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THE ROLE OF OUR OWN CONIFER FORESTS FOR BUILDING A SUSTAINABLE SOCIETY IN WALES

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THE ROLE OF OUR OWN CONIFER FORESTS FOR BUILDING A SUSTAINABLE SOCIETY IN WALES

Report – December 2020

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Sir Dietrich Brandis designed modern sustainable forest management protocols to tackle deforestation in Burma over 150 years ago on behalf of British politicians and was knighted for his efforts; his methods were later adopted by the forest service of the USA. American academic Roger Sedjo suggested 40 years ago that the planting of novel high yield industrial forests could ameliorate global deforestation; later he shared a Nobel Prize for his contribution to the IPCC. Tālis Kalnārs introduced the central European concept of perpetual forestry to Wales and suggested that this nation could be transformed to a forest-based economy; he was awarded the MBE. Honourable scientists and foresters across the planet have dedicated their lives to explaining the role of plantation forests in tackling *laissez-faire* exploitation of natural forests. The forest science originally set out by Brandis has been taught for over a century at Bangor University, the first in Britain to offer forestry degrees. The WWF and FAO embrace plantation forests and yet in Wales these forests are critically misunderstood and undervalued.

The author of this report makes no apology for quoting the following passage from a recent academic article ominously entitled *Underestimating the Challenges of Avoiding a Ghastly Future:*

> *Humanity is causing a rapid loss of biodiversity and, with it, Earth's ability to support complex life. But the mainstream is having difficulty grasping the magnitude of this loss, despite the steady erosion of the fabric of human civilization. While suggested solutions abound, the current scale of their implementation does not match the relentless progression of biodiversity loss and other existential threats tied to the continuous expansion of the human enterprise. Time delays between ecological deterioration and socio-economic penalties, as with climate disruption for example, impede recognition of the magnitude of the challenge and timely counteraction needed. In addition, disciplinary specialization and insularity encourage unfamiliarity with the complex adaptive systems in which problems and their potential solutions are embedded.*
>
> *Widespread ignorance of human behavior and the incremental nature of socio-political processes that plan and implement solutions further delays effective action.*
>
> *We summarize the state of the natural world in stark form here to help clarify the gravity of the human predicament. We also outline likely future trends in biodiversity decline, climate disruption, and human consumption and population growth to demonstrate the near certainty that these problems will worsen over the coming decades, with negative impacts for centuries to come. Finally, we discuss the ineffectiveness of current and planned actions that are attempting to address the ominous erosion of Earth's life-support system. Ours is not a call to surrender—we aim to provide leaders with a realistic "cold shower" of the state of the planet that is essential for planning to avoid a ghastly future.*

www.frontiersin.org/articles/10.3389/fcosc.2020.615419/full

Image 1: Douglas fir in north Wales, one of the largest conifer trees in Europe.

EXECUTIVE SUMMARY

- The WWF and FAO embrace plantation forests and yet in Wales these forests are critically misunderstood, undervalued and often denigrated.
- *Quality* is regularly used as a weasel word in order to reinforce negative views about Welsh homegrown softwoods. The term *quality* is better ascribed to end products, not wood types.
- Plantation forests comprise around 7% of the planet's forest area whilst sustainably supplying over 50% of industrial roundwood.
- Modern British sustainable forest management techniques were established 150 years ago and are still appropriate for efficiently growing construction grade softwoods.
- Exemplar stands of high grade Douglas fir in north Wales grow some of the largest conifer trees existing in Europe.
- Older conifer stands across Wales have great potential to produce high grade joinery softwood.
- Sitka spruce forests are routinely denigrated, nevertheless over 95% of Welsh spruce sawlogs can be graded to strength class from C16 to C27 because of Sitka spruce's high strength to weight ratio.
- The FAO reported in 2013 that current trends in European forest management could result in an over-supply of wood from broadleaved species, as well as a shortfall of coniferous timber.
- Planted forests are exposed to socio-economic risks due to governance failures. These risks comprise a weak or inadequate forest policy framework including insecure investment conditions.

INTRODUCTION

Several well-known foresters and academics who have worked in Wales, for instance Charles Ackers (associated with the Leighton Redwood Grove), Tālis Kalnārs MBE and Roger Cooper of Bangor University have promoted Wales and western Britain as ideal for growing conifers. Kalnārs and Cooper even suggested that forest-based industries in Wales could play a leading economic role with conifer forests as the new principal industrial renewable resource. Informed foresters nowadays agree that the Welsh environment could sustainably grow more high-yield conifer forests on grade 3b agricultural land or currently underutilised wasteland such as bracken-infested land. As far as Wales' future is concerned, exemplifying one species over sixty years ago Charles Ackers quite clearly saw huge potential for Welsh homegrown Douglas fir comparing it to that grown in Washington and Oregon: *There is no reason to suppose that we cannot grow in our western counties equally good 80 year old crops*. However, it is still a commonly held belief that fast growth of conifer species in Britain produces low grade timber. This overused trope has often been cited as the barrier for using homegrown softwoods in construction as well as other value-added applications such as joinery.

Spruce sawnwood processed in the new generation of Welsh sawmills built during the 1980s to convert 20-30 year old thinnings was known to be notoriously unstable in drying. This was because of the high proportion of juvenile corewood present in the logs from young forests; it generally occurs in the first 10-20 annual growth rings. Trees grow mature heartwood after transitioning from this juvenile phase. Juvenile corewood does influence the characteristics of British structural timber but for decades world experts such as Bruce Zobel have pointed out that the same issue arises with young plantation-grown timber all over the world. Zobel has also repeatedly pointed out that because fast grown mature heartwood looks like juvenile corewood, commentators have mistakenly

assumed that their physical characteristics are similar. Fast grown softwoods are regularly utilised for high quality applications in construction nowadays regardless of old normative perceptions. Using high grade timber from old-growth forests is anyway not ethical or sustainable therefore timber users need to better understand, optimise and utilise the characteristics of their local sustainably grown plantation timber. As plantation trees in Britain grow older and continue to lay down mature heartwood growth rings then they can yield higher proportions of high grade, stable, useful timber. Considerable debate exists around the physical characteristics of timber grown under continuous-cover forest (CCF) management. Experts such as New Zealand scientist John Moore point out that even-aged planted forests produce more consistent wood properties whilst CCF stands tend to produce less consistent, lower grade timber with larger knots. This is a complicated topic but generally speaking the more complexity is created within forest structures, the more wood variation can be expected. However, modern sawmills demand increasingly consistent sawlogs in order to operate efficiently at economic scale. The material characteristics of wood improve radially from pith to bark. For instance, during sawmilling the first boards to be cut from the outside of Sitka spruce sawlogs are the stiffest and strongest. Until recently these high performance outer falling boards have tended to be judged as low grade by traditionalists; wood science can be counter-intuitive. Fewer than five text books (including some written by Bruce Zobel) need to be studied in order to understand the wood science necessary for the modern, sustainable forest products industry. This author suggests it is unlikely that more than five commentators working in Wales have read all five books. A suggested reading list can be found at the end of this report.

MODERN SAWMILLING

Informed foresters and wood scientists now consider sheltered parts of Wales to be amongst the best places in Britain and Europe to grow conifers. Future climate change scenarios suggest that western Wales will continue to be capable of growing high yield conifer forests. Those zones with higher rainfall in late summer and autumn will be able to grow conifers with wider latewood rings. Latewood contributes significantly to overall wood density and stiffness, the most important wood properties. Fifty year old sawlogs are commonplace nowadays in the UK and the sawmilling industry has matured. BSW Newbridge on Wye has produced up to 40,000m^3 annually of kiln dried, strength graded, planed C16 softwoods for a demanding construction industry. However, the Newbridge sawmill's own C16 supply chain seems incapable of directly cooperating with the Welsh building sector. This sawmill was mothballed with the onset of Covid 19 but restarted production during summer 2020. Nevertheless its long term future has been in doubt for several years and BSW spokesman Hamish McLeod confirmed in 2019 that BSW would not renew the aging sawline (subsequently the whole of the BSW group was sold to a private equity firm). Judging by the new owners' past performance a leading economist has suggested that BSW are now even less likely to invest heavily in the Newbridge sawmill. Contrastingly, Pontrilas Timber in The Marches has installed one of newest resawing, planing and strength grading lines in the UK capable of grading two C16 joists every second. This sawmill has created a protocol for chain of custody along its processing line so that certificated, labelled C16 Welsh spruce can be offered at volume. Pontrilas sawmill is currently the most efficient and most likely choice for the Welsh construction sector to procure C16 Welsh spruce.

Normative judgements in regard to wood properties and superficially perceived value are not useful. There is enough scientific evidence within existing wood science literature by the likes of Zobel and Buijtenen or Haygreen and Bowyer to counter naïve or agenda-driven generalisations in regard to wood properties regardless of where in the world forests are grown. We know that it is readily possible to grow construction grade timber in Wales; nearly 100% of Welsh Sitka sawlogs will grade to C16. However, UK sawmillers gain no extra profit from processing to C24 grade and are unwilling to undertake mixed C16/C24 production although this is technically possible. Global price volatility make strength graded commodity softwoods troublesome products. The increasing strength of the pound against the euro and the Swedish krona in 2015 made imported construction grade softwood cheaper compared with homegrown material. By 2016 the pound weakened again considerably after the Brexit vote. 2019 saw climate change and disease driving massive sanitation fellings of European spruce. European merchants were then able to oversupply construction softwood into the UK in case of an early no-deal Brexit. When Covid 19 caused market uncertainties early in 2020, Pontrilas sawmill raised their C16 spruce prices by over 25% seemingly to claw back some of the severe trading losses incurred by attempting to match the earlier aggressive European softwood pricing. Price volatility of construction softwoods is also a massive economic challenge to American sawmillers despite having their own random length lumber futures market. It is operated by the CME Group, the world's largest financial derivatives exchange. CME say of lumber: *Prices react to supply and demand imbalances with frequent and often extreme changes.* US lumber prices have reached their highest recorded levels as of November 2020 whilst similar European softwood sawn products were being sold at record low prices of around 180 Euros/m^3 earlier in the year.

ECONOMICS

Several previous Woodknowledge Wales reports have demonstrated that it is technically feasible to use homegrown softwoods in various light-framed panel types, glulam and massive-wood panel types. However technical feasibility does not guarantee economic viability when markets are driven by volatile currency exchanges. Strength grading of timber does not magically add financial value and British rough sawn fencing grade softwoods routinely sell at higher prices than kiln-dried, planed, C16 strength class homegrown construction grade softwoods. Within the UK sawmillers sometimes trade C16 spruce at a loss in order to try and retain their own market share in the face of cheap imports. During 2019 Northern Ireland sawmillers Balcas were selling C16 spruce for 160/m^3 to English merchants. Meanwhile mainland British processors reported that they were selling their C16 sawnwood at a loss partly because UK sawlogs were achieving the highest recorded prices for decades. A decade ago, the Japanese government adopted a points system for timber housing as part of their wood encouragement policy. New houses were subsidised up to 300,000 yen (£1640 at 01/03/15) for buyers who specified the use of homegrown softwood. However no such premium payment process exists in the UK to ameliorate price volatility caused by currency or market fluctuations. Innovative incentives may be necessary to make homegrown structural softwoods the norm for British housebuilders; establishment of a UK softwood futures trading scheme has been mooted. However, American softwood prices are if anything more volatile than British despite the US random lengths lumber futures market.

Implementation of more sophisticated homegrown softwood sawlog selection protocols from forest to log yard before sawmilling may offer potential to match higher value timber to particular applications. The use of language is important. For instance in Britain, large diameter sawlogs are dismissively called "oversize" logs and larger sawmillers try to depress prices of these niche sawlogs. Conversely, large diameter sawlogs from plantations in Japan are sold at a considerable premium for niche products. There are no common sawmilling descriptors for the different types of large diameter softwood sawlogs which enter the UK's roundwood market. This is despite the wide range of wood types or grades present in different zones of large diameter sawlogs or the huge variation between individual large diameter sawlogs. For instance some trees grow very fast throughout their lives laying down wide growth rings, others may have various zones of wide and narrow growth rings and some large logs may have consistent growth rings from pith to bark. Further selection from particular mature heartwood zones after sawmilling may offer significantly higher returns for particular cuts within individual sawlogs. Strategic cutting patterns will yield high grade material. For instance, outer falling boards are of higher density and higher stiffness (MOE); however this material tends to be sold as pallet wood in the UK.

Species such as Douglas fir, which are already valuable on global markets, may offer opportunities for differentiation and selling into markets with higher margins where economic viability is not so dependent on the strength of the pound against other currencies. Wood science defines and measures the material characteristics of wood types allowing informed selection in order to optimise use of varying material properties appropriately. To add to information contained in this report, readers can also access the USDA's *Wood Handbook* freely available from here: http://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf

DISINGENUOUS DEBATES ABOUT 'QUALITY'

UK foresters of an earlier generation such as Elwes, Craib, Chalk, Turnbull, Edlin, Ackers and Hiley wrote enthusiastically about the great potential for plantation forests of exotic tree species. These foresters worked all over the world and had a broad overview of forestry; they were inspired by the potential for growing high yield forests to produce useful, high grade softwoods. Elwes travelled thousands of miles across Britain to record every species of exotic tree growing outdoors for his book *The Trees of Great Britain and Ireland.* Elwes also travelled abroad extensively, for instance to Japan; he was one of the first Europeans to study Japanese tree species such as larch. Chalk and Hiley were amongst the first to report on wood properties of fast grown Douglas fir in Britain. Craib, Hiley and Turnbull studied and reported the properties of fast grown pine in South Africa. However, whilst publishing positive results from experiments in plantation forest management some British foresters were accused of growing 'rubbish'; the fast growth of some conifers under UK conditions was misinterpreted by non-experts. The findings of both Hiley and Turnbull were disingenuously debated from 1955 to 1958 with (amongst others) the practical forester Charles Ackers doggedly supporting the notion that we can grow useful softwoods of high value to British society.

Over sixty years later the neoromantic fashion for denigrating the 'quality' of wood from planted conifer forests in Britain continues. Some NGOs and membership organisations, for instance the Structural Timber Association (STA) directly contradict scientific evidence from expert institutions

such as Edinburgh Napier University. Careers of several journalists, for instance Michael McCarthy and George Monbiot, have been bolstered by their neoromanticist rants against conifer forests at events such as The Hay Literary Festival. The anti-conifer storyline was also propagated in Japan by the Welsh/Japanese author of *Moving Zen*, C. W. Nicol. He was a well-known literary personality in Japan who often lambasted the industrial plantations of Japanese cedar which feed the Japanese housebuilding sector. The consequence of irrational anti-conifer propaganda is that even within the modern forestry and sawmilling industry the belief is sometimes expressed that we cannot grow high grade conifers in the UK. Strongly opinionated lobbyists have created absurd mythologies about modern forestry and contemporary researchers of sylviculture are forced reactively into justifying the existence of planted conifer forests in Britain. Anti-rationalist mythologies about scientific endeavour are easily propagated nowadays; well-educated westerners have been duped into doubting vaccines and debating climate change. However, recent political actions to implement nett zero carbon economies by using sustainable forest resources have encouraged many governments to re-examine the role of high-yield forest plantations. Their capacity to sequestrate CO_2 which can then be stored within the fabric of timber structures and products is difficult to deny, although some internet "trolls" continue in their quests.

The term 'wood quality' is often used and but rarely defined by its casual users. This term is generalist and generally unhelpful when describing and defining particular wood types or the variations of wood in order to ascribe appropriate applications using different properties. The term 'wood qualities' might be more useful because it takes into account the wide variations in properties found within tree stems, between trees, between forest stands and between zones in which they grow. Wood qualities need to be defined in terms of end use and fitness for purpose otherwise wood quality becomes an arbitrary term. Indeed because quality is often used as a judgemental weasel word, use of the neutral term 'wood properties' might be more appropriate. Users need to understand that timber from plantations is different from that of old growth forests but not necessarily of 'bad quality'. Fitness for end purpose is the only absolute criterion for selection of timber.

A 1960 article in *Unasylva* recounts the historical experience of New Zealand foresters with *Pinus radiata*. It is pertinent to the 60 year old 'wood quality' debate continuing here in Britain now:

> *The scale and speed of exotic planting have been so great in New Zealand that there have been acknowledged mistakes, but it is interesting to find how much success has been achieved.*
> *The exotic planting boom of 1923-36 led to serious mistakes and financial losses. It is wrong to attribute those losses to faults in the chief species concerned, P. radiata. The losses were due to mishandling. Subsequent successes have proved what an excellent tree is this pine when well handled, and how productive it is of good lumber and pulp if so handled. The New Zealand Forest Service considers among the major mistakes that were made in planting exotics were unsuitable sites, inferior seed and planting techniques, lack of tending (weeding, thinning), too wide spacing, inadequate fire protection, a bad age-class distribution, and, in some cases, poor location in relation to markets. This is a formidable list on which it is easy to be wise after the results are apparent.*

Furthermore with a degree of prescience in regard to current debate about design of future plantations the article says of mixed-age forests:

> *Those who advocate uneven-aged forests of intimately mixed species must take account of the strong preference of manufacturers for considerable coupes of one species and age to simplify and concentrate extraction work and give as much uniformity as possible to the batches of material arriving at any one time at the pulp mill or sawmill. It may be necessary to compromise between the planting of different species according to the varying sites available and the economic advantages of uniformity to the manufacturer so as to secure the optimum, avoiding both unhealthy or inadequate crops and undue processing costs.*

Problems associated with establishment and perception of conifer plantations in Britain were discussed by W. L. Taylor in *Journal of Forestry* in 1958. The author blamed dogma and inelastic formulae for harming conifer forestry in Britain; *it was authoritatively spread around that we could not grow quality conifers in Britain.* However, it was clear at the time that industrial plantation forestry was so new to this country that foresters could not possibly know enough about the complex interactions of seed quality with provenance, local conditions and the many other factors which influence forest growth. Hindsight is easier to use than foresight and the former is utilised by those detractors without the foresight and imagination to see the potential for conifer plantation forests. Taylor sums it up succinctly: *Softwoods are among the most versatile of natural products. Surely we grow our conifers to enable us to make the fullest use of this versatility*.

WOOD VARIATIONS; WELSH USPS

Wales has highly varied terrain, microclimate and soil types. Anything that can change tree growth patterns may cause wood variations according to wood scientist Bruce Zobel. Therefore the variability of the Welsh landscape gives huge potential to grow a wide range of softwood types even within a single species, see image 2 below. It is possible to find Welsh softwoods with growth rings as small as 1mm wide or as large as 25mm wide. The year 15 larch on the right of image 2 has growth rings up to 15mm wide, slow grown year 50 larch on the left has some growth rings around 0.5mm wide. The white scale-bars denote juvenile corewood. Commodity timber processors and even many smaller processors working with Welsh grown softwoods currently do not select in order to further valorise specialist timbers and do not understand the properties of the varying wood types in order to match them with appropriate products. This is hardly surprising; very little study of wood variation is carried out in the UK. Wales is in a unique position within the UK; owning a small, manageable plantation forest area with great potential for partial transformation to growing high value softwoods selected for appropriate high value applications. Trials with specialist processing and marketing of existing minor softwood species and oversize logs of principal species could allow SMEs to develop bespoke, branded products which are sold through differentiation rather than by lowest price in already crowded markets. We need to re-examine our conifer forests, understand the wood we grow and market it with a positive attitude.

Welsh forests cover around 300,000 ha, the management of which suffer from conflicting societal demands, expectations and aspirations. They comprise roughly half conifer, half broadleaved species. Only around half of the forest is managed and productive; this is the plantation conifer forest which is composed largely of exotic species brought originally from the Pacific northwest coast of America by the Scottish plant collector David Douglas in the early 19th century.

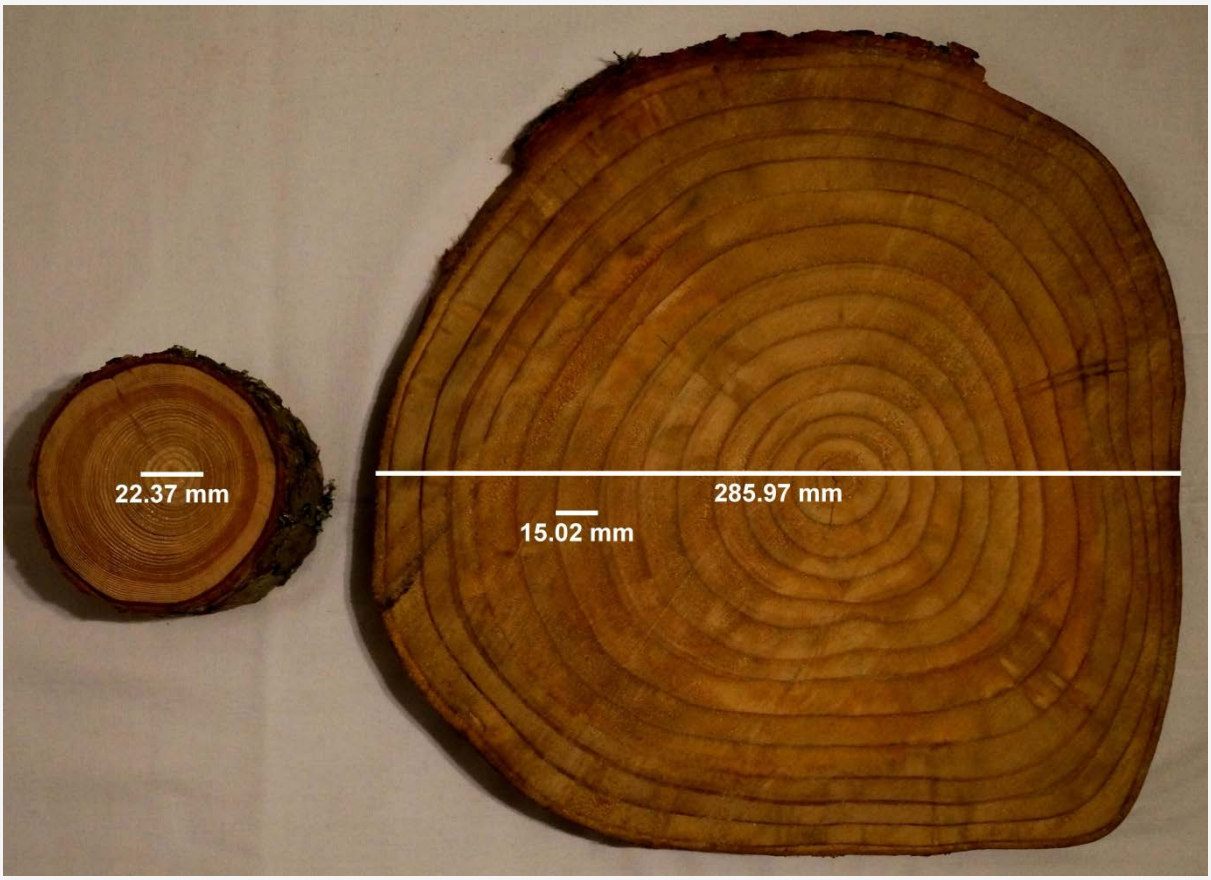


Image 2: 47 year old Japanese larch (left) & 15 year old (right) grown on Welsh sites 3km apart

We still have a limited understanding of the wood properties of many homegrown softwoods. Furthermore no large scale systematic study of wood properties of any species between sites had been undertaken in Britain before the 2007 Sitka spruce benchmarking project led by New Zealand forester John Moore. The final report was only published in 2011; therefore many of the judgements about use of Sitka spruce up to that date were at best subjective. Information on other UK-grown conifer species can be so scarce that researchers still refer to Gwendoline Lavers *The strength properties of timbers* published nearly half a century ago. Anyway because of changes in forest management practices some commentators such as John Moore suggest that historical data on wood properties may not necessarily be relevant now anyway. 60 years ago, forester W.L. Taylor considered the renaissance of forestry in Britain to be in its early stages. Although progress has been made especially through the efforts of researchers working in Scotland, we still lack basic data for many softwood species growing here. Zobel makes it clear that the only way to know what type of wood will be produced by exotic species in a particular environment is to grow them there and then study their timber properties. However, the type of wood science that we need to catalyse 'a renaissance of British forestry' is under-represented, and severely under-funded.

Douglas fir (arguably one of the most valuable conifer species growing in Britain in a changing climate) has been studied even less than Sitka spruce. The most comprehensive recent work was done by Jonathan Bawcombe and published as a thesis in August 2012; however this project only covered Douglas fir grown in southwest England. The UK-wide study of Douglas fir undertaken by

Tom Drewett under the aegis of SIRT (Strategic Integrated Research in Timber) based at Edinburgh Napier University was published in 2015. Despite the limited amount of recent research carried out on the properties of homegrown conifers, it is becoming clear that parts of western Britain are capable of growing softwoods comparable to plantation timber grown world-wide; Douglas fir being a case in point.

Jonathan Bawcombe's thesis on Douglas fir is available here;
http://opus.bath.ac.uk/32245/1/UnivBath_PhD_2012_J_Bawcombe.pdf

WIND INTENSITY IN BRITAIN

High average wind speeds across parts of Britain may strongly influence both hardwood and softwood properties not only by formation of spiral grain and reaction wood but also possibly affecting stiffness (MOE). According to Forest Research scientist Paul Mclean this influence is not fully understood. Certainly many planted exotic conifer species but most especially Sitka spruce and Douglas fir anyway originate from locations with high average wind speeds; i.e. Queen Charlotte Islands, Vancouver Island and the Rocky Mountains. Therefore arguably both species are already well adapted to growing in windy zones so there is a question as to why British conditions might adversely affect those species any more than conditions in northwest America. However, thigmomorphogenetic theory as proposed by F. W. Telewski and others states that plants respond to wind and other mechanical perturbations using internal trade-offs in a way that allows continued plant survival in windy environments. Studies are contradictory and have shown that induced flexure causes both increased stem elasticity (lower MOE) and lower flexibility. Through adaptive growth, stems can also form elliptical cross sections along the same axis of prevailing wind and stem height may be reduced according to German biomechanics professor Claus Mattheck.

Forest plantations have often been established on lower value marginal land in exposed uplands in Britain where declining agriculture offered opportunities for afforestation, for instance Kielder forest in northeast England. Adverse weather conditions have influenced mechanical properties of growing trees either through thigmomorphogenesis, reaction wood formation, spiral grain formation or combinations of these processes. Foresters have noted how forest-edge trees are often extremely asymmetrical with normal branches directed into the forest and very heavy branching outward towards the light. It should be noted that despite these challenges to growing consistent industrial roundwood, Britain has developed a significant, modern softwood processing industry capable of supplying commodity timber markets. Sheltered forests growing higher grade softwoods could supply higher value bespoke markets.

Excellent article on thigmomorphogenesis; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4406077/

WOOD APPLICATIONS

Wood is a remarkable material which varies greatly; contrast for instance the wood properties of very low density balsa compared to those of very high density lignum vitae. Over millennia people have utilised the widely varying properties of wood to make an enormous range of products and artefacts from the smallest and most humble of objects such as wooden spoons to some of the largest structures and machines on the planet e.g. the Tacoma dome in America, the Todaiji Temple in Japan (see image 3 below) and the 'Spruce Goose' aeroplane built by the Hughes Aircraft Company at the end of WW2. At the other end of the scale, high-specification nanocellulose products are being commercialised currently. As the structure of Welsh conifer forests change in order to accommodate societal expectations, climate change and policy change, there will be a wider range of wood types available for future generations; especially if more species and/or age diversity is implemented. In order to make best use of wood grown in Wales and foster innovation, we need to gain a better understanding of its varying properties. Armed with more knowledge, better strategies can be formulated and informed product development can be carried out leaving no excuse for attempts at *ad hoc* research and design projects which rarely lead to successful commercialisation. In order to describe and use wood adequately and efficiently we need to know and quantify several of its properties, therefore the word 'quality' is of limited utility.

Image 3: Todai-ji in Nara, Japan; historically one of the largest timber structures in the world

The woodknowledge Wales report *Welsh Softwoods in Construction* which was published in December 2013 and updated in 2016 (available here). This report analysed and set out how Welsh-grown softwoods could be used in construction. However it also demonstrated the lack of value adding to Welsh softwood sawlogs; most are processed into fencing products and pallet wood.

LARCH IN TIMBER ENGINEERING

Although timber engineering has been mooted in various strategies, none is carried out at economic scale, for instance there is no glulam manufacturer in Wales. Two Woodknowledge Wales reports from the last decade analysed options for adding value to diseased Japanese larch from Welsh forests. For instance here; https://woodknowledge.wales/wkw-resource/japanese-larch-and-its-innovative-applications-in-construction. The following actions were also clearly stated in this Winston Churchill Fellowship 2014 report: https://www.wcmt.org.uk/fellows/reports/utilisation-larch-within-construction-japan

- We should take advantage of the large volume of strong, durable larch timber which will become available over the next decade; the best of our diseased larch forests could and should be used to catalyse creative low cost low carbon architecture.
- Japanese larch is ideal for glulam (glue laminated beams) and other engineered structural components capable of replacing steel in large structures. UK governments could use market pull through public procurement to kick-start private investment in manufacturing plants by specifying use of larch glulam in schools, hospitals and other public institutions.
- Japanese larch is ideal for *Brettstapel*, an innovative structural panel for use in multi-storey buildings, whether timber or steel framed. It could be manufactured by Welsh SMEs with little capital investment. A great deal of research and prototyping has been carried in Wales.
- The British forest and construction industries are overly conservative and dismissive of UK grown conifers. Our neglect of Japanese larch is a negative paradigm; it has been grown in Britain for over 150 years and we have only recently carried out enough research to enable its use in construction. We need to invest in wood science to widen our understanding of the potential of homegrown softwoods in construction.
- We need to implement diversification of our conifer forests as soon as possible; *Phytophthora ramorum* in Japanese larch is a warning to the forest industry.
- UK governments or their agencies could specify larch for mass housing and because imported larch is more expensive than UK grown material, the UK timber specification would have a greater chance of surviving the procurement processes.
- Procurement studies need to be commissioned in order to speed and optimise the passage of homegrown softwoods such as larch into the construction supply chain; UK government and UK forest agencies need to learn how we might make speedy and best use of our timbers as different diseases progress across Britain.
- Comparative studies of British and Japanese construction supply chains could help us to better understand the obstacles to innovative construction using UK grown softwoods.
- We should follow the advice of WWF and FAO; promote, optimise and expand UK-grown conifer plantations.

VARIABILITY IN TREES

The importance of variability in trees cannot be overstated and generalised statements about wood properties of any particular species are at best unhelpful. Tree to tree differences within a species, within a stand or within a provenance are large. The variation of wood properties within one species

can be greater than between species and it is necessary to sample at least thirty trees to obtain a valid estimate of wood properties within any given stand. For instance *Radiata* pine trees grown on the same site can exhibit up to 60% difference in wood density and there can be more differences within one site than the average differences between sites. Within any one tree variations in properties can be greater than differences between the same species grown in the same environment. Leading American wood scientist Bruce Zobel summarised as follows:

- Tree to tree variation is so large that it is of major importance for all wood products.
- The magnitude of variation within individual trees makes it difficult to distinguish site, environmental or silvicultural effects on wood properties.
- The amount of tree to tree variation differs considerably between species; some species can have more consistent wood properties than others.
- Earlywood and latewood properties differ greatly and their relationship alters factors such as machinability, latewood properties greatly influence final product quality and strength.
- Much tree to tree variation is genetically controlled.
- Use of vegetative propagation can produce trees with similar wood within clones but wide variations between clones.
- High variability between trees and strong genetic control makes for very successful improvement of wood properties.
- Foresters, processors and researchers need to recognise the variability of wood, learn to live with it and learn how manipulate it to obtain optimal outcomes.

Variability caused by geography and provenance is summed up by Zobel thus:

- Wood grown at higher elevations has lower density (and stiffness) than wood grown at lower elevations.
- Wood grown at higher latitudes has lower density (and stiffness) than wood grown at lower latitudes; Dan Ridley-Ellis of Napier University states that there is a strong tendency for increased density (and stiffness) from northeast to southwest Britain.
- Wood grown at higher latitudes generally has smaller knots because of smaller limb size and less degrade due to crooked trees.
- Wood density can be higher in maritime conditions compared with drier inland zones.
- In warmer climates with extended growing seasons where rainfall is high in late summer and autumn, conifers grow more latewood therefore have higher overall wood density and stiffness.
- Wood of the same species within its natural range can vary significantly.

It is clear that the changing Welsh environment could positively influence some important softwood properties. Effects of latitude and elevation are complex but anyway sourcing and selection of material from selected sites in Wales is relatively easy. Considering the large range of environmental conditions across Wales there has to be significant potential for obtaining different types of wood for varying, optimal applications such as specialist joinery. Source sites will need to be recorded for future reference and mobile phone apps could readily play a part in this knowledge building.

Much research has been carried out across the world on timber engineering methods for overcoming defects in timber which could have been minimised by different forest management or long term tree improvement programs. There is huge scope for genetic improvement of timber

through tree breeding because most wood properties are so strongly inherited. Genetic editing through CRISPR is already under consideration by major UK tree nurseries because this may be the only tool available to fight the waves of pests and pathogens killing many of our tree species. CRISPR might be used to improve disease resistance, drought resistance and wood properties. Some species are already highly adaptive with a wide geographical spread. Optimal matching of different seed provenances to Wales' changing landscape could improve the performance and survival of some species as the climate warms.

- Tree form, growth rate, wood morphology and wood chemistry can all be manipulated to improve wood but efforts so far have tended to be focussed on fast growing, pest resistant trees despite the desirability of growing high grade timbers.
- Management or improvement of wood properties will help selection of log and wood types to more efficiently target specific high quality end products.
- Better knowledge of our softwoods and matching wood types to quality products will allow more effective marketing; focussing on positive attributes or USPs rather than lowest price.
- Different wood types arising from tree to tree variations and within-tree variations can be selected during processing in order to better utilise and valorise particular wood properties. This selection method is different to that of machine strength grading where strength classes are assigned from a spread of values analysed by statistical procedure. Assigning strength class (e.g. C16 or C24) does not necessarily create higher profit margin for processors.
- Genotypic and phenotypic wood variations can create a range of wood properties with their own unique selling points. Certainly wood density and stiffness (MOE) can be improved.

Better knowledge of how wood properties might be optimised for particular applications can inform the design and future management of high yield Welsh forests. The huge range of variations in wood properties clearly points to the need for selection of different grades or types of wood in order to optimise their utilisation. Quality is often used generically to describe timber but is generally meaningless in this context. Users need to know whether a particular wood type is fit for their desired application. In Wales, quality is often used as a weasel word in order to reinforce negative views about homegrown softwoods. The term quality is better ascribed to end products, not wood types. We will need a new range of descriptive terms to match the wide range of wood types available from modern, well designed and managed plantation forests.

PLANTED AND PLANTATION FORESTS

Not only do we need to understand wood variability better here in Wales; we also need to better understand the role of the conifer forests where most British and European industrial timber is grown. Britain is the third largest sawnwood importer in the world. Whatever softwood we do not grow in our own country is grown in plantations or planted forest mostly in Sweden and Latvia. Plantation forests are now considered to be foundations for creating sustainable economies. The Food and Agriculture Organisation of the United Nations (FAO) emphasises the importance of man-made forests around the world. The FAO clearly demonstrates that global industrial roundwood needs can be met by using a small proportion of the world's forested area for growing high yield plantation forests and enriching existing forests by strategic planting. The figures are compelling;

global area of plantation forests increased from 178 million ha in 1990 to 264 million ha in 2010, then making up 7% of total forest area. Although only covering this small proportion of the planet's forest area, estimates show that plantation forests supply between one third to two thirds of global industrial roundwood demand and sequester 1.5 gigatons (1.5×10^9 tons) of carbon per year. In other words (and allowing a large margin for error) current global industrial roundwood needs can be met from plantation forests grown on only 6% of the world's land area. The best case future scenario may allow us to triple roundwood output on only 18% of the world's land area.

The report *Planted forests are a vital resource for future green economies* summarises the results from the 3rd International Congress on Planted Forests and is available here: http://www.fao.org/forestry/37902-083cc16479b4b28d8d4873338b79bef41.pdf

This report states: *The contribution of planted forests to addressing the major socio-economic and environmental challenges of our time – poverty alleviation, food security, renewable energy, climate change and biodiversity conservation – is widely acknowledged. In many developing and developed countries planted forests have become a substantial component of the productive and protective forest resources. The congress noted in this context that statistics on wood production from planted forests including small woodlots and trees outside forests are incomplete and tend to overlook local markets for fuelwood, poles and other minor wood products. Globally, extensive areas are estimated to be available for forest restoration, rehabilitation or reforestation.* However the report also notes that in Europe there is a growing mismatch between actual societal demands and forest policy: *Current trends in European forest management could result in an over-supply of wood from broadleaved species, as well as a shortfall of coniferous timber from European forests, in particular as an increase in harvest is difficult to achieve due to restrictive environmental policies.* On the other hand in Asia planted forests are perceived as a force for good: *The National Development Strategy of China (2013) emphasizes the establishment of an Ecological Civilization. Planted forests are increasingly assigned to protective and multiple-use functions with the objective to optimize land use at a landscape level.*

Researchers and foresters are aware that high yield plantation forests need reconfiguring in order to gain wider acceptance: *Large-scale single species plantations with strong environmental impacts should be replaced by more ecological and integrated approaches at stand and landscape levels, including mixed species plantations, and greater use of silvicultural systems based on close-to-nature principles.* However: *Planted forests are exposed to socio-economic risks due to governance failures. These risks comprise a weak or inadequate forest policy framework including insecure investment conditions.* Forests with varied structures and/or tree species and management can contribute significantly to biodiversity whilst sequestrating fossil fuel CO_2 emissions. However there is little clear evidence that expectations in regard to resilience of intimately mixed forests are realistic. Recent experience has shown that mixing of tree species has actually allowed pathogens such as *Phytophthoras* to adapt and jump species. It is salient to point out that recent human pandemics have been caused by species mixing. As management of plantation forests in Wales moves towards close-to-nature methods and if industrial forests are to be diversified by age and/or species mixes then interventions such as thinning or single tree selection become more complex and costly. Greater wood property variations along with lower yields of high grade timbers can be expected. Forest managers are happy to increase management complexity for clients but always have to ask *who is paying?* Higher management costs need consideration in any forest diversification policies. The wider range of softwood types/species produced by diversified forests will need to be tested, characterised and certificated. Research will

need to keep pace with forest policy implementation in order to efficiently utilise newly introduced wood species. Sylviculture and wood science will need to be more reactive, certainly in the face of sudden large production increases caused by the need to process diseased timber. Citizen science and mobile phone data collection will be essential low cost tools. Foresters need a clear long term evidence-based strategy which protects productive forests or creates new designs for productive carbon-efficient forests. Experts all agree that Wales faces a biodiversity crisis. Most Welsh industrial roundwood is produced in Sitka spruce forests which comprise only 4% of land area. It is therefore clear that actions to increase biodiversity actually need to be carried out by the massive agricultural sector which manages 80% of the Welsh landscape including most of our dysfunctional broadleaved forests. Increasing biodiversity in Sitka spruce plantations is merely "tinkering" in the face of the climate emergency called by Welsh government.

Some researchers suggest that there is no conflict between the goal of stand diversity and the goal of wood quality. Some foresters assume that stands with a higher diversity of structure (tree size) and a higher diversity of species may even contain a higher percentage of high grade logs. However, foresters and researchers from the UK and New Zealand have suggested otherwise. Certainly even-aged forests under conversion to continuous cover forestry (CCF) with significant numbers of edge trees around felling coupes may increase formation of undesirable reaction wood in those edge trees because of heavy branching on the light side of coupe margins. Less desirable light-seeking leaning trees may also grow in these margins thus increasing the proportion of low grade logs within continuous cover stands. This concern may only apply to stands during the conversion phase to continuous cover management, because by definition continuous cover silviculture when mature implies optimising photosynthesis with no edges within forest stands. Perhaps simply increasing thinning cycles could be as desirable as CCF. Anyway until more continuous cover silviculture is carried out and studied in Wales, this topic can only be debated. Certainly the Bradford-Hutt plantation grown over an old industrial landscape at the Devon Great Consols clearly demonstrates the risk of heavier branching under CCF regimes. Some of the factors are set out below in this table taken from the paper *Trees for the Future* by Elspeth Macdonald *et al*.

As table 1 suggests, well-managed even aged plantations (which may also benefit from an understorey) allow production of more consistent or uniform sawlogs demanded by modern processors. High-pruning and other silvicultural interventions can help trees to form higher grades of timber. However this approach lacks the 'green' storyline of continuous cover forestry which in Germany has the more romantic name of *dauerwald* or eternal forest. Anyway, selected British conifer plantation forests managed for higher value timber could surely benefit from an understorey regardless of the silvicultural system employed. It may be useful to study the extensive literature available from the United States Department of Agriculture (USDA) on the topic of Pacific north-west (PNW) coast old growth forests. However, aspirational UK foresters need to understand that diversified PNW forests are in economic decline compared with the high yield, efficient southern pine industrial plantations which have largely replaced Washington and Oregon as the USA's major industrial forest resource.

	Advantages	Disadvantages
Planting	1. Opportunity to select species 2. Volume and quality gains from improved progeny 3. Control over stocking 4. Minimal variation in age class structure resulting in more uniform growth and timber properties	1. Possible stem form problems associated with nursery practice and early instability (toppling) (Watson and Tombleson, 2002) 2. High establishment costs 3. Possible patchy stocking – future timber quality problems
Natural Regeneration	1. Improved stability – possibly better stem form 2. Potentially high stocking and large number of trees for selection in thinning 3. Potentially low cost 4. Fits well with Continuous Cover Forestry	1. No opportunity for improvement in growth or timber quality through use of selected provenance/progeny 2. Difficult to control species mix – may have a lot of low value species (e.g. hemlock, grand fir) 3. Costs of respacing/pre-commercial thinning

Table 1: Advantages/disadvantages of planted/naturally regenerated forests

The mixture of natural and anthropogenic processes and events which have shaped PNW forests may give clues as to how we get better results from our own forests. Underplanting Douglas fir with shade bearing species such as Western hemlock or Western red cedar imitates nature whilst achieving timber improvement through decreasing branchiness which otherwise requires management by high pruning. Underplanting with beech (as in Germany) or native alder might also achieve the same objective whilst improving forest microclimate and boosting environmental credentials of plantation forest.

One aspect of growing multi storeyed forests is clear; trees with desirable or marketable properties selected for long term retention will benefit from reduction of side branching and creation of a beneficial micro-climate within a shade bearing understorey. Western hemlock is currently an unfashionable species blamed particularly for its invasiveness. This perception could be turned on its head; natural regeneration is easily achieved with Western hemlock and as a shade-bearer it is ideal for continuous cover and multi storey forests. In order to justify extra management input, timber from more intensively managed stands will need to be sold into higher value markets. Therefore we need to know more about the material characteristics of species such as Western hemlock in order to optimise marketing. Sixty years ago Ackers wrote: *The timber from this tree is now so very well known in our import trade that I hardly need enlarge on its importance. Homegrown timber is getting a good name.*

The British joinery sector seems to have forgotten how desirable joinery grade Western hemlock timber has been; until recently sawnwood sold for as much as £700/m^3. Western Hemlock was a

relatively new industrial species for both British and American markets. In 1908 it made up only 0.2% of output in America and by 1926 it was the third most important species. However, because it is shade-bearing and consequently not self-pruning, its persistent branches will lower ultimate yields of clear timber compared with Douglas fir and Sitka spruce when converted. On the other hand, common defects which frequently degrade other softwood species occur less with Western Hemlock; for instance, dead knots, spiral grain, resin ducts or pockets and blue stain are all less common compared with its associated PNW species. However both in Britain and its native range stem fluting is a well-known problem. Fluting is associated with fast growth in Western hemlock. Narrow spacing, slower growth conditions under shade and shorter rotations reduce fluting. Therefore growing it as a 'catch crop' under large valuable trees such as Douglas fir could optimise growing conditions and valorisation for both species.

According to older data from G. M. Lavers, homegrown Western hemlock is of the same stiffness as Sitka spruce; this has recently been confirmed by some limited research at Edinburgh Napier University. American literature suggests that Western hemlock has some excellent working properties; it has very high shock resistance for its weight and hardness is moderate. Perhaps most importantly its hardness within growth rings is relatively uniform (falling somewhere between hard and soft pines); making it even-wearing with good shaping and machining properties. Western hemlock demonstrates how traditional and subjective perceptions of tree species grown in Britain can be at variance with evidence.

There are many conifer species which have been grown on trial plots across the British Isles. Western hemlock is one of these many exotic species which older generations of foresters judged as potentially useful for its ease of establishment and good material properties however along with Sitka spruce this species has been demonised. Softwoods from Europe may not continue to be readily available to Britain with the advance of climate change and the increasing pests and pathogens it brings. A new rational approach to forest design in Britain will need to embrace under-utilised resilient species.

BRANCHES

Branchiness in Welsh plantation forests is perceived badly by both foresters and the public. Foresters see large branches and knots as indicating low strength or 'red' grade logs and the public have difficulty in seeing any amenity value in the dark, branch-filled spaces between rows of trees. However, images from YouTube and other websites clearly demonstrate that conifer forests in their native range can be as branchy for instance here: https://www.youtube.com/watch?v=yFFwEVxnbQU Old USDA literature shows that side branches also grow thickly in naturally regenerated even aged Douglas fir forests in Washington and Oregon, see image 4 below. This is a passing phase and self-pruning occurs as stands age. Size, location, angle and frequency of branches are seen as major wood quality factors. However because plantations here are generally not retained after year 50 and we know that self-pruning does not occur until around year 70 in Pacific NW America we cannot expect to see this transition in most of our plantation forests. Some British commentators perceive plantation-grown conifer trees as too branchy/knotty to make higher grade timber but actually the trees are generally too young to have formed thick layers of clear wood over their knotty core after self-pruning. Protagonists for regular thinning have pointed out that when precisely performed this

intervention can help sweep branches from stems of retained trees as neighbouring trees are direction-felled. Anyway (as Zobel has often stated), species provenance, tree breeding, tree spacing and rotation length are all key factors in improving out-turn of high grade wood.

Longer rotations have been suggested by John Moore and Elspeth Macdonald as a simple management option in the UK; their data showed increased yields of strength graded construction timber from mature heartwood of older Sitka spruce sawlogs along with reduced rates of rejection because of distortion. However, according to Macdonald, windthrow will be a limiting factor for many British sites. Therefore long term retention can only be a solution on selected, more sheltered sites. Researchers working in Scotland under the Strategic integrated Research in Timber project or SIRT have already pinpointed the factors influencing wood properties from conifer plantations in Britain. Pragmatic decisions for gaining higher grade timber from industrial forests in Wales could already be made on the basis of work done in Scotland as well as that done by Zobel. The economics of interventions such as high pruning of high value British conifers needs more study; many foresters have strong opinions on this topic but there is little data. Every sylvicultural action or intervention needs to demonstrate added value or they will result in adding cost. In *Trees for the Future* Elspeth Macdonald *et al* conclude:

> *Silvicultural intervention can play a key role in determining the quality of timber produced from conifer forests in the future. The outcome will not depend on any one action – impacts on timber quality depend on every aspect of management. A key priority must be commitment to the production of quality timber at each stage: "from plant to plank"!*

Image 4: An old image of heavily branched trees in a 50 year old Douglas fir stand in PNW America

Perhaps some more selected sheltered conifer plantations in Wales could be subject to long term retention in order to study stem improvement with age. Forester Paul Raymond Barker has created some multi storeyed stands of older Douglas fir on the Llangoed Estate near Builth Wells. Several decades ago FC Wales forester Mark Yorke created some exemplary CCF Douglas fir stands on the edge of Coed y Brenin north of Dolgellau. Long term retention allows thicker layers of high grade clear material to grow around the juvenile core and knotty inner heartwood. This then implies the

need to separate high grade clear timber from lower grade knotty or juvenile timbers by specialist sawmillers. Long term retention of Douglas fir along with understorey planting can create a forest with old growth forest features and a choice of harvesting options. However the increased management, extraction and processing costs will need to be balanced by adding value through careful selection and marketing of sawlogs or sawn products. Over 70 years ago in *Practical British Forestry* C. P. Ackers calculated that clear timber made up 15% or less of the total crop from old growth forests in PNW America and that in Britain with correct management (or possibly with high pruning) we could do better. This point was often repeated by well-known CCF protagonist, the late Tālis Kalnārs MBE. All practical foresters emphasise that sylvicultural choices need to be weighed against cost if forest owners expect to keep their forests profitable. A pragmatist might ask why any forest owner (including the state) would consider loss-making actions as sustainable anyway.

DISCUSSION

Conifer plantations supply almost all of Wales' industrial roundwood needs from only 7% of Welsh land area and half of Wales' total forest area; the other half of forest area is made up of largely unmanaged native broadleaved forests. Forest industry representatives are concerned that our small productive conifer forest area may suffer production shortfalls in the future because of weak or inadequate implementation of a pragmatic forest policy. Furthermore there is a perception within the forest industry that some Welsh government policymakers still aspire to create more non-productive native broadleaved amenity forest at the cost of softwood production. According to the late Martin Bishop of CONFOR; *planting more broadleaved forests will create yet more unmanaged forest in Wales.* However, the WWF predicted in 2013 that under their 'Living Forests Model' global demand for industrial wood could triple by 2050. If this is the case, under the present planting scenarios Welsh conifer forests may not even be able to supply one third of Wales' own industrial roundwood demands in 2050 at a time of unprecedented global demand for timber. In such an emergency there will be demand for all grades of wood from juvenile to best grade clears.

The WWF report suggests that increased demand should be met by both plantations and increased management of natural forests. However in Wales almost all current forest management and timber production is carried out in plantation forests. This report is specifically intended to counter claims that Welsh conifer forests mainly produce 'low quality' or 'low density' sawlogs. Actually wood science demonstrates that we can grow some exotic conifer species with properties equal to the same species growing in their native ranges. Indeed, Japanese larch timber grown in Wales appears to demonstrate somewhat higher stiffness (MOE) than that grown in Japan and recent bending tests carried out at Napier University show it is also on average slightly stiffer than Scottish-grown Japanese larch. According to Dan Ridley-Ellis of Napier University the results were statistically significant even if the methodology did not allow firm conclusions to be made. Nevertheless it is a recorded phenomenon that softwoods tend to decrease in density and stiffness with increasing latitude and altitude. Wales has a rainfall distribution which favours some conifers and its mild autumns allow extended growth periods at the time of year that conifers lay down the denser, stronger latewood zones of growth rings. In other words the Welsh environment has distinct, positive attributes for growing high grade, high stiffness softwoods. This is an excellent USP for Welsh conifer forests.

Our main problems are perception and misinformation. Actually we can make better use of the timber grown in our highly productive plantation forests because we already grow conifer trees with a range of appropriate properties for use in high value added products. However the Welsh forest industry mind-set has largely been stuck in a commodity culture based around processing Sitka spruce for high volume markets and is incapable of realising the full value of sawlogs which fall outside the volume processors' specifications. For instance 'oversize' logs which are too big for modern mills such as BSW Newbridge have been considered to be a problem rather than a different type of (and more valuable) asset. Smaller sawmillers seeking large diameter Sitka spruce in the past have done so not because of the potential for processing differentiated products but simply because they are unwanted by the volume processors and have historically been cheaper. As availability of Sitka spruce has declined in recent years, larger sawmillers have been forced to take in higher volumes of other species, e.g. larch from *Phytophthora ramorum* affected forests. However, larger mills have preferred to substitute this larch for spruce within their existing markets rather than develop new markets. Despite its potential for niche construction markets and ready availability of new machine grader settings, most high stiffness construction grade larch is likely at best to be sold as C16 material by volume sawmills. To sell the strongest softwood grown in Britain in this manner appears to demonstrate a somewhat risk-averse marketing culture. The Japanese (both historically and recently) built some of the largest timber structures in the world with their own softwoods. However the British are (with a few honourable exceptions) still mostly making fences with their own timber. At best the British are just starting to use homegrown C16 strength graded softwoods in low rise timber framed construction whilst somewhat contrarily they built the world's first modern nine storey timber structure using imported cross laminated timber (CLT) panels.

In order to supply increased future demands for industrial roundwood, the proportion of wood grown in high yield plantations will need to increase globally and societies will need to use it more efficiently. We can use wood science to counter the misinformation surrounding effects of growth rate on wood qualities. There can be high and low density woods in equally fast growing trees and even within individual trees; however the wide range of published scientific literature has been cherry-picked to support disingenuous points of view according to US wood scientist Bruce Zobel. Anyway we will need to use land more efficiently because *they're not making it anymore!* High yield plantation forests are the rational choice for sustainably growing more timber on a crowded planet. Furthermore growing conditions and silvicultural interventions can be better managed within plantations in order to optimise response of trees and influence timber qualities. Exotic timbers grown in forests away from their native habitats may exhibit different characteristics to those grown in their original environments but these differences do not necessary make the wood types inferior.

A modern, large scale forest product industry has been developed in New Zealand through continuous investment in wood science and silvicultural research. In a country with only slightly larger land area than the UK, forest cover in New Zealand now stands at around 31% of land area with conifer plantations covering only 7% of total land area. The planted forest comprises just over 1.7 million ha (with 1.5 million ha of *Radiata* pine) producing 23 million m^3 of roundwood annually. Forest products contribute 3% of New Zealand's GDP. They are the country's third largest merchandise export and according to the New Zealand Forest Owners Association the industry has set a target to

double export earnings by 2022. New Zealand has been the largest exporter of logs to China; 13.4 million m^3 in 2017.

Amongst the researchers now working there is Bangor University alumnus Addis Tsehaye who studied variations in wood properties of *Radiata* pine grown in New Zealand, contributing to the body of data which underpins the industry's progress. Fast grown, wide ringed *Radiata* pine seems like an unlikely candidate for manufacture of quality products but research demonstrated its potential and New Zealand joinery products are now marketed widely in the UK. *Accoya* acetylated joinery wood is made with *Radiata* pine from New Zealand; the density of earlywood and latewood within annual growth rings is closer than for many other softwoods allowing excellent machining properties.

LOG VARIABILITY

Wales produces some of the largest Douglas fir grown in Europe and despite the fact that this is a valuable niche market species, in the past most large Douglas fir sawlogs have been sold to specialist sawmills in England thus losing potential local economic gain for Wales. There has been a failure to recognise the value of specialist softwood sawlogs in Wales. Few SMEs optimise income from them through better matching to bespoke end products and subsequent product marketing. This failure has reinforced negative perceptions about growing and selling large diameter softwoods in Wales. A self-fulfilling negative culture is shared by foresters and sawmillers alike. Indeed, sawmillers are often happy to denigrate specialist timber grown in Wales simply in order to drive down log prices. This has led to more hand-wringing by foresters only seeing opportunity cost and consequent folly in growing older, bigger conifers but then having to sell them too cheaply. Assumptions and accusations such as those made by Aldridge and Hudson in the 1958 *Quarterly Journal of Forestry* about fast growth of species such as Douglas fir persist.

Debates continue and intuitive views on wood "quality" are still expressed in 2020. However, specialist timber merchants 'Capricorn Eco Timber' near Stafford no longer discriminate between homegrown and PNW American Douglas fir; they sold merchantable grade material from both sources at the same price around £600/m^3 in 2013. Furthermore Capricorn make the point that old growth Douglas fir is no longer available anyway so even imported clear material is from second and third growth or planted forests. With imported high grade Douglas fir being sold at £1000/ m^3 (same price as joinery oak) in 2013, it is now worthwhile to select higher grade homegrown material for sale into the same value added markets according to Capricorn's manager. iWood is a Staffordshire-based timber merchant which has grown rapidly by utilising online sales. As of autumn 2020 their merchantable Douglas fir beams are offered at almost £800/m^3 plus VAT. Another online timber merchant based in Somerset as of autumn 2020 is offering 50mm thick American joinery grade Douglas fir at up to £4500/m^3, they offer UK-grown western red cedar cladding at £2000/m^3. These higher prices may well be exceptional but they are real offers (website "snip" evidence below).

In autumn 2020 large diameter Douglas fir sawlogs from Scotland were offered by a well-known English roundwood merchant at £140/m3. Similar high grade Douglas fir is grown in Wales but rarely processed here in any volume. A niche sawmiller in north Powys reported in 2019 that he converted no joinery grade softwood, normally selling higher grade DF as structural timber. Very high grade Douglas fir from a well-known north Powys estate is shown in image 5 below. Juvenile corewood

extends over nine or ten rings and is hardly discernible in this image. The growth rings in the mature heartwood vary between around 2.5mm to 3.5mm in width marked by small, to scale, white bars. These growth ring characteristics are, by the way, in line with European timber traders' descriptions (or claims) regarding 'high quality' joinery timber although wood scientists reject such subjective judgments. It is increasingly clear that selected Welsh-grown Douglas fir could find a place in very high value added new markets. By offering easy online procurement processes, at least two online timber merchants based in England have created very high margins for just in time delivery of these homegrown softwoods.

Image 5: Very high grade Douglas fir from North Powys

Image 6 below shows Welsh-grown Douglas fir timbers from two different sites with obvious ring-width differences and different wood properties.

Image 6: Douglas fir from two different Welsh sites with large variations in wood properties

The wide latewood rings in the large dimensioned stock from West Wales suggest high rather than low density despite the obvious fast growth of the tree. Both timbers could be described as high 'grade' or 'quality' but those descriptions do not convey the information needed in order to make informed decisions about suitability for particular applications. Large diameter Douglas fir sawlogs can yield very wide stable boards which are not available in other common softwood species. There is an untapped potential for selling material of this type into high value specialist niche markets.

Suppressed, old, 'drawn' small diameter softwoods grown in Wales have also been seen as problematical and are often undersold for fencing posts although their wood properties are not dissimilar to the small diameter slowly grown softwoods of the Baltic region. Nordic and Baltic producers make a point of marketing the wood properties of their slow grown softwoods, for instance: *Rather severe climatic conditions in Russia causes quite slow wood growth that leads to the narrow-ringed structure of timber. According to the European standards the annual ring growth for the high quality coniferous timber should not exceed 4mm. Russian timber in general has annual ring growth about 1.1-3mm.* Welsh processors have so far not recognised the potential to properly valorise slow-grown small diameter softwoods despite advice freely given by expert French foresters to the old FC Wales.

Indeed because small diameter juvenile thinnings have been in short supply for many years in Wales, suppressed small diameter conifer timber with narrow growth rings (a completely different product to juvenile thinnings material) has been routinely processed into fencing products. Image 7 below shows a scantling cut from a suppressed homegrown larch tree from a 47 year old plantation. After edging it was only 50mm wide; the smaller growth rings are only just over 1mm in width. A batch of thirty such samples were milled, dried, planed and successfully used in an experimental niche joinery project.

Image 7: a scantling cut from a suppressed homegrown larch tree with narrow ring width

If there is a degree of hand-wringing at our lack of creativity and poor marketing skills, there is also a degree of finger-pointing by those NGOs and commentators who would prefer to see the end of softwood production in Wales. If Welsh Government is to make pragmatic choices for the future of Welsh forests then there is a need to break out of the negative circular thinking which dominates the industry and the micro-politics surrounding it. Sawmillers routinely denigrate homegrown softwoods in order to reduce log prices; Welsh softwoods historically achieved some of the lowest roundwood prices in Europe not because of 'quality' issues but because of the vicious circle of misinformation which surrounds the timber processing industry in Britain. The wide range of wood types grown in Wales, especially those produced by very fast and very slow growing conditions are not being sold into markets which reflect their special, indeed unique properties. Welsh foresters could benefit from understanding how smaller Japanese timber producers and processors have specialised in production of niche, high grade timber from designated areas called *sanchi*. Giving small specialist plantations a name which suggests USPs or even spiritual values might help boost their perceived value. *Grove* is a well-received romantic descriptor which might gain traction for small mosaic forests of specialist conifer species.

The Welsh forest has been shaped by the Industrial and Agrarian Revolutions and two world wars. Its future size and design has still not yet been decided and disingenuous debates spanning a whole generation or conifer growing cycle have been informed not only by rational analysis of future needs of the sustainable society to which Welsh Government aspires but also national romantic ideologies which still tend to focus on planting native broadleaved forests. There is a wide spectrum of services expected of forests grown in developed western societies and an aspiration that all forests be multi-purpose. However there are few mechanisms developed which create incomes to offset the extra costs incurred. It is therefore logical for now to focus on the management of commercial exotic softwoods grown in Wales in order to optimise incomes from them. Selecting, grading and marketing them more intelligently will generate more income through positioning selected softwoods in value-adding niche markets. Welsh processors are already good at converting homegrown softwoods for selling in commodity markets. A modern, productive conifer processing industry has been established in Wales which is capable of partly servicing the demands of a sustainable construction industry. However we have only just started to realise the potential for marketing specialist or bespoke softwood products. If marketing is the vital tool for placing timber products in the modern marketplace, wood science is the principal tool for understanding those materials which we wish to market better.

Wales has an ideal environment for growing conifers but there has been a public misunderstanding regarding the role of planted conifer forests. Ignorance, opinion and polemic have created a self-perpetuating negative mythology which has stalled expansion of conifer plantations in Wales and England. Gerald Ratner notoriously sabotaged his family's jewellery business by denigrating the products sold in his shops. Uninformed or disingenuous commentators have inaccurately and unfairly used the 'Ratner word' to describe Welsh-grown softwoods reinforcing the myth that Welsh conifer forests only grow low quality wood; this is quite simply untrue. The variable Welsh environment produces a wide range of timber types but we do not select out and grade the more valuable softwood types effectively at the moment. Furthermore, studies carried out by John Moore and Elspeth Macdonald confirm that spruce wood quality is improved by increasing rotation lengths. There may be no premium for growing spruce with greater yields of higher stiffness wood at present,

however because older stands already exist there are opportunities to process and position higher grade spruce sawnwood within existing joinery or other higher value added markets. Older large diameter sawlogs from stands in more sheltered Welsh sites could yield wide boards that are not available from Scandinavian or Baltic sources. Furthermore larger diameter sawlogs may allow easier selection and separation of juvenile corewood from the much more stable, higher density, stiffer mature heartwood.

Sitka spruce is now the main species of choice for the modern UK sawmilling sector and homegrown softwood has contributed up to 40% of UK consumption although this figure decreased slightly in 2018. Nevertheless according to the Timber Trades Federation (TTF), in 2018 Britain produced 3.67 million m^3 of sawnwood and is now a larger sawn softwood producer than Latvia. Britain is the world's 19^{th} largest producer with an output approaching that of Czechia and New Zealand. British Sitka spruce is fit for purpose in a competitive, demanding market dominated by well-established foreign suppliers. However, the UK is still the world's third largest importer of sawn softwood.

UK SITKA SPRUCE; AN INTRODUCTION TO MACHINE STRENGTH GRADING OF C16 TIMBERS

The material properties of wood are influenced by inherited genetic traits of individual trees interacting with many site factors including climate, weather, altitude, latitude, orientation, soils, disease, pollution and light distribution. Material properties of wood vary enormously between species, between forest stands, within forest stands and within single trees. Wood properties vary greatly within individual trees both radially from pith to bark and with height from roots to crown.

Pragmatic judgments are made by wood scientists and statisticians in order to make best use of available data on material properties of different species of wood from across delineated geographical areas, e.g. national boundaries. National boundaries do not influence material properties of wood and only a few main species are grown within industrial planted forests in many countries all across the planet (as with principal food crops). National boundaries may delineate regulatory frameworks within which particular species are utilised. Plant selection and breeding has influenced the material properties of the world's principal industrial tree species, utilising individual species' adaptive traits. As climate change increasingly affects the availability of land for growing agricultural crops and forests, tree breeding will become increasingly important to optimise tree growth in the face of changing environmental conditions. All of the most important material properties of wood within a single species can be influenced by selection, tree breeding and gene editing. These properties include wood density, wood stiffness (modulus of elasticity or MOE), knottiness and knot size, branchiness and branch angle (e.g. "weeping"), microfibril angle (MFA) within wood cells, and spiral grain. Some of these properties can be influenced by silvicultural interventions.

Strength grading is a modern method of determining whether individual pieces of timber are fit for purpose as structural elements in construction. There are two processes; visual grading and machine grading. Mass construction of timber framed housing cannot economically utilise labour-intensive visual strength grading although it may suit special projects, prototype and bespoke housing. In order to create the most recent datasets needed for machine strength grading of Sitka spruce grown in the

UK, around 1000 pieces of Sitka spruce were subjected to bending tests strictly defined by EU standards. The sizes of timber elements tested reflected the sizes of structural timber commonly utilised in the UK. To obtain material properties data, Sitka spruce sawlogs from across the UK were cut into the selected set of timber sizes and tested under strict laboratory conditions. The main wood properties influencing strength class are stiffness, strength and density. Knots and angle (or slope) of grain to the axis of a timber sample also influence strength classes. The huge datasets from laboratory tests are processed using statistical analysis in order to to ensure that no more than 5% of C16 spruce sawnwood falls below the defined characteristic values after machine strength grading. For C16 these values are; stiffness (MOE parallel to grain) 8kN/mm^2, strength (bending parallel to grain) 16N/mm^2, density 310kg/m^3.

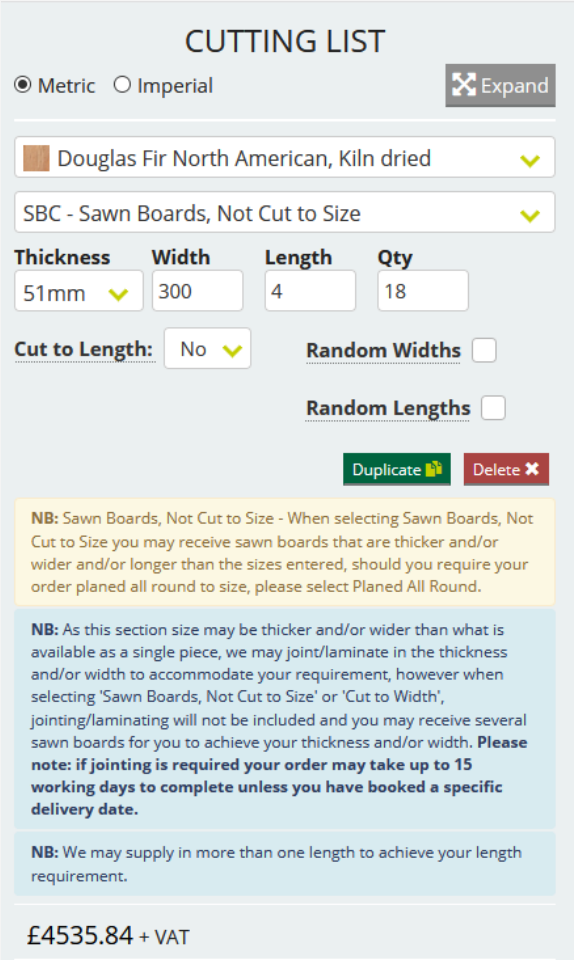
Informed researchers in the UK agree that nearly 100% of UK grown Sitka spruce sawlogs will convert to C16 strength grade sawn timber at economical scale and yield. Profitability is subject to global currency fluctuations, politics, storms and disease (as with other global commodities). C16 machine strength-graded softwoods have the same defined mechanical and structural properties regardless of their country of origin. C16 spruce may be used in most common timber frame applications, constrained by the calculations performed by structural engineers to justify their own design specifications, parameters and conditions.

Material properties of wood are strongly influenced by moisture content (M.C.). Timber can be machine strength graded wet or dry but best yields are obtained with dried timbers; strength graded softwoods are generally sold at a maximum of 20% M.C. Use of wet or 'green' softwood is occasionally permitted (and calculated for) within specially designed bespoke construction. The mechanical viability of Sitka spruce for construction is influenced by the proportions of juvenile corewood (generally the first 10-15 growth rings in UK spruce) to mature heartwood encountered within individual sawn pieces of timber. The location and volume of juvenile corewood within individual pieces of sawn timber of any species can influence the drying and strength characteristics of timber; sometimes strongly influencing moisture-movement (swelling or shrinkage) and/or distortion (bow, twist or crook). This is true for timber grown all over the world. Timber is dried under controlled conditions (e.g. in specialised kilns) in order to minimise in-service drying and distortion. Fast grown plantation forest species across the world are dried using kiln management techniques and species-specific schedules of drying and rewetting, thus optimising yields of useful structural timbers whilst minimising wastage through problems such as overdrying and distortion. UK grown Sitka spruce exhibits no particular, idiosyncratic wood properties that preclude strength grading and utilisation as structural elements in mass timber framed housing.

SFM AND PROPAGANDA

Sustainable forest management (SFM) practices and interventions in industrial forests are used deliberately or accidentally to influence or utilise all perceived operating factors including natural events to optimise the production of timber for the use of society. Societies generate and operate forest policies influenced by historical events and cultural, political and scientific feedback. Science is not necessarily the main agent for changes in governmental (or NGO-influenced) forest policymaking although scientific method was responsible for the first treatises on SFM. Productive planted forests

and industrial plantation forests are subject to anti-rational or neoromantic societal feedback despite being created to prevent deforestation and to efficiently fulfil societal and industrial needs. Neoromatic feedback (especially through social media algorithms) is always subject to confirmation bias. Rational experts expounding scientific method and critical thinking cannot compete with this dynamic. British foresters and wood scientists need honest interpreters to correctly inform the public and their political leaders as to how forests might be recruited as agents of climate mitigation.



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