experiments have recently been established. The use of Ecoplugs containing glyphosate have been studied, and it has been found that they can be an effective, low-impact method of controlling the invasive, Phytophthora-hosting weed *Rhododendron ponticum*. Ecoplugs can also be used to selectively kill standing trees, resulting in a lower risk of *Heterobasidion annosum* infection than conventional chemical thinning (Willoughby et al., 2017b; Willoughby et al., 2019; Tubby et al., 2017). Research has also found that *Gaultheria shallon*, another highly invasive and difficult to remove non-native species, can be controlled on a large-scale by carefully timed herbicide applications (Willoughby et al., 2018; Willoughby and Peace, 2018). Wide-ranging technical advice and expert support has also been provided in relation to pesticide use and reduction in chemicals.

Figure 2. Established native woodland of birch, rowan and alder seven years after direct seeding at Slattadale, Highlands. (Photo: ©Forest Research)

To support improved plant production in British nurseries, a review was conducted to highlight problems identified by nursery managers when raising trees from seed. Based on the review, experiments were drawn up and implemented in the lab and nursery. A key problem is often seed-lot quality, which is determined using various tests. X-rays, for instance, were used to track changes while upgrading poor quality seed-lots of European silver fir (McCartan et al., 2015) (Figure 3). Dormancy and pre-chill duration were tested to determine whether longer pre-chill periods could be exploited to produce Douglas fir seedlings in one year (McCartan, 2018).

What is the impact of pests and diseases on the creation and retention of forests?

This challenge is about understanding the impact of current, and potential new pests and diseases, and developing practical methods for mitigating the worst of their effects.

Although much of the FC funded research on this topic falls outside this particular programme, an important body of research and advice has been provided on a wide range of pests and diseases. Several are newly emerging threats such as those affecting sweet chestnut (chestnut blight and the oriental chestnut gall wasp) (Morath et al., 2015; Pérez Sierra et al., 2018) and most recently *Ips typographus*, which attacks spruce. Scientific support and advice on tree pests and diseases includes input provided to the Forestry Commission Plant Health team on surveys and identifications of new pests and pathogens, and to Defra as part of the work on the UK Plant Health Risk Register https://planthealthportal.defra.gov.uk/.

A significant body of practical advice is provided each year via the Forest Research Tree Health Diagnostic and Advisory Service (http://bit.ly/2tX4lZS). It responds to more than 2000 pest and disease enquiries from across Britain each year, and encourages the reporting of tree health concerns through the online Tree Alert tool https://treealert.forestresearch.gov.uk. In all three countries, the most common enquiries related to ash, followed by oak in England, spruce in Scotland and larch in Wales. Tree pest enquiries were dominated by oak processionary moth, and Chalara ash dieback was the most frequent disease enquiry. Together with support provided by the Observatree citizen science project, these enquires contribute to early warning surveillance as well as raising awareness and ensuring appropriate management can take place.

Research addressing the impact of pests and diseases includes the investigation of the use and the aerial application of fungicides to control *Dothistroma* needle blight (DNB). This research, conducted with Forestry Commission Scotland, investigated the operational feasibility and environmental issues surrounding the future use of aerial pesticide applications in landscape-scale disease management programmes. Detailed, practical guidance on the integrated pest management of *Hylobius abietis*, including the latest information on use of non-chemical approaches and alternatives to cypermethrin, has also been produced (Willoughby et al., 2017a), based on collaborative research developed across the forestry sector.

Following the withdrawal of warfarin for grey squirrel control research has investigated alternative approaches for their management. In recent years, new trap technologies have been developed and different approaches to control by shooting have been tried. These innovations have been described, alongside established methods, in an updated FC Practice Note on *Controlling Grey Squirrels*, which is due to be published later this year.

Figure 3. X-ray image of European silver fir seeds showing mostly filled seeds with embryos surrounded by food reserves, some empty seeds with no content, and inert matter such as bracts or cone scales; resin vesicles are clear in the seed coats. (Photo: ©Forest Research)

Research in both Ireland and Scotland has indicated that expanding populations of pine martens have been associated with a decline in grey squirrel population and a recovery in red squirrels. In a number of partnerships we have collaborated to better understand the interactions between the three species and how insights from this may be exploited to reduce unwanted impacts from grey squirrels and perhaps the need for their control. For example, a collaborative project with Exeter University has used radio-tracking in pine marten re-introduction sites in Wales to study the effects on grey squirrel movement and foraging behaviour. In addition, a partnership with the University of Aberdeen has funded a PhD to investigate interactions between red squirrels, grey squirrels and pine martens at a landscape scale, to better understand how populations of the three species will depend on habitat characteristics.

Complementing this work, social scientists have investigated stakeholder attitudes to the management of pests and diseases. A number of case study species have been explored in detail, including grey squirrels, rhododendron, *Phytophthora ramorum*, feral pigs/wild boar,

and deer (generally). The programme has also enabled research with Red Squirrels United to understand awareness of squirrel conservation issues and attitudes towards management methods amongst local communities, landowners and squirrel conservation volunteers (Dunn et al., 2018). Additional funding from Defra has been received for the study of public and stakeholder attitudes towards oak processionary moth control measures.

Conclusion

The funding provided for this programme has enabled us to maintain and plan for the continuation of scientific expertise and the provision of advice on many of the important issues that underpin the delivery of resilient forests. It has also made it possible to set up longer-term experiments such those on alternative species, and to maintain existing long-term silvicultural and hydrological studies, that will yield essential information to allow us to address the challenges of the future. Further consolidation of programme activities is now being undertaken to provide the springboard for the delivery of a revised research strategy.

This article has only attempted to provide a flavour of some of the work that has been carried out by this research programme over the past four years, but a full list of written publications is available on the Forest Research website www.forestresearch.gov.uk/research/delivering-resilient-forests/publications-about-delivering-resilient-forests/.

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