Forest Resilience in British Forests, Woods & Plantations

2. Plantation forests of spruce and other conifers

Jonathan Spencer continues his four part series looking at different aspects of how we can increase resilience.

Post war policies of increasing food production and expanding forest area led directly to the challenging position foresters now find themselves in with large expanses of relatively new afforestation on soils of mediocre quality, generally planted as monocultural stands, often in areas of high wind hazard and exposure (Tsouvalis, 2000). Most upland spruce and mixed spruce/conifer forests are of recent 20th century origin, on degraded upland soils, and are of limited timber tree diversity with narrow genetic provenance. But they are very extensive and have the potential to function far more as 'natural' forests (Mason and Quine, 1995).

The tree species chosen to establish these new forests were the higher performing conifers from north west USA and Canada, with a strong predominance of Sitka spruce, with other conifers where soil conditions permitted, or in the case of lodgepole pine, where growing conditions were marginal for Sitka spruce. About half of the UK's forests are dominated by spruce and other timber producing conifers (Forestry Commission, 2012), almost exclusively planted on poor soils of limited agricultural worth: wet peats, peaty gleys, podsols, and podzolic gleys. Tree species were carefully chosen according to site condition and soil type, with adverse soil characteristics mitigated by drainage, ploughing and nutrient inputs to facilitate establishment (Mason and Quine, 1995). Unlike most remnant ancient woodlands in the north and west of Britain, the new forests are extensive and interconnected with other habitats, themselves of forest origin (such as extensive bogs, river and stream complexes and occasional craggy outcrops).

Since production of the first article in this series, the US Global Change Research Program (USGCRP, 2017) has produced "the most comprehensive summary of climate science since 2013". This update warns that we are now in the warmest period in the history of modern civilization, with "warmest" implying more extremes of weather: deeper droughts, heavier rainfall events, stronger winds, more excitable weather and only short periods in winter below freezing. A 2°C rise in average temperature is certain between now and 2050 "under all plausible future climate scenarios".

Kielder Forest, April 2015. Forest Enterprise foresters in Kielder considering the challenges of climate change and the development of new approaches to forest management and resilience. 2015 was a key turning point in the development of rethinking our approaches to forests capable of supporting the needs of future generations. Kielder Forest now has approximately 10 'snow days' a year whereas some 20 years ago the number was approximately 60. Winters are warmer, the forest soils are getting drier and the environment is changing quite fast. (Photo: JWS)

The achievement of earlier generations of foresters in establishing such large areas with trees, now producing significant ecosystem benefits in the form of timber, carbon sequestration and water management, is nothing short of remarkable given the unpromising and inhospitable canvas upon which they were operating. The challenges of establishment have been overcome and young forest ecosystems now exist at considerable scale. This article explores measures aimed at enhancing resilience in these forests and considers the impact of such measures on their management. Adaptation to climate change is now urgent, although current options to increase forest resilience are not widely appreciated. Forest resilience and the importance of forest ecology were explored in the first article in this series (Spencer, 2018). Its application to extensive production forests is considered here. In this context forest resilience is perhaps best described as "The capacity … to continue to provide most, or all, of the ecosystem services, even if the composition and structure are permanently altered by disturbances" (Convention of Biological Diversity (CBD), 2009; Elmqvist et al., 2003). The provision of timber and fibre production are the services most obviously linked to the plantation forests considered here.

Sitka spruce ecology

Sitka spruce has a very wide longitudinal range, from Alaska through British Columbia to the northern fringes of California. Genetic variation is mainly clinal rather than in discrete races. Different genotypes from California to Alaska exhibit variation in height growth, timber qualities, seed and needle characteristics, response to day length, and critically for British forests, frost tolerance (Deal et al., 2014; Tittensor, 2016).

The species is typically found on acidic soils, with pH values of 4.0 to 5.7, and is frequently an early pioneer on immature soils recently exposed by glacial retreat. It requires relatively high amounts of available calcium, magnesium, and phosphorus, and grows best where soils are derived from rocks rich in these minerals. It commonly occupies alluvial soils along streams, sandy or coarse-textured soils, or soils having a thick accumulation of organic material. It is tolerant of ocean spray, which may well be associated with its demand for minerals in otherwise acidic or nutrient poor oligotrophic soils. It frequently grows alongside red alder (*Alnus rubra*) or Sitka alder (*A. sinuata*). Western hemlock is a frequent associate in many Sitka dominated forests. Growth is poor on poorly drained swampy ground.

In Britain Sitka spruce stands are mostly growing on soils compromised by past land use, with poor drainage and a deficiency of minerals, though initial soil treatments prior to planting (drainage, ploughing, fertiliser applications) have mitigated some of the shortcomings of unpromising soil conditions at establishment (Smith and McKay, 2002; Mason and Quine, 1995).

Spruce – drought, pests and diseases

Spruce dominated forests are generally regarded as resilient against pests and pathogens, though both Sitka and Norway spruce suffer from a wide range of fungal pathogens and insect pests, especially when stressed by drought or heat (Cameron, 2015). Several of these can have major impacts, notably outbreaks of bark beetles such as *Ips typographus* and *Dendroctonus micans*. With a future increase in environmental stresses associated with the climate and weather, the resilience of spruce stands may well be open to question in coming years.

Studies of Sitka spruce in Oregon (Reeb and Shaw, 2015), towards the southern end of its range (the drier), have found that warmer winters are inducing disease and insect outbreaks. Trees of non-local provenances were more prone to insect attack. Tree species are more vulnerable to climate and environmental change at the margins of their range, suffering from environmental stresses such as drought and hence prone to insect and pathogen impacts when conditions deteriorate. Measures advocated in Oregon to

Forest of Bowland, 2006. This photograph clearly illustrates the impact of clearfell operations, exposing the developing forest soil to extremes of temperature (sun scorch and frosts), drought and/or waterlogging, a rising water table and challenging restocking conditions. (Photo: JWS) alleviate the impact of pests and diseases included growing the trees in association with red alder to reduce the impact of white pine weevil; establishing mixed stands to dampen the effects of airborne fungal diseases; and maintaining tree vigour, this last being regarded as the best defence against *Armillaria* and other soil inhabiting pathogenic fungi.

In continental Europe Norway spruce is similarly suffering from bark beetle outbreaks thought to be induced by drought stress resulting from changes in winter snowfall and subsequent drops in water table (Bialowieza forestry staff, pers. comm.). Both silver fir (*Abies alba*) and Douglas fir (*Pseudotsuga menziesii*) are now being considered as alternatives in central European forests as drought reduces the performance of Norway spruce (Vitali et al., 2017). Changes in both weather and tree health at the margins of climatic suitability for spruce are of direct relevance to the future of Sitka and Norway spruce in Britain, particularly in drier locations and at lower elevations, while elevated nitrogen levels in leaves and needles, and stress induced by individual competition in unthinned stands are closely associated with increased insect attack and damage (Kolb et al., 1998).

Observations in natural spruce forests in boreal conditions of North America and Europe suggest that major outbreaks of insect pests (notably of *Ips* and *Dendroctonus* species) are an inevitable feature of their ecology (Kimmins, 2004). More encouragingly, the wet maritime conditions under which Sitka has evolved appears to have led to a capacity to cope with fungal pathogens, when not stressed by drought (Tittensor, 2016). The impact of novel pathogens and insect pests are clearly exacerbated by poor tree health and environmental stresses such as drought and aerial pollution, warmer winters, global trade in wood products and poor biosecurity measures, and can only be partly mitigated by the adoption of control strategies and biological control options. Forest resilience will have to be predicated on a wider range of actions, soundly based on effective ecological and biological resilience built into the forest stands themselves (CBD, 2009).

Implications of climate change for existing conifer forests

Given their extent, productivity, and economic utility, it is important that the future management of conifer plantations aims to establish a level of resilience.

Resilience measures will be dependent principally on (Spencer, 2018):

- Genetic variation within species.
- Species diversity within forests or stands.
- Structural diversity within and between stands.
- Intact, functioning forest soils that drive nutrient and water cycling.
- Acceptance of changes to species composition over time.

Conifer plantations have already changed considerably throughout their near century long development. Soils are less prone to waterlogging in their lower horizons and have established deep, humus rich horizons on the surface. Soil fungal communities continue to increase in species diversity and complexity where forest soil development is uninterrupted by clearfells and restocking (Humphrey et al., 2003). Recruitment of trees through natural regeneration into planted stands from surrounding crop trees now becomes possible, as does recruitment from unplanted arrivals such as birch, willows and other species, all of which supports the continued development of forest community complexity. Abundant seed source from established trees, sheltered conditions and a more supportive soil environment now

allows for the establishment of a wider range of tree species, both native and conifer, including those that are more susceptible to frost, drought and exposure.

The regular removal of timber and other products, however, continues to remove key nutrients from the forest ecosystem (notably phosphorous and potassium) and closer attention to nutrient fluxes will need to be considered in the future development of forest management regimes. Most studies conclude that medium to long term rotations (80-120 years) in temperate forests in which only the stems are harvested pose little threat of site nutrient depletion (Kimmins, 2004). However, short rotation biomass harvests, prolonged periods of fallow between tree establishment, whole tree harvesting and the prolonged exposure of poor soils in high rainfall areas may all lead to issues of site nutrient depletion in second and later rotations.

The clearfell and replant model, however, remains the favoured option in areas where high winds are the limiting environmental factor. This greatly disrupts soil development and associated fungal communities and hence the potential to harness and retain plant nutrients. Soil function is compromised through soil disturbance, exposure, drought, rising water tables, soil compaction and associated waterlogging, although the soils do clearly benefit from the flush of nutrients available from needles, brash and roots as they decay (Smith and McKay, 2002).

Underplanting of Corsican pine, Thetford Forest October 2016. The trials have utilised the forest conditions found under heavily thinned stands of Corsican pine badly affected by Dothistroma needle blight to establish a wide range of planted conifers, notably Douglas fir, western red cedar and various Abies species. These tend to be the species less able to cope with the exposed planting conditions found in more traditional clear fell conditions. They are favoured both by the sheltered forest conditions and the developing forest soils. Deer fencing or rigorous deer control is essential, though as a consequence large amounts of natural regeneration has been promoted with native broadleaves (birch, rowan, holly, some oak and the occasional hawthorn and hazel), alongside naturally regenerating conifers such as Douglas fir, western red cedar and scots pine. Up to 12 tree species can be found within deer fences. Growth is impressive though vigorous bramble growth can be challenging.
(Photo: Terry Jennings, Forest Enterprise England)

Introducing species and genetic variation into established forest stands

Significant improvements in conifer yield have been achieved through the use of genetically improved stock from tree improvement programmes, but this carries an associated cost of reduced variance for other characteristics such as disease resistance (Muller-Starck and Ziehe, 1991). Techniques for establishing additional intra-specific genetic variation of trees (from other provenances of Sitka spruce, for example), or trees of other species into existing stands are not yet widely adopted, although new species additions are a common feature of restocking. Planting mixed species at establishment is well proven but restricts species choice to those capable of coping with the exposed conditions created by extensive clearfells, which can preclude the ready establishment of frost sensitive and drought tolerant species such as *Abies*. Trials of underplanting heavily thinned *Dothistroma*-infected Corsican pine with a wide range of more shade and frost sensitive conifer species look promising, with young trees flourishing within the forest conditions maintained under a canopy of retained pine. Some trials in establishing seed trees (of Douglas fir and native shade tolerant broadleaves such as hornbeam) at carefully chosen locations on the edges of stands have been undertaken with the expectation of them seeding into established stands. This is a potentially useful technique for introducing genetic variation into established stands under transition to low impact silvicultural systems and for enhancing stand species composition with minor components of readily regenerating species such as birch, rowan, western hemlock or western red cedar.

Why have more species of trees within a stand?

Lessons from native spruce forests suggest strategies for managing plantations elsewhere in the world (Drever et al., 2006). ‘Naturalistic’ mixed Sitka spruce stands, with western hemlock, Douglas fir or grand fir have been suggested as models (Cameron, 2015). North American Sitka spruce forests have complex age and tree size structures, but comparatively simple species composition, often with 90% of the standing volume consisting of Sitka spruce and western hemlock. Both species respond well under clearcutting and smaller-scale natural disturbances, achieving canopy closure within 20-30 years, followed by a long period of stem exclusion in undisturbed or non-thin regimes. The presence of broadleaved trees, dead snags and retained old trees enhance biological and conservation qualities without risk to the subsequent generation of trees. Alder and aspen, crowded out by the maturing conifers, do not reduce the size of the larger spruce or hemlock, and their death represents a source of deadwood and woody debris in rivers, streams and within the forest. This enhances biodiversity, forest performance and soil development, and leaves a legacy of nitrogen and other nutrients in the developing ecosystem (Deal et al., 2014).

Studies of mixed stands in boreal and northern temperate forests found them to be as productive as monocultures while being more resistant to pest and disease damage (Greiss and Knoke, 2011). Most convincingly, evidence gathered from plots collected across some 400,000km^3 of Sweden, (Gamfeldt et al., 2013) showed that:

- Tree species richness in production forests showed a positive relationship with most ecosystem services (notably carbon storage and tree biomass).

- Biomass production was approximately 54% higher with five tree species than with one.

- But no single species of tree was able to promote all such ecosystem services.

The authors of this study concluded that the management of production forests benefits from multiple tree species to sustain the full range of benefits that society obtains from forests, although they also noted that some services were in direct conflict, tree biomass production and deadwood provision, for example.

The role of minor species is widely appreciated in the research literature, although species with critical functional roles need not necessarily be abundant. In natural conifer forests alder plays a key role, fixing atmospheric nitrogen in root nodules and ultimately distributing it through the forest as leaf litter and decaying wood. Aspen plays a key role in forest soil development and forest soil carbon sequestration in native spruce forests and in the maintenance of forest conditions in early succession (Startsev et al., 2007). In North America some forestry systems entail the underplanting of existing stands of 40-60 year old aspen with spruce, delivering high survival rates and good growth rates for spruce. The planting of aspen following conifer harvesting also has advantages in terms of reducing pests, in particular pine weevil (Mansson and Schlyter, 2004). Once aspen is established through planting, its suckering habit largely ensures its continuance between rotations. Western hemlock, western red cedar and other shade bearing conifers introduce species and stand diversity at forest scale and act a hedge against the incidence of pests and disease in main timber trees, and allow tree species choices from a wider range of tree genera.

In summary, species diversity imparts the following key advantages to forest productivity and performance:

- Increased cycling of and access to nutrients from subsoils and lower soil horizons (and greater retention of nutrients within the system).

- Enhanced capture of light and other resources through increased resource use efficiency of the forest ecosystem.

- Improved tree health and resilience to disease through the promotion of diversity in mycorrhizal species of fungi.

- Enhanced productivity and performance, and an increase in standing timber/biomass available for harvest.

- Enhanced carbon sequestration and storage in soil.

- Mitigation of risk in the event of catastrophic loss of main tree species to disease or insect pests

Transforming conifer monocultures into conifer-birch mixtures provides gains in the biodiversity of many taxonomic groups. The biodiversity gains can be enhanced further when other forest management techniques (e.g. increased rotation length, retention of large woody debris and deadwood, and the presence of other minor tree species) are incorporated into the stand. Spruce growth can be improved in mixed stands with pine compared to pure stands on similar substrates (Mason and Connolly, 2013), and an accelerated growth of spruce can be achieved through beech admixtures on poor sites (Pretzsch et al., 2015). These results support the argument that soil conservation, biodiversity and forest stand diversity are all key functional components in establishing forest resilience (CBD, 2009; Gamfeldt et al., 2013) and that 'naturalistic' forests are more productive than monoculture plantations.

The North American spruce forest literature focuses on integrating the role of other tree species; in Britain the challenge lies in establishing the absent timber tree species diversity and minor species into stands and accommodating them within new or modified silvicultural systems. We are in effect reassembling forest ecosystems, forest genetic variation and species abundance from a mix of imported elements and reestablished native species recovered from fragmented relicts. Management of such stands, however, presents considerable technical challenges, higher management costs, and inherent opportunity costs associated with the maintenance of resilience and tree health. The possible benefits of forest resilience need to be weighed against the known costs and perceived risks faced over the long commercial lifetime of the stand.

Second rotation silviculture and associated management issues

The inevitable impact of climate and environmental change dictates that our approach to the management of existing commercial plantations will have to change. This is widely appreciated by forest ecologists; rather less so by foresters engaged in the practicalities of forest management and establishment.

However, the enhanced ecological conditions that impart increased resilience may not always be welcome. Vigorous growth of vegetation and young trees hamper tree planting operations; naturally regenerated stands take time to recruit and reach full stocking of timber trees and indeed may not do so at all. The complexity of having trees of more than one species and of varied age classes complicates forest mensuration and stock control; it becomes more difficult to forecast timber production, and stands do not present themselves as uniformly aged and shaped, single species of tree. There are tradeoffs between optimising forest characteristics conferring resilience with minimising the cost and complexity of forest management. Adjustments to forest management and silvicultural systems will need to be made to accommodate the costs and benefits of pursuing either the continued use of clearfell and replanting of single species plantations or the adoption of more complex approaches.

High wind class hazard locations present a particular challenge as there are few alternatives to clearfelling unthinned stands. Breaking up extensive stands at harvest and creating a more blocky mosaic of varied age class (and perhaps of varied species) is one option at restocking, although benefits to soil development and rooting depth through the adoption of mixtures and the use of natural regeneration may be lost as a result. Shorter rotations have also been suggested as a means of mitigating wind risk. A comprehensive review of silvicultural options can be found in Cameron (2015).

Many of these challenges might be addressed through adopting a range of silvicultural options within and between forests, or from a more mosaic approach to species diversity (as opposed to stands of mixed species) although these may not accrue all the benefits associated with intimately mixed species stands (Gamfeldt et al., 2013). However, all essentially have opportunity costs associated with the adoption of resilience measures. In this respect they are similar to any measures taken to mitigate risk. In time these risks and benefits might be more readily accommodated in mainstream forest economics with a move towards the adoption of 'Natural Capital Accounting' approaches, though this increase in societal value will not necessarily be reflected in changes in cash flow and income that might be incurred.

Summary

Spruce forests are widely considered as resilient and not under significant threat from novel tree pests and diseases. Uncertainty about the prevailing risks and the wider benefits of species and management diversity, however, are sufficiently uncertain as to create a degree of scepticism and inertia. Other conifer forests are clearly more vulnerable. The degrees to which significant change is required, when and how it should be pursued, to what level of desired resilience and at what scale requires further discussion.

The emergence of new plant pathogens and insect pests can be mitigated through changes in composition and choice of silvicultural options. The impact of abiotic aspects of climate change, notably the incidence of droughts, increased wind speed or the frequency of storms, is far less clear. There is no clear consensus as to how wind and weather will change across Britain with increased average temperature. In the absence of clarity, and clear constraints in areas of high wind hazard, it will become difficult to advocate any particular strategy. Perhaps that in itself is an important part of any resilience strategy… it must itself contain variation in its adaptive elements.

Any move away from established economic models of plantation forestry becomes an 'insurance policy' and the costs will have to be weighed against the benefits and perceived risks. The risks can be addressed in various ways (mosaic plantings of different monospecific stands, more naturalistic forests, species diversification within and between stands or within and between forests) or the risks associated with a changing climate over the economic lifetime of the crop can be accepted as such and investment made accordingly. In most instances low input/low output models appear to be the most likely approaches to be adopted, with the justification for larger areas of forest generating rather lower yields of timber arising from a greater appreciation of the other ecosystem services that they provide (Forest Enterprise England, Natural Capital accounts, 2017).

Given the commercial and economic importance of UK conifer plantations a far better understanding of the extent to which additional resilience measures are required is in urgent need of development. To achieve this will require a sound understanding of the underlying ecology of forest resilience (see Part 1 in this series) and a sound appreciation of the diversity and character of forest communities that prevailed under climate conditions in the past (the subject of the forthcoming Part 3 in this series). Both will be required to inform future policy and practice (the subject of the last paper in this short series). In the meantime, current UK Forestry Standard requirements and the requirements of UKWAS certification give more than adequate room for innovation, experiment and trial in the development of more resilient silvicultural practice and technique.

Perridge Estate, Devon, 2015. This photo illustrates the potential future of resilient productive conifer forests as mixed species stands with groves dominated by a range of timber species, a thriving understorey of native elements and naturally regenerating younger conifers. Investment is required in establishing light demanding timber species within established woods, and natural generation of more shade tolerant species proceeds throughout the stands development. Soils are not exposed to leaching, waterlogging or drought, though silviculture is more demanding and complex and deer management essential. (Photo: JWS)

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Jonathan Spencer MBE is Head of Planning & Environment for Forest Enterprise England, with wide professional interests in the history and ecology of woods and forests, the conservation of their historical character and wildlife, and in forest resilience, silviculture and management.

Forest Enterprise, Forestry Commission England, 620 Bristol Business Park, Bristol BS16 1EJ.

Email: jonathan.spencer@forestry.gsi.gov.uk