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ROYAL FORESTRY SOCIETY

Research Review 2020

A review of recently published forestry-related research

Contents:

Introduction

Welcome to the first Quarterly Journal of Forestry Research Review. In this Royal Forestry Society member publication we review recently published forestry-related research, presented as short summaries of scientific research papers covering a diverse range of topics. This publication was made possible thanks to an RFS member donation. Compiled and edited by Freia Bladon.

Resistance of European ash to the emerald ash borer

The emerald ash borer (EAB; *Agrilus planipennis*) is a phloem-boring beetle that has severely affected ash (*Fraxinus*) species in North America and the Moscow region of Russia, causing widespread mortality of ash trees. Although there have been no reported discoveries in the UK to date, there is concern that if EAB arrived in Britain any European ash trees (*Fraxinus excelsior*) that had not succumbed to ash dieback may be wiped out by the beetle.

However, a new study offers some cautious optimism, finding that *F. excelsior* has moderately good resistance to EAB. Researchers inoculated ash saplings with EAB eggs and larval development was compared between *F. excelsior*, black ash (*F. nigra*) which is highly susceptible to EAB, and Manchurian ash (*F. mandshurica*) which, while not immune, has high but incomplete resistance (presumably due to the coevolution of the tree and the beetle, both being native to Northeast Asia). Researchers found that the frequency with which larvae of EAB developed to later stages in *F. excelsior* was much lower than in the highly susceptible *F. nigra*, but similar to that in the resistant *F. mandshurica*. Results suggested that while *F. excelsior* is not immune to initial attack by EAB, it has the resources to restrict the beetle's development.

While the results of this study are encouraging, the authors stress that caution should be taken in extrapolating these results to field settings although they note that in Russia, *F. excelsior* has suffered much less damage by EAB than the widely-planted, very susceptible green ash (*F. pennsylvanica*). There is also concern that *F. excelsior* trees suffering from ash dieback may be more vulnerable to attack by EAB - the resistance of *F. mandshurica* to EAB is diminished when stressed environmentally.

The researchers did not find evidence for genetic variation in responses to EAB in *F. excelsior*, so there may be limited scope for tree breeding for EAB resistance. Instead the authors suggest that efforts to protect ash in the UK should focus on excluding the beetle through restricting imports of ash wood.

Adult emerald ash borer (EAB; *Agrilus planipennis*). (Photo: David Showalter)

Showalter, D.N., Saville, R.J., Orton, E.S., Buggs, R.J.A., Bonello, P. & Brown, J.K.M. (2020) Resistance of European ash (*Fraxinus excelsior*) saplings to larval feeding by the emerald ash borer (*Agrilus planipennis*). *Plants, People, Planet*. 2: 41-46.

Rewilding forestry

Rewilding is increasingly being considered as an environmental management strategy, with the potential to restore degraded ecosystems and enhance biodiversity. The concept is proving highly popular amongst conservationists, ecologists, policy makers and others. Several major rewilding projects have been implemented in the UK, for example at Glen Affric in Scotland, Ennerdale in Cumbria and Knepp Castle Estate in West Sussex, and such projects are being held up as conservation best practice.

However, as a new paper highlights, this interest in rewilding has seemingly not been mirrored amongst forest scientists, with very few research outputs engaging with the concept. Dandy and Wynne-Jones (2019) offer some potential explanations for this lack of engagement, and argue that there is much to be gained from an increased interaction between forest science and rewilding. For example, the authors suggest that "certain silvicultural approaches, such as continuous cover forestry or low-impact silvicultural systems, could usefully inform rewilding projects in their immediate approaches to transition from even-aged species diversity poor forests to forests more sympathetic to long term 'natural' autonomy". There are other parallels between certain aspects of forestry

Grazing can be an integral element of 'rewilding' efforts. (Photo: Chris Sandom)

and rewilding, an example being the obvious synergy between rewilding and the restoration of plantations on ancient woodland sites (PAWS) scheme.

Dandy and Wynne-Jones suggest that "rewilding has considerable potential for refreshing and reframing aspects of forestry policy and practice, including approaches to resilience". There are, however, "substantial unanswered questions regarding what the forests and forest management systems might look like that meet the demands of the rewilding agenda whilst also producing the material and cultural benefits (e.g. timber, recreation, flood protection) that contemporary forestry currently supplies". Moving forward it appears critical for forest science to engage more strongly and directly with rewilding - there appears to be a growing demand for knowledge that effectively integrates the two.

The authors point out that their 2019 paper is a commentary, and welcome comments and feedback on the topic.

Dandy, N., & Wynne-Jones, S. (2019) Rewilding forestry. *Forest Policy and Economics*. 109: 101996.

Direct seeding: Established native woodland cover of birch, rowan and alder, 10 years after cultivation and sowing. (Photo: Forest Research)

Direct seeding and upland woodland restoration

Previous work by Willoughby et al. has highlighted the potential of direct seeding in the creation of new broadleaved woodland in Britain (see references within Willoughby et al. (2019) below). In recent years there has been increased interest in the technique of direct seeding, given its potential advantages over conventional planting from silvicultural, environmental and economic perspectives. New research by Willoughby and his co-authors suggests that direct seeding can also be a viable technique for converting upland non-native conifer forest back to native woodland consisting of birch (*Betula pubescens*), rowan (*Sorbus aucuparia*) and alder (*Alnus glutinosa*), on less fertile, freely drained restock sites. The research shows that direct seeding has the potential to create diverse, resilient woodland that is more naturalistic in appearance and denser spaced than that produced by conventional planting, and at a similar cost. However, the authors stress that an appropriate silvicultural regime is essential to the success of the technique with several key elements requiring careful consideration; site selection, species choice, sowing rates, sowing date, seed pre-treatment, cultivation, protection and weed control.

Willoughby, I.H., Jinks R.L. & Forster, J. (2019). Direct seeding of birch, rowan and alder can be a viable technique for the restoration of upland native woodland in the UK. *Forestry*. 92(3): 324-338.

Irregular silviculture and woodland birds: Left: A stand which is a well-developed transformation to irregular high forest. Right: Marsh tit *Poecile palustris*. (Photos: Daniel Alder)

Irregular silviculture and woodland birds

Continuous cover forestry (CCF), sometimes referred to as 'irregular forestry', continues to gain support within the UK and European forestry sector. With this growing interest in CCF there is an increasingly important need to improve our understanding of the responses of biodiversity to a shift to irregular silviculture from other silvicultural systems.

The results of a recent study, one of the first of its kind in Europe, help to contribute to such understanding. Researchers looked at the implications of transformation to irregular silviculture for woodland birds within temperate English broadleaf woodland. Several species of woodland birds in Britain have undergone significant declines in recent decades, in some cases associated with changes in woodland structure, and there is particular interest in whether irregular forestry can aid the recovery of such populations.

Researchers compared woodland structure and bird abundance across four stand types in a large working broadleaf woodland in lowland southern Britain: limited intervention (formerly managed, now neglected); coppice; irregular high forest; and transitional high forest (being managed towards irregular high forest).

The results highlighted important differences in both woodland structure and bird communities between stand types. Irregular stands were characterised by a more open woodland structure with larger trees, a developing understorey and an intimate mixture of tree ages - unlike any other stand type. Within these irregular stands, breeding bird abundance was the highest for 10 of the 20 species studied, compared with five in coppice, three in transitional, and only two in limited intervention.

The results suggest that irregular silviculture in the UK's broadleaf woodlands can provide several British bird species with a highly suitable and in some cases preferred habitat, particularly compared with under-managed woodlands. Some species of conservation concern are especially likely to benefit from the wider adoption of irregular silviculture e.g. marsh tit *Poecile palustris,* which during the breeding season was found to be twice as abundant in irregular high forest than in any other stand type within the study. The findings also suggest that many woodland bird species in Britain are likely to benefit from neglected woodland being brought into active management.

Alder, D.C., Fuller, R.J. & Marsden, S.J. (2018) Implications of transformation to irregular silviculture for woodland birds: A stand wise comparison in an English broadleaf woodland. *Forest Ecology and Management*. 422: 69-78.

Tree restoration and climate change mitigation

In a high profile study published in the journal *Science*, Bastin et al. suggest that restoration of the Earth's natural tree cover should be considered as one of the most effective means of removing carbon dioxide from the atmosphere and tackling climate change.

The study is the first to quantify the global tree restoration potential - how many trees the Earth can support and where they could exist - and their associated carbon storage potential. The research, which utilized satellite imagery from Google Earth and machine learning to produce a predictive model, estimates that globally there is space for an extra 0.9 billion hectares of trees in areas that would naturally support tree cover (excluding urban or agricultural land). These extra trees could remove and store 205 (+/- 71) gigatonnes of carbon from the atmosphere at maturity, a considerable proportion of the extra carbon that remains in the atmosphere today as a result of human activity (~300 gigatonnes). This novel analysis is valuable in demonstrating that the potential for tree restoration to mitigate climate change may previously have been underestimated, although the authors do not suggest that tree restoration should be considered as the unique solution to climate change. The publication of the paper provoked a huge reaction from the media, and stimulated some intense debate within the scientific community – some groups have supported and some disputed the findings.

Bastin, J.-F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Zohner, C.M. & Crowther, T.W. (2019) The global tree restoration potential. *Science.* 365: 76-79.

State and sustainability of British urban forests

Understanding the condition, composition and structure of British urban forests is key to ensuring their sustainability. Whilst some countries around the world have a detailed understanding of the condition and sustainability of their contemporary urban tree populations, in Britain such comprehensive information is lacking. However, one new study provides data that acts as a basis to this understanding, examining the composition, condition and structure of 12 British urban forests, and recommends a framework to assess their sustainability using indicators including canopy cover, size diversity, species diversity, tree condition and site suitability based on hardiness to cold.

The study examined data from i-Tree Eco surveys – these surveys allow quantification of the structural characteristics of the urban forest using tree measurements and other data, and include trees on both public and private land.

Researchers found that generally urban trees are in good condition and are well suited to current minimum winter temperatures. However, the size distribution of trees in many areas requires improvement and more large size trees are needed. In addition, tree species diversity is generally low, and the authors recommend that in order to improve the resilience of our urban forests, their species composition should be diversified. Using their sustainability framework, the authors report that of the 12 cities studied overall Cardiff's urban forest ranked the highest, with Burton, Oldham, Swansea and Wrexham lacking sustainability.

The authors suggest that wider use of the framework developed as part of this study, alongside the establishment of detailed tree strategies, could help local authorities work towards improving the sustainability of urban forests in Britain.

Vaz Monteiro, M., Handley, P. & Doick, K. J. (2020) An insight to the current state and sustainability of urban forests across Great Britain based on i-Tree Eco surveys. *Forestry*. 93(1): 107-123.

Scots pine highly attractive to mountain pine beetle

The North American mountain pine beetle, *Dendroctonus ponderosae*, is an aggressive bark beetle native to western North America. The beetle attacks and kills a wide range of pine trees including lodgepole and ponderosa pine, targeting large mature trees. An ongoing outbreak of mountain pine beetle that started in British Columbia in the early 1990s has destroyed more than 18 million hectares of forest, and the beetle is currently expanding its geographical range due to climatic warming, and now colonizing and killing novel hosts.

Mountain pine beetle *Dendroctonus ponderosae* actively boring on a Scots pine in the Black Hills of South Dakota where this study was conducted. (Photo: Derek Rosenberger)

There is limited understanding of how conifers might fare if a novel aggressive North American bark beetle like mountain pine beetle were to be introduced to Europe. However, a new study's findings strongly suggest that a novel host - Scots pine (*Pinus sylvestris*) - is highly attractive to mountain pine beetle. The authors found that mountain pine beetle can detect, attack and kill Scots pine trees, and in a retrospective assessment of an outbreak found that nearly 90% of Scots pine showed signs of attack. While the tree's ultimate vulnerability to mortality in outbreaks remains uncertain (there was some evidence that the density of attack and likelihood of mortality was lower relative to ponderosa pine), the results are important in that they suggest that Eurasian Scots pine forests are at risk should the insect be accidentally introduced. Mountain pine beetle has previously been intercepted in international trade, and some evidence suggests that even small founder populations can give rise to outbreaks.

Rosenberger, D.W., Venette, R.C. & Aukema, B.H. (2019) Susceptibility of Eurasian Scots pine, *Pinus sylvestris* L., to the aggressive North American mountain pine beetle, *Dendroctonus ponderosae* Hopkins. *Forest Ecology and Management*. 445: 20-25.

High variability in tree marking

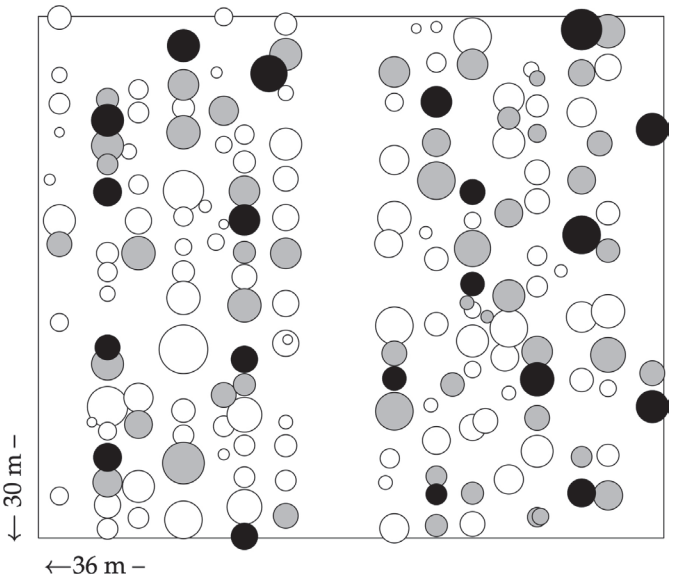
A new citizen science study has highlighted that the variability of selecting individual trees for forest management operations is considerable. Teaming up with the Forestry Commission Ae Training Centre, an international team of researchers studied the decision-making behaviour of forest practitioners at 36 silvicultural training sites throughout Britain.

Forest practitioners were asked to apply two different thinning methods, low and crown thinning, and to mark trees accordingly, where the latter plays a crucial role in continuous cover forestry.

The results of the study suggest that tree marking in forestry is far from being exact, and that general agreement on the selection of individual trees is only slight to fair, which the authors suggest is contrary to textbook and common industry opinion.

The researchers also found that the variability in selecting trees was generally considerably lower in low thinnings compared with crown thinnings. The authors suggest that this is due to UK forestry practitioners being traditionally more familiar with and better trained in applying low thinning methods. However, since crown thinning is an important component of continuous cover forestry, and as this approach to silviculture is becoming more widely adopted in the UK, the authors suggest that there is a need for more training in this thinning method and that the training also includes machine operators. Given the same instructions, practitioners new to forestry surprisingly often mark trees for crown thinnings more accurately and more consistently than experienced practitioners. The authors relate this unexpected finding to the fact that the thinking of novices is less influenced by past experience or traditional practices.

The study also showed that the decision-making process



Map of frame trees (= future crop trees, black) and their competitors (grey) marked for thinning by a student of Bangor University at a training site in Clocaenog Forest (North Wales). (Image: Arne Pommerening)

when marking trees was facilitated in stands that were more complex in stem-diameter and canopy structure, perhaps due to the stronger contrasts between alternative choices. The authors suggest that this should be taken into consideration in the design of future training plots, and recommend that training should also include more varied stand structures such as those resulting from continuous cover forestry.

The authors developed new analysis methods of human tree selection behaviour and are willing to share them with interested practitioners and organisations. Contact: arne.pommerening@slu.se.

Pommerening, A., Pallarés Ramos, C., Kędziora, W., Haufe, J. & Stoyan, D. (2018) Rating experiments in forestry: How much agreement is there in tree marking? *PLoS ONE*. 13(3): e019474.

Value of small woodlands

A recent study has found that small woodlands in agricultural landscapes are of greater value than previously thought.

The study looked at 224 small and larger forest patches in agricultural landscapes across Europe (covering France, Belgium, Germany and Sweden). The diversity of six taxonomic groups was assessed, along with the potential of these forest patches to supply various ecosystem services incorporating provisioning, regulating and cultural services.

The researchers unexpectedly found that although smaller woodlands in agricultural landscapes supported lower overall biodiversity than larger woodlands, they have the potential to deliver multiple ecosystem services at a higher level on a per area basis than larger woodlands, particularly if they are classed as ancient. The authors attribute this to the positive edge effect within these small woodlands (some as small 0.4ha). Smaller woodlands have a relatively high edge-to-core ratio compared to larger forests, meaning that more light penetrates, the microclimate is warmer and drier and there is more nutrient input from surrounding farmland. The authors suggest that this can in turn alter the delivery of some ecosystem services. For example, topsoil carbon storage is increased due to an increased soil biological activity, meaning that soils may have the capacity to act as better carbon sinks and aid in mitigating climate change. The risk of tick-borne disease is lower, likely due to unfavourable microclimate conditions for tick larvae. Also, in the landscape studied where roe deer represent an important game species, game (roe deer) production potential was increased in smaller woodlands due to an increased abundance of palatable plants.

Given the value of these small woodlands in agricultural landscapes, the authors draw attention to the fact that such woodlands are not currently considered by major policies such as the EU Natura 2000 network and the Common Agricultural Policy, and urge for the development of policy instruments that ensure their future conservation.

Valdés, A., Lenoir, J., De Frenne, P. et al. (2020) High ecosystem service delivery potential of small woodlands in agricultural landscapes. *Journal of Applied Ecology*. 57(1): 4-16.

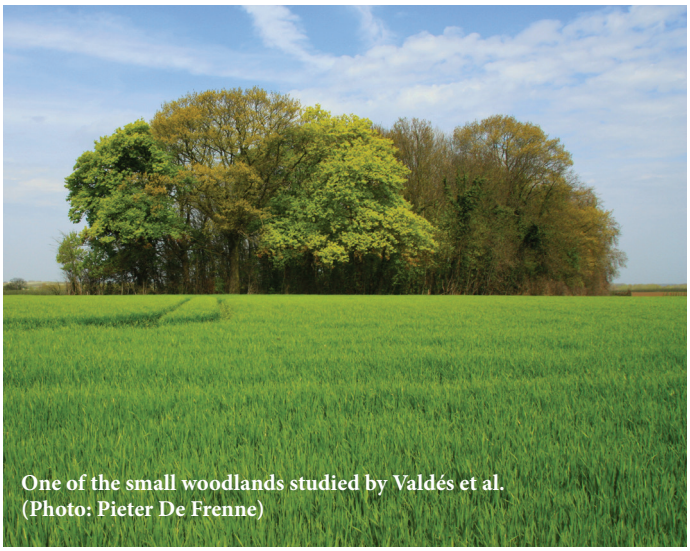
Genetic basis of resistance to ash dieback

New research has identified the genetic basis of resistance to ash dieback in UK populations of European ash (*Fraxinus excelsior*) trees, offering new hope for the future of ash trees in the landscape.

Researchers sequenced DNA from over 1,250 ash trees across 14 sites in southeast England (part of Forest Research's mass screening trial) to find inherited genes associated with ash dieback resistance.

The study found that ash dieback resistance is a highly polygenic trait, controlled by multiple genes – more than 3,000 locations in the DNA of ash trees were found to contribute to resistance. This suggests that breeding programmes for the development of more resistant ash may be viable and breeding could be accelerated by predicting the resistance of trees on the basis of genetic markers.

Current Forestry Commission England guidelines for woodland managers focus on the enhancement of natural selection, and recommend that ash trees without ash dieback symptoms should be retained for as long as possible and measures be taken to promote natural regeneration from these trees. The results of this new study suggest that this approach is likely to be effective in increasing the proportion of trees showing resistance to ash dieback in woodlands.
The findings are encouraging from a long-term perspective and



One of the small woodlands studied by Valdés et al. (Photo: Pieter De Frenne)

Variation in ash dieback in a wood in Surrey. (Photo: Richard Buggs)

offer hope that restoration of ash woodlands may be possible either by natural regeneration or selective breeding.

Stocks, J.J., Metheringham, C.L., Plumb, W., Lee, S.J., Kelly, L.J., Nichols, R.A., & Buggs, R.J.A (2019) Genomic basis of European ash tree resistance to ash dieback fungus. *Nature Ecology and Evolution*. 3: 1686-1696.

Mapping the 'wood wide web'

Beneath every forest is a vast interconnected subterranean network of root-associated microbial symbionts that are essential for tree growth and survival. This 'wood wide web' of symbiotic microbes – bacteria and fungi – is vital in enabling trees to access limiting nutrients, sequester carbon and withstand the effects of climate change. A recent study by Steidinger et al. (2019) has for the first time mapped these symbiotic microbial networks, providing information on which tree-associated microbes live where and why. The team used a database of over 1.1 million forest inventory plots containing over 28,000 tree species across more than 70 countries, and machine learning to complete the global map. Mycorrhizal fungi are the most abundant symbiotic partners; arbuscular mycorrhizal fungi (AM) penetrate the host root cells, while ectomycorrhizal fungi (EM) surround the roots without penetrating them. Both EM and AM are heavily influenced by variables such as temperature and moisture. The study found that 60% of the world's trees are connected to adjacent trees by vast networks of EM, and that EM fungi are dominant in high latitude, temperate and boreal forests. These EM fungi play a crucial role in helping to sequester carbon from the atmosphere and are more vulnerable to climate change than AM fungi. AM fungi are more dominant in lower latitude, tropical forests, where they enhance carbon cycling and promote rapid tree growth. The authors predict that if carbon emissions continue unabated to 2100, there could be be a 10% reduction in EM fungi (and the tree species they support) across the globe, being replaced by AM fungi, and that this could ultimately cause an increase in atmospheric carbon levels. Data from this study will aid future research into how forests respond to and contribute to global climate change.

Steidinger, B.S., Crowther, T.W., Liang, J. et al. (2019) Climatic controls of decomposition drive the global biogeography of forest-tree symbioses. *Nature* 569: 404–408.

The economic cost of ash dieback

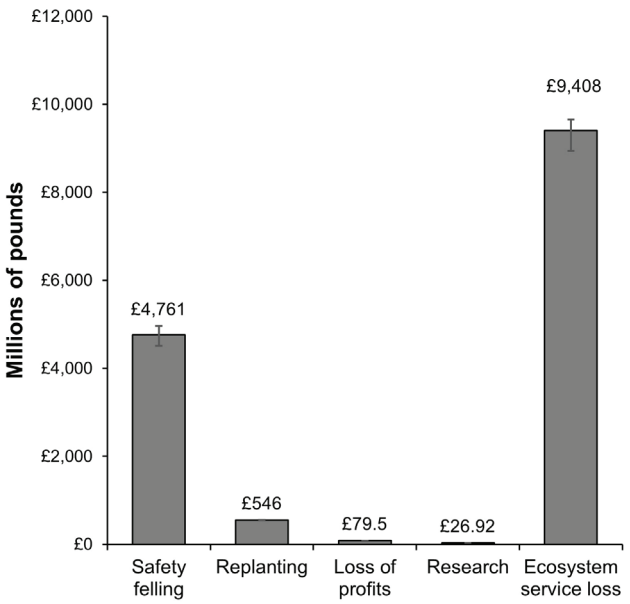
Until recently, there had been no attempts to estimate the full economic cost of a tree disease. However, researchers have now done just this - for ash dieback in Britain - and the results have shocked many. Using data from a wide variety of sources, researchers estimated that ash dieback will cost the British economy £14.8bn (over 100 years), and more than half of this (£7.8bn) is expected to be incurred within the next 10 years. This total is a third more than the cost of the foot-and-mouth disease outbreak in 2001, and 50 times larger than the annual value of trade in live plants to and from Britain, which is the most important route by which invasive tree pests and diseases enter the country.

The largest component of the total predicted cost was the loss of ecosystem services such as water and air purification and carbon sequestration. However, other significant costs were also identified that would have been missed by methods such as Natural Capital accounting and Payment for Ecosystem Services assessments. Clean-up costs, such as felling dangerous trees on roadsides, railway lines and in towns and cities contributed £4.8bn to the total. Many of these clean-up costs will fall to local authorities with the worst affected, Devon County Council, expected to incur annual costs of over £30 million.

The authors recommend a nationwide planting scheme, replacing lost ash trees with other native trees, and estimate that this could reduce the overall cost by £2.5bn by ensuring that lost ecosystem services are replaced.

As part of the study researchers also identified 47 other tree pests and diseases that could arrive in Britain and cost an additional £1bn or more. The authors advise that there should be a greater focus on and investment in plant biosecurity measures to protect our remaining tree species, including far tighter controls on imports of live plants.

Hill, L., Jones, G., Atkinson, N., Hector, A., Hemery, G., & Brown, N. (2019) The £15 billion cost of ash dieback in Britain. *Current Biology*. 29(9): 315–316.



Components of the total tangible cost of ash dieback in Britain. (Image: Louise Hill)

Structurally complex forests sequester more carbon

The amount of carbon that forests sequester is known to be influenced by both species diversity and the density of vegetation. However, new research has found that forest structural complexity is the strongest predictor of carbon sequestration potential – structurally variable forests with multi-layered canopies sequester more carbon.

Researchers used novel lidar technology to sample canopy vegetation arrangement across a number of temperate forest types in eastern USA, and examined the link between canopy structural traits and net primary production (NPP), a measure of the amount of carbon that is invested in plant biomass. The study found that forest structural complexity was the most important driver of NPP (and hence carbon sequestration potential), with forests that are highly variable in terms of the vertical and horizontal arrangement of vegetation sequestering more carbon.

The authors suggest that this is because vegetation in structurally complex forests is able to absorb and use light more efficiently due to the multiple layers of leaves present compared with a single layer of vegetation in structurally simple forests. Multi-layered canopies contain a complement of sun and shade leaves adapted to function in a range of light environments, meaning that overall a structurally complex canopy is more efficient at utilising light. This in turn means NPP/wood production in structurally complex forests is increased and consequently the amount of carbon sequestered enhanced.

The authors note that these results could have implications for forest management and land-use policies, given that preserving and enhancing the structural complexity of forests could increase their capacity to act as a global carbon sink. The study also suggests that there is potential to use lidar to accurately assess forest structural complexity, and so could be used as a novel method of predicting the carbon sequestration potential of forests.

Gough, C.M., Atkins, J.W., Fahey, R.T., & Hardiman, B.S. (2019) High rates of primary production in structurally complex forests. *Ecology*. 100(10): e02864.

Structurally complex forests studied by Gough et al: The cove forests of the Great Smoky Mountains National park, USA are rich in both structural and biological complexity, supporting high rates of forest productivity. These forests are home to over 100 woody species. (Photo: Jeff Atkins)

Front cover: Variation in ash dieback in a wood in Surrey. (Photo: Richard Buggs)

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