DOES BREXIT PROVIDE AN OPPORTUNITY FOR THE WELSH GOVERNMENT TO DELIVER ITS SUSTAINABILITY GOALS THROUGH LAND-USE CHANGE FROM LIVESTOCK GRAZING TO BROADLEAF WOODLAND?

A Case Study

A dissertation submitted in partial fulfilment of the requirements

for the degree of *Master of Science* (MSc) in Forestry

of Bangor University

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Date: 1st August 2019

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This dissertation is the result of my own independent work/investigation except where otherwise stated.

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Abstract

The woodland at Bron Haul a mix of mostly broadleaf, mostly site-native species, planted as an intimate mixture in the 1990s on land previously used to graze sheep. It has been managed for multiple objectives including biodiversity, landscape value, shelter and for the production of high-quality timber. As such, it has been awarded prizes for woodland management by both the Royal Forestry Society and the Royal Welsh Show and exemplifies a type of woodland that the Welsh Government (WG) wishes to see planted under the Woodlands for Wales strategy.

This dissertation explores the expense to the public purse of creating new woodland and the ability of woodland creation to meet some of the WG sustainability goals laid out in the Wellbeing of Future Generations (Wales) Act 2015 using Bron Haul woodland as a case study.

This study compares grants received to establish and manage mixed broadleaf woodland at Bron Haul in its first 23 years (£111,469) with the agricultural subsidies that would have been due to support livestock farming under the common agricultural policy (CAP) if planting had not taken place (£96,603). Woodland grants are a contribution to real costs incurred and have been available only on an intermittent basis, whereas CAP payments have been regular, predictable, and have involved the land manager in no additional expenditure. This demonstrates the barrier that current agricultural subsidies present to incentivising land managers to meet woodland planting targets. Brexit and withdrawal of the UK from the CAP present an opportunity to remove this barrier and design land-based subsidies that are targeted at achieving the Welsh Government's land-use objectives.

The study goes on to examine the ability of the woodland to contribute to sustainability goals. Bron Haul woodland has sequestered around 206.6 tonnes CO_2e/ha in living biomass over the last 22 years. In addition, the removal of livestock has reduced GHG emissions through reducing; methane from enteric digestion; nitrous oxide from the application of fertiliser and animal waste; and has increased the carbon sequestered in soil through the change in land-use.

In the final chapter, the future timber potential of the site is considered. The harvesting of the first saw logs, suitable for enduring end use, is predicted to commence 34 years after planting. From then on, the woodland should yield regular income from high quality timber grown under a continuous cover management regime, realising the WG vision for resilient, genuinely multi-purpose woodland.

Bron Haul from South, 1982

Bron Haul from South, 2013

Acknowledgements.

My profound gratitude to Dr Ruth Pybus for her assistance in so many aspects of putting this dissertation together, from IT support to holding the other end of the surveyor's tape during field work.

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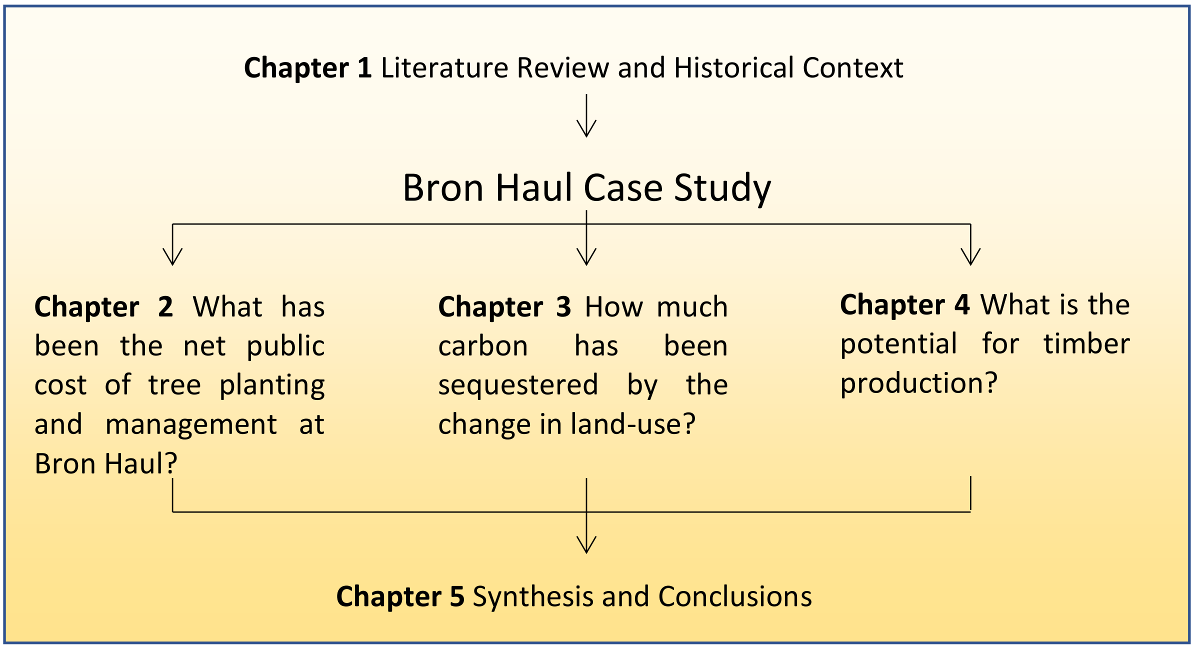
Introduction

Brexit creates an opportunity for Wales to escape the constraints of the Common Agricultural Policy (CAP). The agricultural landscape of Wales has been dominated by reliance on CAP payments which have locked the farming industry into an agricultural system almost totally reliant on sheep and cattle. This domination of the rural economy by livestock farming is at odds with the wider requirements of Welsh Government (WG) land-use policy laid down in the Environment (Wales) Act 2016 and the Wellbeing of Future Generations (Wales) Act 2015. These pieces of legislation put sustainability at the heart of WG policy.

Wales is committed to an 80% reduction in greenhouse gas (GHG) emissions by 2050 compared to 1990 levels in all sectors of the economy. More recently the Westminster government has strengthened this target and pledged to reduce net emissions of GHGs to zero by 2050 for the whole of the UK. In the agriculture and land-use sector it is envisaged that woodland creation and reducing livestock numbers, will be central to delivering this objective (Climate Change Committee, 2018). These emissions targets rely heavily on woodland planting as the only proven technology for removing CO_2 from the atmosphere. However, there is little quantitative data on the effectiveness of multi-species broadleaf woodland, planted in Wales, to deliver carbon sequestration. Although Natural Resources Wales (NRW) has produced a desk-based study of the theoretical productivity of new woodland (Ambrose-Oji et al., 2012) there is an absence of real-world data.

This dissertation will measure the sequestered carbon and timber potential in a 22-year-old woodland. It has been planted and managed under a succession of WG grant schemes and is of the type advocated in the current Woodland for Wales Strategy (Welsh Government, 2018c). It will also demonstrate how livestock grants have been a bar to woodland creation.

The overall structure of the dissertation is shown in the diagram below.



Chapter 1 includes a literature review describing the historical and current political drivers of land-use subsidy. The recent history of land-use decisions at Bron Haul will be described in this context.

Chapters 2, 3 and 4 will quantify separate aspects of Bron Haul woodland, each with its own introduction, method, results, and brief discussion.

Chapter 2 will examine the grant expenditure on 16ha of broadleaf woodland creation and management at Bron Haul. This will be compared to the financial support that would have been available had sheep farming continued.

Chapter 3 will quantify the carbon sequestered in a 22-year old, 1.2ha subcompartment at Bron Haul and discuss how this compares with the known carbon costs of livestock farming.

Chapter 4 will evaluate the potential timber crop in this same subcompartment in terms of quality, species and time to harvest. It will discuss the issue of supply chain and markets for quality broadleaf timber in the UK.

Chapter 5 will bring together the findings from chapters 2, 3 and 4 in a discussion of the benefits of changing land-use from ruminant based agriculture to broadleaf woodland.

CHAPTER 1 Literature review and historical context

1.1 The Historical Context of Land-use Policy

Current land-use in Wales is the product of a century of government interventions at the UK and later European Union (EU) level, with political events starting with two European wars and concerns about food security through to more recent concerns about loss of biodiversity and anthropogenic climate change. This section will set out how land-use policy has developed, culminating in the CAP which dictates how European funding is used by member states to support certain land-uses.

1.1.1 Forestry Policy

Following the depletion of British forests up to and during the first world war, the Forestry Commission (FC) was established in 1919 with the objective of re-establishing a strategic timber reserve. This was achieved largely through large-scale planting of conifers in the uplands, often involving land acquisition through compulsory purchase orders. Although the second world war started long before any of this new planting had reached production, the immediate shortage of timber caused by the success of the German naval blockade of Britain made the inter-war planting seem prescient. At the end of hostilities, coniferisation was reinvigorated and continued both by the FC and by wealthy individuals and investment companies who were encouraged to plant by the exchequer introducing incentives through grant support and the income and corporation tax regimes. Within agricultural communities, this large-scale planting of conifers was seen as a blight on the landscape, and an attack on a way of life (Watkins et al., 1996) with forestry and agriculture seen as being in competition for land.

In the 1970s and 80s the highest rate of income tax was 60% and through a tax instrument known as Schedule D, higher rate taxpayers were able to defray the costs of woodland planting against income from other sources, creating an effective additional planting grant of 60%, only available to high-income individuals. In 1988, a media campaign exposed the exploitation of Schedule D by wealthy individuals, including well-known media figures, to protect income from taxation by investing in the planting of large areas of sitka spruce in areas like the Scottish flow country, and the Schedule D arrangements were discontinued. At this time, the existing Forestry Grant Scheme was replaced by the Woodland Grant Scheme (WGS) with increased rates for both conifer and broadleaf planting. Woodland creation was still considered to be desirable by government but was now to be directly funded primarily through grants administered by the FC. One consequence of this change in forestry support was that the rate of woodland creation never returned to pre-1988 levels (figure 1.1), though it could be argued that the decrease in the top rate of income tax from 60% to 40%, which occurred in the same budget, may well have had the same effect on planting rates. However, the introduction of the WGS made woodland planting relatively more attractive to lower rate taxpayers (Hart, 1991).

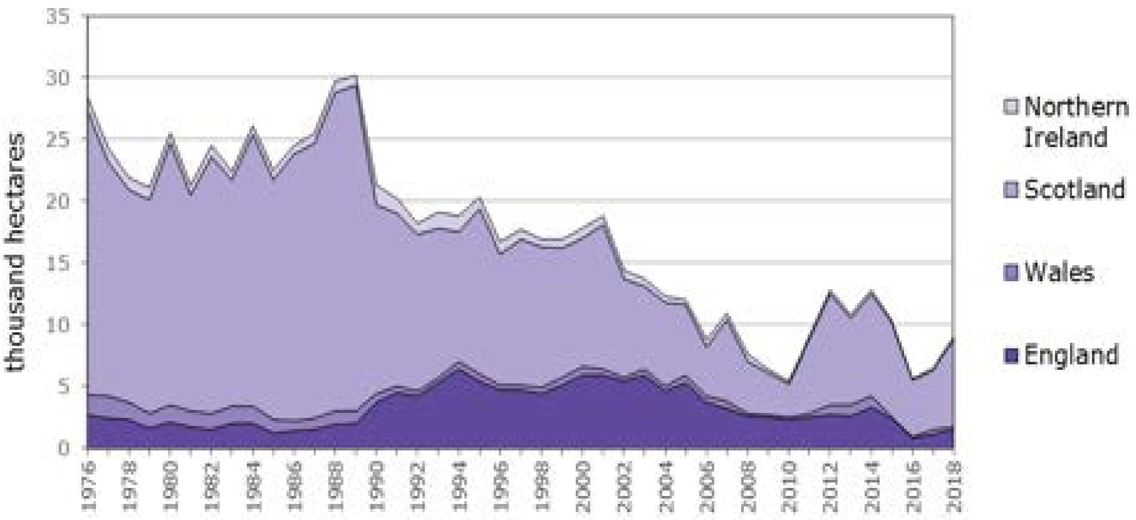


Figure 1.1 New Planting in the UK 1976 – 2018. From forestry statistics (Forest Research, 2018)

Woodland Management Grants (WMGs) were introduced in 1992. Subject to a 5-year plan agreed with the FC, owners could receive £25/ha/yr for broadleaf woodlands between 11-40 years old to help fund general silvicultural operations and to enhance the environmental value of their woodland. A supplemental £10/ha/yr was available for areas of under 10ha. WMGs were intended to promote quality timber production and placed an obligation on the recipient to control grey squirrels. Also, in 1988, the Farm Woodland Scheme introduced compensation to farmers for agricultural income foregone when they converted farmland to woodland. This gave an annual income of up to £190/ha/yr for as long as 40 years for oak and beech and 30 years for other broadleaves, for planting on arable land or improved grassland.

Lower rates applied for land within the Less Favoured Area (LFA), and for conifers. This later became the Farm Woodland Premium Scheme (FWPS) with payments of up to £250/ha/yr for a maximum period of 15 years. These schemes recognised the importance of the farming community as land managers with the power to implement government afforestation plans.

In 2006 the WGS was replaced in Wales by the Better Woodlands for Wales (BWW) grant scheme, with annual funding of £3.25 million for improving Welsh woodland management in line with the Woodlands for Wales recommendations and action plans (Ambrose-Oji et al., 2012). The scheme was funded through the European Regional Rural Development Plan (RDP) 2007-2013 Axis 2, which was tasked with 'Improving the environment and countryside' with emphasis on sustainable land-use, and support for non-productive forestry elements. One of the primary objectives of the BWW was combating climate change.

The BWW scheme was in turn replaced in 2012/2013 by the Glastir Woodland Management (GWM) scheme. The GWM scheme differed from BWW in that applications were rated, using a points system, against Glastir objectives depicted on target maps. Only those applications that scored enough points were awarded contracts. The Glastir management objectives included improving biodiversity through woodland connectivity and operations to encourage species and structural diversity, improvement of water quality and flood alleviation, improved carbon sequestration, improved woodland resilience through appropriate selection of species and silvicultural system and improving access to woodland for recreation. In reality, access to GWM was severely limited as much of the budget was diverted to dealing with the consequences of *Phytophera ramorum* in larch, and so many woodland owners who had begun management under BWW were unable to access the GWM funding.

Since the end of Schedule D, government motives for encouraging woodland creation have remained remarkably consistent. The list of reasons for promoting the expansion of forest area in the UK given by Francis in 1989 (box 1.1) would not be out of place in the most recent WG policy documents.

Box 1.1 Reasons for promoting woodland planting (Francis, 1989)

- A reduction in dependence on imports
- A renewable supply of timber to support the timber processing industry and supporting sustainable employment in rural communities
- To provide opportunities for recreational and sporting activities
- Diversification of the landscape and the provision of wildlife habitat
- To reduce the impact that the UK is having on the world's natural forests
- To contribute to a moderation of the process of global warming

1.1.2 Agricultural Policy

During the second world war (1939-1945) the success of the German naval blockades created serious pressure on the UK's ability to import food and livestock feed. As a result, the production of home-grown grain and root crops was hugely expanded, meat production fell, and food rationing was introduced. The Agriculture Act 1947 was introduced to consolidate gains in agricultural productivity with the aim of 'promoting and maintaining an efficient agricultural industry' (Section 1) capable of supplying a large proportion of the nation's food and supporting the income of farmers. The mechanism used to achieve this goal was to introduce guaranteed prices for 11 crops; cattle, sheep, eggs, wool, sugar beet, potatoes, wheat, oats, rye, barley, and milk (Bowers, 1985). Prices for these commodities were set in annual reviews in discussions between government and the farmers' representatives. At the same time direct support for technical advances such as the use of artificial fertilisers were promoted by the Agriculture and Dairy Advisory Service (ADAS).

By the time of the annual review in 1952, the main driver for increased productivity was concerns around the balance of payments. Increasing meat production was prioritised, with a preference for beef and sheep over pork and chicken to reduce feedstock grain imports. By 1958, concerns over the rising cost of agricultural payments to the taxpayer led to the decision that no further increases in production were needed, but by 1965 the introduction of import controls on meat and cereals shifted the costs from the exchequer to the consumer and increasing food production funded by market management was back on the agenda. In response to support payments available to farmers in the European Economic Community (EEC), the Agriculture Act 1967 (UK Government, 1967) introduced headage payments for hill livestock, grants for ploughing and draining the uplands, and amalgamation grants to persuade small farmers to leave the industry. The headage payments were production subsidies paid per head for keeping, and breeding from, ewes or suckler cows.

The UK joined the EEC, later to become the EU, in 1976, and adopted CAP. CAP had been launched by the EEC in 1962 with the twin aims of affordable food and a fair income for farmers and fitted well with UK agricultural policy, with direct price support and headage payments remaining the principle mechanisms for subsidising livestock farms. By 1984, CAP was generating food surpluses across Europe and quotas were introduced to restrict the production of many commodities.

Eligibility for headage payments became dependent upon holding quota for the appropriate number of ewes or cows, either through historic entitlement, or allocated through the national reserve. The national reserve of quota was built up by a levy on those selling quota and was distributed to young entrants into the industry or those buying land from which the quota had been removed by a departing tenant. In 2003, the EU decided to break the link between subsidy and production which led to the introduction of the current basic payment scheme (BPS) in 2005. The BPS was heralded as an end to production subsidies but in fact was based on historic subsidy received under the headage payment regime. BPS is paid to those with management control of eligible land, with each livestock farm receiving a per hectare rate depending on the amount of headage payment it received in the reference years 2000-2002.

BPS payment is conditional on the land being kept in good agricultural condition as defined by criteria described in the cross-compliance rules. Under these rules, forestry or any land that became afforested either by planting or natural regeneration, is excluded from receiving BPS. However, under the most recent Glastir Woodland Creation Scheme, (which began after the planting of the woodland under consideration in this study,) agricultural land planted with trees continues to receive the BPS for the duration of the current RDP.

The BPS has become hugely important to farmers in Wales and for many it makes up the vast majority of their income. Indeed, for the average hill sheep farm the basic payment exceeds the net profit of the farm business by 67% (IBERS, 2018). Therefore, under preparations for Brexit, it is recognised that some form of payment to land managers will be necessary to support rural communities. In 2017, direct income support to farmers in Wales through the BPS was £235m (Welsh Government, 2018b). However, it is unclear to what extent Westminster will be prepared to fund rural payments in Wales post-Brexit.

The consultation document Brexit and Our Land (Welsh Government, 2018b) acknowledges that the CAP has had 'mixed results' for the Welsh environment; has failed to confront agricultural production of GHGs; and has been a barrier to woodland expansion. Departing from the EU will mean that land-use policy in Wales will become the responsibility of the WG. This will create the opportunity to use agricultural support payments to bring land management into line with the objectives of the Environment (Wales) Act 2016 and the Wellbeing of Future Generation (Wales) Act 2015.

1.2 Welsh Government Land-use Policy

1.2.1 Current Legislation and Strategies

The realisation that climate change caused by human activity is a major global threat has led to a series of international agreements, most recently the Paris Climate Change Accord 2015, which have led to nations responding with policies to ensure compliance with internationally agreed targets. The Welsh and UK governments have agreed to reductions of GHG emissions, measured as tonnes CO_2e, of 80% compared to 1990 levels across all sectors by 2050 (Environment (Wales) Act 2016). In the land-use sector, which covers agriculture and forestry, this has led to a series of WG Acts, policy reviews and strategies.

In the Land-use and Climate Change report to the WG (2010) five scenarios for achieving 80% cuts in emissions of CO_2e in farming and forestry were examined. The favoured scenario (scenario 5) involved increasing woodland cover in Wales by 100,000 hectares over 20 years (from 2010-2030) equivalent to planting 5000ha/yr. This new woodland was envisaged to be mainly deciduous and grown for high quality timber with enduring end uses. It was to be planted on relatively poor mineral soils, including land graded 3,4 and 5 and would provide an additional GHG sink of 1,600ktCO_2e/yr by 2040. This new woodland was to be planted by private landowners, mostly farmers, and funded through planting grants. Other benefits of this new woodland foreseen in the report would be additional habitat, conservation of natural beauty, better water quality and flood control and the creation of new work and recreational opportunities. This ambitious target for woodland creation was accepted as policy and included in the Woodlands for Wales strategy (Welsh Government, 2009). Although uptake of planting grants has been slow (figure 1.2) the 100,000ha planting ambition was retained when Woodlands for Wales was updated in 2015.

The Climate change (UK) Act (2008) requires the UK government to produce a 5 yearly climate change risk assessment. Section 80 of the act includes a requirement that ministers in the WG respond to the risk assessments with periodic reports on actions and objectives on the impacts of climate change. In order to create an integrated response to climate change the WG brought in the Wellbeing of Future Generations (Wales) Act 2015, and the Environment (Wales) Act 2016. These acts provide a framework for a low carbon, sustainable Welsh economy.

The Environment (Wales) Act 2016 is divided into 7 parts, the first two of which focus on climate change. Part 1 provides for an ecosystem-based approach to natural resource management drawing heavily on the United Nations (UN) Convention on Biodiversity. This has given rise to a natural resources policy which is informed by evidence presented in the form of periodic State of Natural Resources Reports (SoNaRR). SoNaRR provides indicators to measure the extent to which sustainable management of natural resources is being achieved. The aim is to use the guidance of the International Union for The Conservation of Nature to implement nature-based strategies to achieve multiple environmental and societal benefits. In addition, the Environment (Wales) Act 2016 instructs NRW to publish and review area statements. These statements draw on evidence from SoNaRR and national natural resources policy to manage natural resources appropriately at a local level.

Part 2 of the Environment (Wales) Act 2016 sets out a framework for achieving GHG emission reduction targets and makes these legally binding.

The Wellbeing of Future Generations (Wales) Act 2015 places an obligation on a list of public bodies, which includes NRW to work towards achieving 7 wellbeing goals:

- a prosperous Wales
- a resilient Wales
- a healthier Wales
- a more equal Wales
- a Wales of cohesive communities
- a Wales of vibrant culture and thriving Welsh language
- a globally responsible Wales

Several of these goals include references to climate change mitigation, biodiversity and ecosystem resilience. The wellbeing goals are heavily reliant on the condition of Wales' natural resources as described by SoNaRR. Through these documents, the WG is attempting to link legislation regarding sustainability with iterative processes of monitoring and development of locally appropriate plans for resource management.

The Branching Out Report (Welsh Government, 2017) produced by the Climate Change and Environment and Rural Affairs Committee reported on how well the Woodlands for Wales Strategy was being delivered. They welcomed the WG's continued commitment to the 100,000ha planting target but drew attention to the divergence between this target and reality (figure 1.2). It was noted that planting rates since 2014 were particularly poor. The industrial forestry sector blamed poor planting rates on an over-rigorous use of environmental impact assessment requirements whilst the take-up of farm woodland creation grants was limited because the process was seen as too bureaucratic, the payments were too low compared with BPS received for continued agricultural use, and the permanent nature of the land-use change was considered undesirable by farmers.

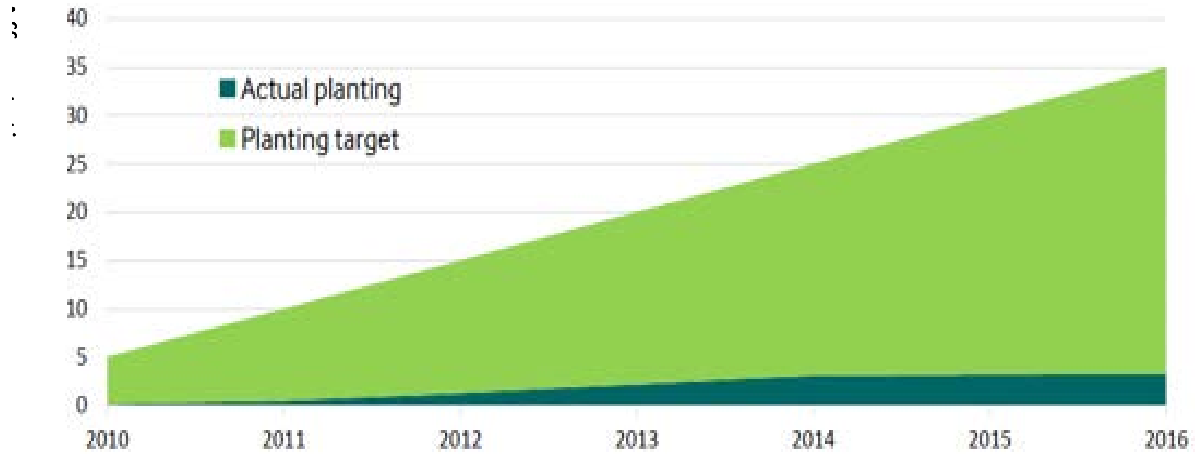


Figure 1.2 Cumulative shortfall in WG afforestation targets in thousands of hectares (Welsh Government, 2017)

The most recent update to the Woodland for Wales Strategy (Welsh Government, 2018c) has amended earlier ambitions for tree planting. It quotes advice from the UK Climate Change Committee recommending planting rates of between 2000 and 4000 hectares per year between 2020 and 2030 and suggesting these levels of woodland creation continue until 2050, by which time the area of new woodland created should be at least 66,000ha. This accepts that the land-use sector in Wales will decarbonise more slowly than other sectors of the economy.

1.2.2 Brexit and WG policy

The recent consultation document, Brexit and Our Land (Welsh Government, 2018b), asks for responses to a set of proposals from the WG as to how agriculture in Wales will be funded once CAP payments cease. It sets out why WG considers CAP payments to be unhelpful and proposes replacing the current scheme of per hectare payments available only to 'active farmers', with a two pillared approach where funding is available to all land managers in Wales. The 2 pillars will comprise;

- An economic resilience scheme where funds are available to both farmers, foresters and supply chains that process produce, to encourage investment in skills and infrastructure and promote production and marketing.

- A payment for public goods (ecosystem services) which arise from land management activities.

This shift in approach to supporting the rural economy has the potential to re-apportion spending away from livestock farming and towards a sustainable woodland based economy with the many attendant ecosystem benefits this would entail.

The consultation considers 3 scenarios for the post brexit trading relationship that the UK will have with the rest of the world and the impacts that these will have on agricultural commodity prices. In all scenarios both the price and output value of the sheep farming sector are projected to fall. It appears inevitable that the removal of direct income support combined with a fall in sheep prices will cause sheep numbers in Wales to fall dramatically post Brexit. This provides an opportunity for woodland expansion as suitable land becomes available for tree planting.

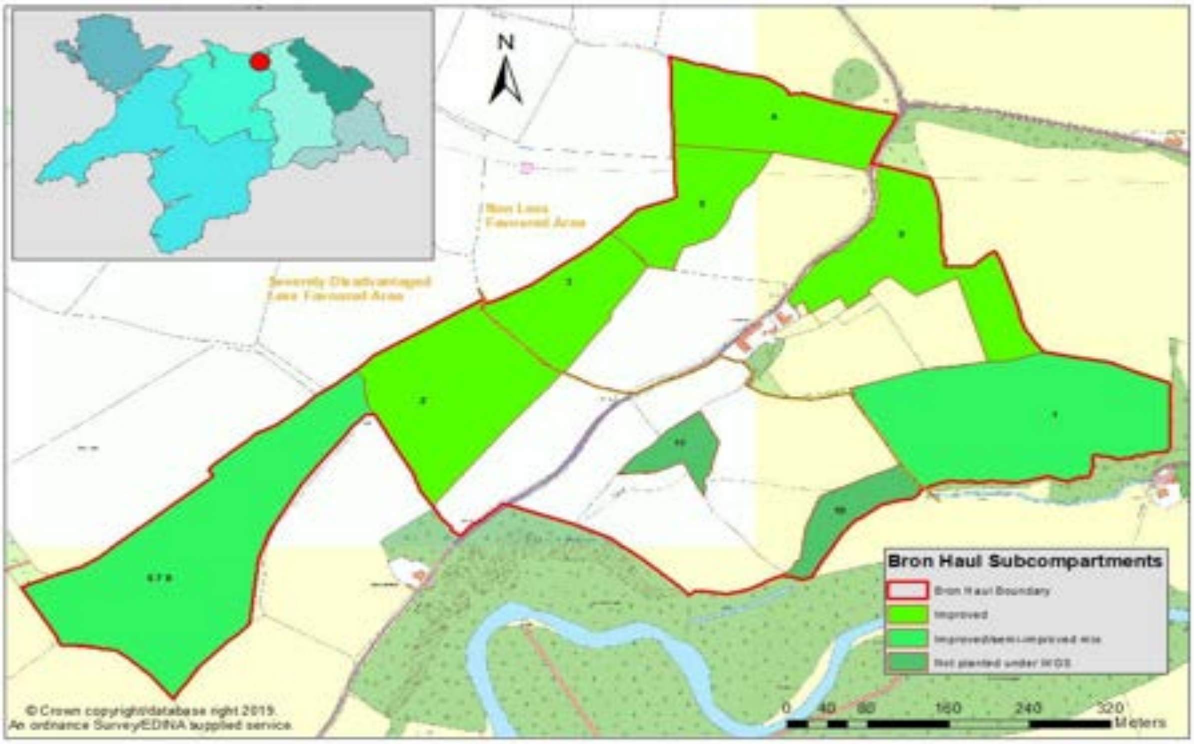
1.3 Bron Haul Woodland Project

Bron Haul is a 28ha farm situated on the south facing side of the Elwy valley in the parish of St. George, Abergele (map 1.1). The elevation of the land is between 80 and 200 metres above sea level. The land is moderately to severely sloping and the soil is mostly thin brown earth over shale.

1.3.1 Agricultural Land-use

Until 1978 Bron Haul was a mixed tenant farm of 23ha on the Kinmel Estate, with a dairy herd of around 9 friesian cows and a flock of 100 suffolk cross sheep. The cessation of churn collection and the introduction of bulk milk tanks made this small dairy business unviable, and combined with the retirement of a nearby tenant, this prompted Kinmel Estate to take advantage of the farm amalgamation grant scheme and join the two farms into one 'more economically viable unit' concentrating on sheep farming. The Bron Haul farmhouse and buildings, along with 2ha of land were sold to the current owners, and a small ash woodland was planted.

When the 21ha of former Bron Haul land came on the market in 1994 it was possible to reunite the farm with its land. Because the sheep quota associated with the land had been taken by the departing tenant, the new owner obtained quota from the national reserve. A quota to keep 200 sheep, (and therefore the entitlement to claim the associated agricultural funding,) was awarded. Sheep farming commenced, and a more ambitious tree planting program was conceived.



Map 1.1 Bron Haul Location map showing subcompartments.

The motivation for tree planting at Bron Haul was multi-factorial. The 1995 WGS contract for sub-compartments 4 and 5 states, ‘We propose to grow marketable timber as an alternative to agricultural production using predominately native broadleaved species, and to do this in such a way as to create rich wildlife habitat of great scenic value.’ This was a statement designed to satisfy the requirements of the FC in order to receive WGS and FWPS funding. More broadly, the project was a response to the environmental concerns of the owners and was seen as economically justified by the belief that carbon taxation, or rationing, was soon to be introduced, with an inevitable boost to timber and firewood prices. Anthropogenic climate change was generally accepted by this time with the UK prime minister, Margaret Thatcher, describing climate change as, 'a major threat to humanity' and calling for international action when addressing the United Nations in 1989.

1.3.2 Woodland establishment

Woodland creation at Bron Haul began in 1990 with the planting of 0.4 ha of predominantly ash woodland, with a small proportion of oak (*Quercus petrea*) and wild cherry, in part funded under the WGS. Then, as now, the FC (now part of NRW) was encouraging private landowners to plant mostly site-native broadleaved species at close enough spacings to promote timber production (2250 stems/ha). In 1995, 3.4ha of mixed broadleaf woodland was planted. This time, a complex selection of species was intimately mixed. The species listed on the WGS application were; oak 11%, ash 5%, beech 3%, wild cherry 8%, rowan 2%, birch 3%, lime 2%, sweet chestnut 8%, red oak 5%, holly 2%, crab apple 2%, wild pear 2%, willow 3%, hazel 8%, and 35% alder. The alder element was a mixture of three non-native species, Italian, grey and red alder, which were planted as a nurse crop with the idea that they would increase site fertility through nitrogen fixation. In practice the red oak was not planted. Instead, the native oak element was increased to 16%. A similar species mix, with the addition of 5% larch, was used in planting schemes in the following 4 years. By 1998 an area of 10.88 ha had been planted.

A further 4.3ha of steep and inaccessible former woodland, which included 0.4ha of mature and veteran oak, ash and beech canopy, was purchased in 1998. This area was restored to native woodland using natural regeneration and transplants grown from locally collected seed to achieve a stocking rate of 1100 stems/ha. Rigorous weed control in the years following planting has led to good rates of establishment and rapid early growth in all subcompartments.

1.3.3 Woodland Management

The 10.8ha of woodland planted on improved or semi-improved grassland (map 1.1) has been subject to two thinning operations, as well as both formative and high pruning, and contains many stems that should ultimately produce high quality timber. These operations were supported by government grants under the BWW (2008-2012) and GWM (2014-2019) schemes. In addition, these schemes helped to fund squirrel control, access tracks, some fencing and gates and the removal of tree shelters. GWM also included payments for excluding livestock from wooded areas in the scheme. The process of introducing continuous cover management is under way across these compartments. The aim of management is to concentrate increment into individual trees that have been selected for health, vigour and the length of knot-free, straight stem. These selected stems will be allowed space within the canopy, through successive thinnings, to allow them to achieve marketable size in as short a time as possible.

1.4 Conclusions

The Welsh landscape we see today is the product of a century of political interventions where provisioning has been the primary eco-system service required of the land. In the farming sector this has led to a focus on meat and dairy production whilst the forestry sector has concentrated on producing fast grown conifers.

Political priorities are changing, and the realisation that eco-systems are degraded, and that anthropogenic climate change is a huge threat, has led to a change in policy. It is recognised that the creation of 100,000ha of new, diverse, and resilient woodland should be able to provide a wide range of ecosystem services, including sequestering sufficient amounts of atmospheric $C0_2$ to offset unavoidable emissions from other parts of the land-use sector.

Until now, there has been a lack of evidence that the woodland type being encouraged in grant aided planting schemes can deliver the desired multi-ecosystem service outcome. It is a widely held view within the forestry industry that much of the broadleaf woodland planted in Wales under the WGS is of little value other than for amenity, with an absence of management for timber production and widespread damage by grey squirrels (Oliver Combe, Tim Kirk, Andrew Bronwin, Charles Dutton, and Ian Barrington, personal communications, 2019).

Bron Haul woodland is a prize-winning example of new broadleaf woodland, which has been established and managed under government funded grant schemes as multi-purpose forestry. The sustainable production of high value timber is at the heart of the owner's long-term management vision. As such it provides an opportunity to test whether the WG ambitions for mixed broadleaf woodland to fulfil its sustainability goals are realistic, and what level of grant support such management requires.

CHAPTER 2 What has been the net cost to the public purse of woodland planting and management at Bron Haul?

2.1 Introduction

The planting and establishment of woodland at Bron Haul has received public funding for all operations. This was justified by the public policy objectives met by changing the land-use from pasture to woodland and subsequently improving the economic and biodiversity potential of the woodland, and the putative improvement of ecosystem services through woodland management. In this section, the cost to the public purse incurred by these forestry operations is calculated. Since planting occurred on land that was being used for grazing livestock, and so was attracting agricultural subsidy under the CAP, the woodland grants are compared with the agricultural grants that would have been due had the land been maintained as pasture. This provides an opportunity to examine whether woodland grants are sufficient incentive to encourage farmers to plant trees.

2.2 Method

2.2.1 Forestry grants

Information on the grants received for woodland establishment and management was taken from records kept in the Bron Haul archive. The planting and management plan documents that were produced under the grant-aided woodland planting and management schemes describe the operation types, years and associated grant amounts for each woodland subcompartment. The data extracted from the WGS, BWW and GWM documents are detailed below.

Woodland Grant Scheme

The WGS produced a contract for each of the planting years. The contracts include a brief description of the project, the area to be planted (also shown on a map), the species composition, and the planting grant bands. It also includes the rate of FWPS due, which depended both on whether the land was inside or outside the LFA and whether the grassland was improved or unimproved (table 2.1).

Table 2.1 Summary of WGS grant for each subcompartment

Compartment	Comp. No.	Area (ha)	Total Grant (£)	Grant per ha and averate	Planting Grant WGS (£)	FWPS (£)	LEAP (£)
TP Wood	1	3.4	13,290.00	3,908.82	5,790.00	7,500.00	
Coed Fron Ddu	6,7,8	4.3	6,093.00	1,416.98	5,409.00	504.00	180.00
Gwern	10	0.53	472.50	891.51	472.50		
Quarry Wood	9	1.36	6,076.50	4,468.01	2,326.50	3,750.00	
Hayfield	4,5	2.67	14,820.00	5,550.56	5,070.00	9,750.00	
Coed Ivan	3	1.21	6,897.00	5,700.00	2,359.50	4,537.50	
Y Fron	2	2.4	9,720.00	4,050.00	4,680.00	5,040.00	
Woodpecker wood	11	0.39	0.00	0.00			
Total		**16.26**	**57,369.00**	**3,248.24**	**26,107.50**	**31,081.50**	**180.00**

The grant amount received for planting and establishment for each compartment is expressed both as a total and an amount per hectare. The total is the sum of income from the WGS and FWPS, and in the case of the Coed Fron Ddu the Livestock Exclusion Annual Payment (LEAP). Differences in the per hectare grant reflect different characteristics of the subcompartments before planting. The Gwern attracted a lower grant rate because it was already partially wooded. The Coed Fron Ddu received less grant rate because it was planted at 1100 stems/ha instead of the 2250 stems/ha planted elsewhere. The TP wood also received a slightly lower grant rate because it contained 1.6 ha of unimproved land, mostly bracken or gorse on steep slopes, which did not qualify either for better land supplement or FWPS. The remaining compartments (2,3,4,5 and 9) were planted on more typical improved grassland, that had no woodland remnant or scrub elements. As such, their conversion to woodland had the greatest impact in terms of loss of farm income.

Better Woodlands for Wales

The BWW management plan details a 5-year programme of operations, standards of work required and the grant amount to be paid. The grant was set at 50% of the standard operation costs as determined by FC Wales. The subcompartment numbers from the map accompanying the BWW plan are used throughout this dissertation. The total grant for each compartment is the sum of the amounts for pest control, silviculture and infrastructure (table 2.2).

Table 2.2 Better Woodlands for Wales Management Grants (2008-2012)

Compartment name	Compartment number	Area (ha)	Total Grant (£)	Grant per ha (and avg) (£)	Pest control(£)	Silviculture (£)	Infrastructure (£)
TP Wood	1	3.4	3,711.27	867.05	974.38	1,973.60	763.29
Coed Fron Ddu	6,7,8	4.3	3,356.52	780.59	1,199.83	2,156.69	0.00
Gwern	10	0.53	151.43	285.72	151.43	0.00	0.00
Quarry Wood	9	1.36	1,606.62	1,181.34	388.62	1,218.00	0.00
Hayfield	4,5	2.67	4,243.93	945.28	762.97	1,760.92	1,720.04
Coed Ivan	3	1.21	1,040.10	859.59	342.90	697.20	0.00
Y Fron	2	2.4	2,007.86	836.61	660.06	1,347.80	0.00
Woodpecker wood	11	0.39	104.35	267.56	104.35	0.00	0.00
Total		**16.26**	**16,222.08**	**752.97**	**4,584.54**	**9,154.21**	**2,483.33**

Pest control covered the installation, maintenance, and operation of traps to control grey squirrels. The silvicultural operations funded were pruning and uneconomic thinning (the value of timber felled did not cover the operational costs). The highest grants/ha were associated with the TP wood (subcompartment 1) where an extraction track was constructed, and the hayfield wood where the erection of deer fencing was funded to protect an area managed as coppice beneath power transmission lines.

Glastir Woodland Management

Similar to the BWW plan, this contains details of management prescriptions, capital works, and stock exclusion payments for each year of the plan, along with the accompanying grant amounts, maps and a felling licence (table 2.3).

Table 2.3 Glastir Woodland Management grants (2014-2018)

Compartment name	Compartment number	Area (ha)	Total Grant(£)	Grant per ha (and avg) (£)	Stock Exclusion (£)	Silviculture (£)	Infrastructure (£)	Pest control (£)
TP Wood	1	3.4	11,339.54	1,320.12	1,352.70	3,135.72	3,829.24	3,021.88
Coed Fron Ddu	6,7,8	4.3	6,839.26	580.67	1,693.90	802.98	661.20	3,681.18
Gwern	10	0.53	603.44	369.89	144.50	51.54	0.00	407.40
Quarry Wood	9	1.36	4,809.15	1,724.88	742.60	1,603.23	1,156.47	1,306.85
Hayfield	4,5	2.67	5,901.26	1,313.00	1,067.70	2,438.01	343.00	2,052.55
Coed Ivan	3	1.21	3,140.07	1,303.20	477.65	1,099.22	633.00	930.20
Y Fron	2	2.4	5,246.18	1,264.74	915.20	2,120.18	435.00	1,775.80
Woodpecker wood	11	0.39	0.00	0.00	NA	0.00	0.00	0.00
Total		**16.26**	**37,878.90**	**984.56**	**6,394.25**	**11,250.88**	**7,057.91**	**13,175.86**

The GWM scheme was more generous than the BWW with the total receipts being over twice that of BWW. The silvicultural operations funded were very similar, but infrastructure payments were higher, including funding for extraction tracks in compartments 1,2,3,4 and 5 and re-fencing in several compartments. GWM also included an annual payment for stock exclusion. In addition to funding squirrel control, the pest control payments contributed towards the purchase of two high seats to assist with deer management. The woodpecker wood was not eligible for stock exclusion payments as it was by this time part of a more recent planting scheme, (which is not included in this study).

2.2.2 Agricultural Grants

Information on the levels of agricultural subsidy that might have been expected for continued livestock farming were taken from the Wales Farm Income Booklets. These are compiled annually from the full farm business survey which collects data from a random selection of Welsh farms (550 farms in 2018) on behalf of WG. Aberystwyth University has been publishing the Welsh Farm Income Booklet for 80 years. The most recent 16 years of publications are available on their website, providing data from 2002/3 to 2017/18 (IBERS, 2018). To cover earlier years to coincide with the start of tree planting at Bron Haul, data from 1995-2002 was supplied by IBERS on request (IBERS personal communication, 2019).

The Wales Farm Income Booklet presents data by farm type, based on topography and the type of livestock kept. Bron Haul best fits the category Hill Sheep and Cattle, as it has traditionally kept mixed livestock and most of the land is within the LFA.

Agricultural income foregone is the amount of income from farming subsidies that the afforested area at Bron Haul could have been expected to attract had livestock farming continued. The area of grassland at Bron Haul that had been converted to woodland was calculated for each year. The agricultural income per hectare for each year was estimated from the average agricultural payments published in the Wales Farm Income Booklet. In this booklet, the total payments per hectare that the average hill sheep and cattle farm received are broken down by subsidy type. These subsidy amounts were summed, and the agricultural income foregone was calculated by multiplying this figure by the area of afforested land at Bron Haul.

2.3 Results

The area of woodland at Bron Haul rose from 3.4ha in 1994/1995 to 15.87 in 1999/2000 with a further small increase to 16.26 in 2007/8 (table 2.4). From 1994 to 2000 the agricultural income foregone increased rapidly from £837 to £2060 as the area afforested increased under the WGS. From 2000-2002 there was a sudden decline in agricultural support payments, (this appears as a decrease in the gradient of the red trace in figure 2.1). From then on, the agricultural income foregone did not change greatly over the years despite two reforms in the way CAP payments are calculated, firstly in 2005 when headage payments were replaced by the BPS and then in 2014 when the historic basis for payments began to transform to an area-based payment

Table 2.4 Agricultural income foregone at Bron Haul due to afforestation

Year		1994/5	1995/6	1996/7	1997/8	1998/9	1999/00	2000/1	2001/2
Payments (£/ha)	SPS	0	0	0	0	0	0	0	0
	Tir mynydd\ environment	0	0	0	0	0	0	0	0
	Sheep subsidy	227.36	253.34	187.65	178.05	240.78	211.14	115.63	75.05
	Cattle subsidy	18.95	21.73	34.70	22.23	27.99	20.48	14.18	16.96
	Total	246.31	275.07	222.35	200.28	268.77	231.62	129.81	92.01
Area afforested (ha)		3.4	7.01	9.68	15.34	15.34	15.87	15.87	15.87
Agricultural subsidy lost (£)		837.45	1928.24	2152.35	3072.30	4122.93	3675.81	2060.08	1460.20

Year		2002/3	2003/4	2004/5	2005/6	2006/7	2007/8	2008/9	2009/10
Payments (£/ha)	SPS	0	0	0	174.04	236	238	262	305
	Tir mynydd\ environment	95.54	93.26	106.10	120.99	33	54	34	35
	Sheep subsidy	123.40	127.23	148.04	0	0	0	0	0
	Cattle subsidy	12.14	13.59	35.86	0	0	0	0	0
	Indirect	0	0	0	0	39	39	41	44
	Total	231.08	234.08	290.00	295.03	308	331	337	384
Area afforested (ha)		15.87	15.87	15.87	15.87	15.87	16.26	16.26	16.26
Agricultural subsidy lost (£)		3667.18	3714.86	4602.34	4682.09	4887.96	5382.06	5479.62	6243.84

Year		2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Payments (£/ha)	SPS	287	283	254	259	218	189	209	212
	Tir mynydd\ environment	35	34	0	0	0	0	0	0
	Indirect	45	46	54	53	48	54	51	45
	Total	367	363	308	312	266	243	260	257
Area afforested (ha)		16.26	16.26	16.26	16.26	16.26	16.26	16.26	16.26
Agricultural subsidy lost (£)		5967.42	5902.38	5008.08	5073.12	4325.16	3951.18	4227.6	4178.82

Over the past 24 years the woodland creation and management at Bron Haul has received grant funding of £111,469, and the total agricultural grant income foregone over the same period was estimated at £96,603 (figure 2.1).

The estimated agricultural income foregone shows a steady and reliable flow of income under the CAP. Forestry grants, however, were only available as various planting and management schemes became available to fund operations. The rapid increase in forestry grant income from 1995 to 1998 covers the period when planting was undertaken and WGS planting grants were received.

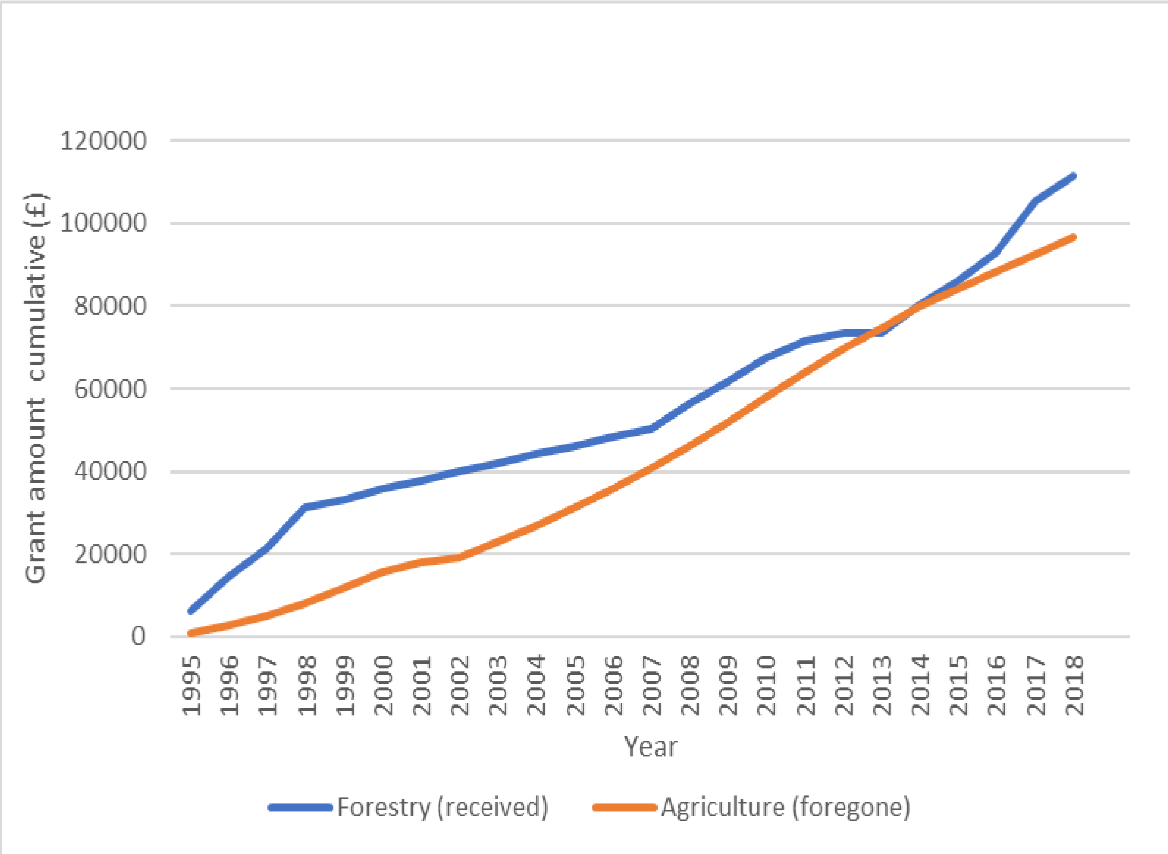


Figure 2.1 Comparison of cumulative forestry grants received with cumulative agricultural payments foregone (see section 2.22)

Between 1998 and 2007 FWPS payments were the only grant received, and by the end of this period the cumulative agricultural payment foregone (£40,863) was converging on the forestry income received (£50,435). The BWW scheme from 2008 to 2012 caused the forestry income to roughly match agricultural income foregone, but when this ended without a replacement scheme the agricultural payments foregone briefly exceed the actual grants received for forestry. The GWM scheme reversed this trend. From the end of 2018 there are no woodland management grants available, and on current trends, the agricultural payments (at about £4000pa) would be expected to exceed the woodland grants by 2022.

2.4 Discussion

2.4.1 Woodland creation has cost the landowner not the taxpayer

For the taxpayer, the establishment and management of broadleaved woodland at Bron Haul to date has created little expense beyond that which would have been incurred by funding ongoing livestock farming. The agricultural payments under the CAP required no special investment or risk for the land manager. The only demand on landowners is that land is kept in 'good agricultural condition' and that cross-compliance rules requiring legal compliance in the treatment of livestock and protection of land and water courses are adhered to. In contrast, woodland creation and management is an expensive and labour-intensive activity. Apart from the FWPS element (£31,081.50) and the GWM livestock exclusion payments (£6,394.25), which can be thought of as income, all other woodland grants were contributions towards real expenditure incurred in materials, planting stock and labour. In the case of BWW, grants were a 50% contribution towards costs based on standard scheme rates for operations. Although grants for creating and managing private woodland have appeared generous, the operations have imposed real costs on the land manager.

2.4.2 Woodland funding has been unreliable

There is a contrast to be drawn between the predictability and reliability of agricultural support and the stop-start nature of funding for woodland. Forestry is dependent on short term WG initiatives with no guarantee that access to schemes will be possible even where they exist. Bron Haul was fortunate to be one of few woodlands to benefit from a GWM plan. Without it there would have been no funding for ongoing essential management, and the forestry grants (received) trace in figure 2.1 would show a flat line from 2012 at £73,590, and by 2018 income foregone would have exceeded grants received by £23,000. This level of uncertainty is a strong disincentive to land managers to plant woodland.

2.4.3 CAP payments have been a barrier to woodland creation by farmers

These observations can go some way to explain why rates of woodland creation in Wales (and the UK generally) have never returned to the levels seen before 1988 when large scale conifer planting came to an end and the focus for woodland creation fell on private landowners and farmers. More recently very ambitious planting targets set by the Welsh Government and supported by what were thought to be generous planting grants, have failed to deliver significant amounts of new woodland (Welsh Government, 2017). Many reasons for the failure of farmers to plant woodland have been given, such as their perception that costs are prohibitive (Wavehill Consulting, 2009) or the identification of a cultural divide between farming and forestry (Wynne-Jones, 2013). These results show that agricultural support payments give farmers a very strong incentive to continue their current, livestock based, business model. Farmers have no incentive to embark upon tree planting; a costly venture about which they have little knowledge, when they are receiving reliable and regular payments for continuing with their current business and way of life with its strong cultural support. This inertia in the rural economy caused by a dependence on CAP payments is illustrated in the IBERS data. Subsidy payments have exceeded net profits, (which include income from subsidy), for the average hill livestock farm in Wales for each of the last 10 years (figure 2.2). Farmers have continued with their existing business model, based on ruminant livestock, despite it being consistently loss making.

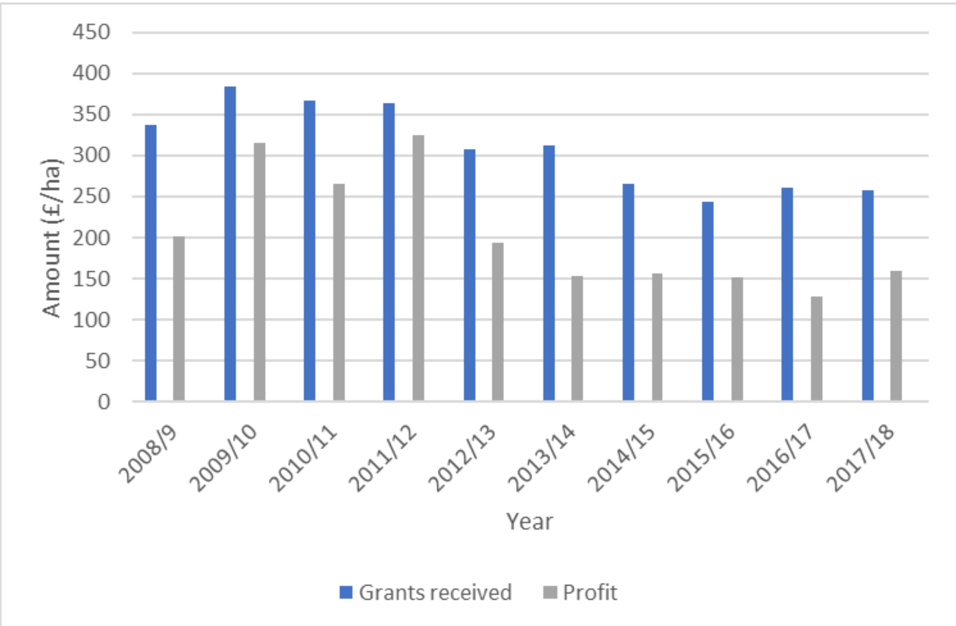


Figure 2.2 Comparison of total grants received to net profit for hill sheep and cattle farms in Wales (using data from IBERS, 2018)

The failure of WG to engage farmers in woodland expansion (figure 1.2) were highlighted in a report commissioned by WG in 2014 which also pointed out that the 100,000ha planting target was vague and aspirational with little thought given to where the planting might occur (ADAS, 2014). The UK Climate Change Committee (UKCCC) observed that the WG policy on woodland expansion was focused strongly on desired outcomes rather than the means to deliver them. They suggested that the in future the current voluntary approach to emissions reductions in agriculture will need to be replaced with stronger government policy.

CHAPTER 3 How much atmospheric $C0_2$ has been sequestered by the change in land-use at Bron Haul?

3.1 Introduction

The ability of woodland to capture atmospheric CO_2 and sequester its carbon component within plant material, whilst releasing oxygen to the atmosphere is recognised as an important ecosystem service provided by woodland. In order to quantify the amount of carbon stored within living trees the FC have developed a carbon assessment protocol (Jenkins et al., 2018). This has been developed by the FC to allow woodland managers to quantify sequestered carbon, potentially to sell carbon credits, but also to provide a standard procedure for producing comparable carbon assessments. The FC protocol only assesses the carbon in living tree biomass and does not attempt to quantify carbon in leaf litter, standing or fallen dead wood or in forest soil.

All forest inventory is most easily achieved within an even-aged, single species forests. Indeed, it can be argued that this has been a major driver in the development of modern industrial forestry practice where the desire to quantify growing timber and manage woodland by proscriptive measures has led to the simplification of forest structure in plantation forestry. The more species present in a forest and the more diversified its structure the greater are the challenges to make accurate estimates of its constituents. To address these issues the FC carbon protocol gives a variety of methods to deal with different woodlands of varying scale and complexity, along with decision pathways to guide the user to choose the most appropriate methodology.

3.2 Method

3.2.1 Scoping

The carbon assessment survey focussed on a single compartment that was small enough to provide a manageable study area and typical of the woodland at Bron Haul. Subcompartment 3 (Coed Ivan) was selected as it:

- has not been thinned since 2015 and is therefore well stocked.
- has a good representation of the species mix and a typical growth rate for the woodland at Bron Haul.

- is a clearly defined subcompartment of a suitable area (1.21ha) that can be thoroughly surveyed with the time and resources available.

- is divisible into smaller blocks by well-defined physical features (external field boundaries and internal tracks) to facilitates organisation of the survey and identification individual trees.

- is representative of the type of agricultural land available in Wales that is currently used as improved or semi-improved grassland grazed by sheep or cattle and is not suitable for cultivation for crop growing because of topography and soil type.

- has good exposure to the southern sky and is therefore suitable for using GPS to locate individual trees.

For this subcompartment, the appropriate survey method identified in the carbon protocol is Method E: Full Tree Count and DBH Assessment (Jenkins et al., 2018). Diameter at breast height (dbh) is the diameter of the stem of a tree measured at 1.3 meters above the ground, measured perpendicularly to the ground and from the uphill side if the ground is sloping (Mathews and Mackie, 2006). Surveying was carried out during January, when lack of foliage aided both GPS readings and visual measurement of timber height and top height.

3.2.2 Equipment

The FC carbon assessment protocol is designed to be accessible to non-professional foresters and relies on measurement procedures laid down in Forest Mensuration (Mathews and Mackie 2006) using simple equipment. The equipment is shown in photograph 3.1 and included:

- A suunto clinometer, calibrated to give a height reading at a distance of either 15 or 20m

- A 20m surveyor’s tape.

- A dbh tape calibrated to convert a measurement of the circumference of the stem of a tree to a diameter

Photograph 3.1 Measuring equipment **a.** surveyor's tape **b.** dbh tape **c.** clinometer.

3.2.3 Stratification

The first requirement of the carbon assessment protocol is to stratify trees into three size categories; tree, sapling or seedling. Within the protocol trees are defined as living trees with a stem dbh>7cm. This is the diameter which has been recognised as the minimum size for marketable timber and was therefore the minimum timber size used in developing the tariff system (Hummel, 1955) on which the carbon assessment protocol relies. Seedlings are defined as a living stem less than 50cm tall. Anything between these two parameters is defined a sapling. Because of the age of the plantation at Bron Haul, there are very few seedlings, and almost all the trees are in excess of 7cm with the exception of hazel which has established as multi-stemmed stools, comprising an understory with very few stems achieving the 7cm threshold. It was therefore decided to treat hazel as a sapling component.

3.2.4 Sampling Protocol for Saplings

The number of hazel stools was counted and every 10th stool sampled to establish the number of stems and the average stem height within the stool. This sampling fraction was taken from table 4.2.2 in the carbon assessment protocol (table 3.1). This was used to calculate the sapling contribution to the carbon assessment protocol by multiplying the total number of stems by the figure for mean carbon content per stem taken from table 6.1.3 in the carbon assessment protocol.

Table 3.1 Sampling Fraction Adapted from FC Carbon Protocol

Estimated number of individuals	dbh sampling fraction	Height sampling fraction
10-20	1:1	1:1
21-30	1:1	1:2
31-40	1:1	1:3
41-50	1:1	1:4
51-60	1:1	1:5
61-70	1:1	1:6
71-80	1:1	1:7
81-90	1:1	1:8
91-100	1:1	1:9
101-200	1:1	1:10
201-400	1:2	1:10
401-600	1:4	1:10
601-800	1:6	1:10
801-1000	1:8	1:10
1001-1200	1:10	1:10
1201-1500	1:12	1:10
1501-2000	1:15	1:10
2001-2500	1:20	1:10
2501-3000	1:25	1:10
>3000	1:30	1:10

3.2.5 Sampling Protocol for Trees

Prior to measuring, an estimate was made of the number of trees of each species and the appropriate sampling fraction was taken from table 4.2.2 in the carbon assessment protocol (shown in table 3.1). The number of trees of each species in the woodland was counted by recording on a tally sheet. The dbh of every tree was recorded. For the nth tree of each species, tree total height and timber height were also recorded. These heights were measured using a Suunto clinometer calibrated to give a reading of height when the operator is stood 15m (as measured using the surveyors tape) from the base of the tree. A reading is taken of the vertical distance of the base, timber height and top height of the tree relative to the clinometer, which is held to the eye of the surveyor. The base height reading is subtracted from the measured timber and top heights to give true heights adjusted for the height of the clinometer relative to the base of the tree, (ie. if the base of the tree is below the height of the eye of the surveyor then the base height measured is a negative value). The timber height is judged by eye by the surveyor as the height where the stem is of 7cm diameter (photograph 3.2).

Photograph 3.2 A stem with a future

Tree B18 A sweet chestnut quality class A dbh 21cm timber height 6.5m

3.2.6 Calculations

Within the protocol it is suggested that species representing less than 10% of the sample can be grouped together and considered as a single representative species. It was decided in this study that a more detailed breakdown of species was needed in particular to separately assess the conifer element, which although comprising few trees, include the largest specimens in the subcompartment and so represent a disproportionately high fraction of the timber, (and therefore carbon) volume. All conifer species were grouped together and considered as hybrid larch, which was also the most numerous conifer species present. Birch, crab-apple, lime, and wild pear were all present in small numbers and were considered as a single group with birch chosen as the representative species for this group to be used in later calculations. Alder and beech were considered individually as it was assumed incorrectly that they comprised over 10% of the trees. The only consequence of this error was increased surveying time.

The data was entered into an excel spreadsheet and the calculations required within the carbon protocol were applied. This yielded a mean stem volume for each species which was multiplied by the number of trees to give a total stem volume. From these figures were derived values for stem, crown and root biomass in tonnes. When divided by two this gave an estimate of carbon tonnes, which was multiplied by 44/12 (molecular mass of CO_2/atomic mass of C) to give tonnes CO_2 equivalent (tCO_2e).

3.3 Results

Table 3.2 shows the number of stems of each species counted in the inventory process along with the percentage this represents of the total number of stems present and compares this to the approximate percentage present in the planting mix. The actual proportion of species in the planting mix is only known for subcompartments 3 and 4 combined, which were planted in the same year. Of the 2250 stems/ha planted, just under 50% (1042/ha) remain. The rest have either been removed in the two thinning cycles or have died. The removal of most of the alder nurse crop in the first thinning cycle accounts for over half of the stems removed.

Table 3.2 Composition of subcompartment 3 (Coed Ivan) by species

Species	Approx. % planted	2019		Species	Approx. % planted	2019	
		% Present	number			% Present	number
Oak	16	10	121	**Alder**	31	5	67
Ash	5	12	146	**Larch**	5	3	33
Cherry	8	20	257	**Hazel**	17	16	208
Sweet Chestnut	8	19	246	**Birch etc**	7	12	150
Beech	3	3	33	**Number of stems in 2019**			**1261**

Hybrid larch, hazel and beech have been thinned roughly proportionately to their planted ratio. Wild cherry, ash and sweet chestnut and the minority species (classed as 'birch etc') have increased in representation, whilst the proportion of oak has declined.

The results of calculations made according to the carbon protocol are shown in table 3.3. tCO_2e embodied in the average tree of each species is shown in figure 3.1.

Table 3.3 Results from the FC Carbon protocol for subcompartment 3

Species		Sweet Chestnut	Ash	Cherry	Oak	Beech	Birch etc	Conifer	Alder	Hazel	Total
n		246	146	257	121	33	150	33	67	208	**1261**
Tariff		19	23	18	14	18	14	21	17		
Quadratic mean dbh (cm)		17.52	20.39	19.49	11.16	16.33	13.65	30.21	14.38		
Mean stem volume (m^3)		0.13	0.22	0.16	0.04	0.11	0.06	0.47	0.12		
Total volume (m^3)		31.97	32.57	41.33	4.65	3.73	8.80	15.39	8.11		**146.5**
Mean top height (m)		11.59	13.80	12.49	8.78	12.36	9.70	16.83	11.40		
Biomass average stem (t)	**Stem**	0.06	0.12	0.08	0.02	0.06	0.03	0.18	0.05		
	Crown	0.02	0.03	0.03	0.01	0.02	0.01	0.04	0.01		
	Root	0.03	0.04	0.04	0.01	0.02	0.02	0.09	0.02		
	Total	0.11	0.19	0.14	0.04	0.11	0.06	0.31	0.08		
Total biomass in stand (t)		26.80	27.79	37.22	4.55	3.49	8.65	10.18	5.43		**124.1**
Carbon in stand (t)		13.40	13.90	18.61	2.27	1.74	4.32	5.09	2.72	6.14	**68.2**
CO_2 in stand (t)		49.14	50.96	68.24	8.34	6.39	15.85	18.66	9.96	22.50	**250.0**
Total biomass (t/ha)		22.15	22.97	30.76	3.76	2.88	7.15	8.41	4.49		**102.6**
Carbon (t/ha)		11.08	11.49	15.38	1.88	1.44	3.57	4.21	2.24	5.07	**56.4**
CO_2 (t/ha)		40.61	42.11	56.40	6.89	5.28	13.10	15.42	8.23	18.60	**206.6**

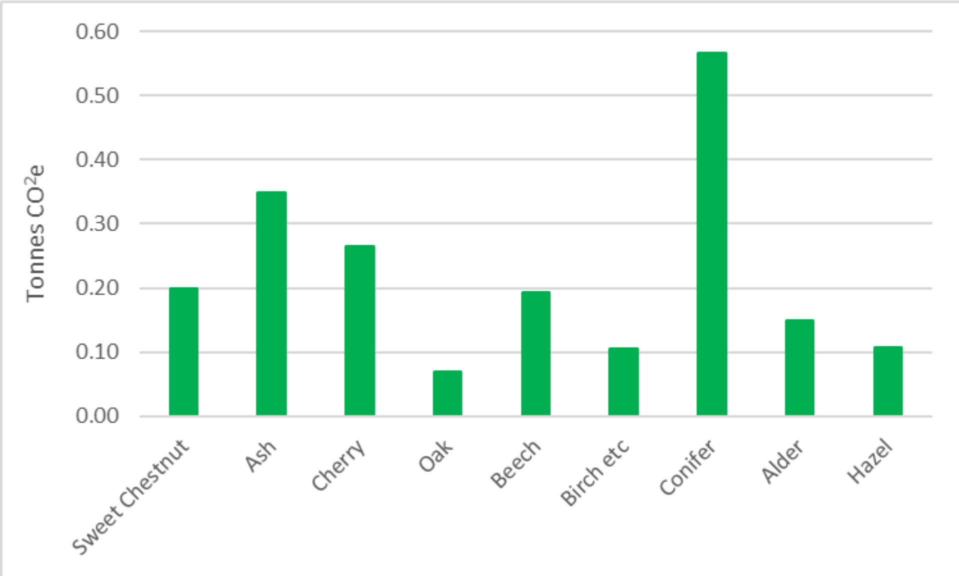


Figure 3.1 Tonnes of CO_2e in the average tree of each species

The conifers were the most vigorous with an average of 0.57tCO_2e sequestered per tree. The largest of these were a few specimens of Monterey pine. The smallest trees were oak with an average of 0.07tCO_2e. When totalled these values give us an estimate of 206.6 tonnes of CO_2 per hectare sequestered in the living biomass of trees in the Coed Ivan compartment of Bron Haul woods (figure 3.2). Although conifer were the largest trees, they represent only 3% of the trees and so their contribution to total carbon sequestration was small compared to the major component of sweet chestnut, ash and wild cherry (figure 3.2).

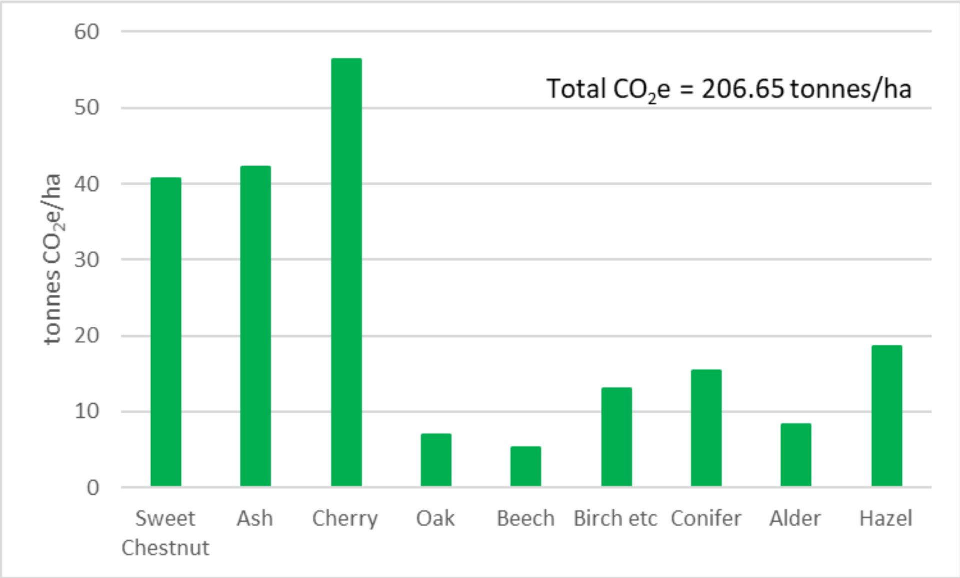


Figure 3.2 Tonnes CO_2e sequestered per hectare in subcompartment 3 (Coed Ivan) by species.

3.4 Discussion

3.4.1 Planting trees on grassland is a highly effective way of sequestering CO_2

Over the last 22 years the planting of woodland in Coed Ivan has generated a stock of carbon held in tree biomass of around 206.6t$C0_2$e/ha (figure 3.2). In comparison, grassland has around 4t$C0_2$e/ha stored in plant biomass (Ostle et al., 2009). Using this figure, changing land-use from grassland to woodland at Bron Haul, has increased the amount of carbon held in biomass by 202.6t$C0_2$e/ha.

202.6t$C0_2$e/ha represents an average rate of sequestration over the 22 years of 9.21tCO_2e/ha/yr. It should be noted that the current rate of carbon sequestration will be higher than this as woodland sequesters little carbon in the first years after planting. The current rate of increment of carbon could be established only by inventory in subsequent years.

3.4.2 Multi-species planting at Bron Haul appears to exceed rates of CO_2 Sequestration predicted by the C-sort model

The rate of carbon sequestration observed at Bron Haul can be compared with the figures produced in an assessment of the outcomes predicted from the BWW planting scheme (Ambrose-Oji et al., 2012). Using the C-SORT model developed by forest research they estimated the amount of $C0_2$ that would be sequestered, over a 20-year period 2008-2028, by the new woodland planted in Wales. Their study considered woodland creation funded by the BWW grant scheme over the 4 years 2008-2011 inclusive. They estimated that the 337.2ha of broadleaf woodland planted would be responsible for sequestering between 2,604t$C0_2$e (low estimate) and 25,540t$C0_2$e (high estimate) with a central figure of 10,614t $C0_2$e. These figures include an estimate for soil carbon sequestered and also a carbon cost of forestry operations. These figures yield an estimated average rate of sequestration of between 0.42t$C0_2$e/ha/yr (low) and 4.21t$C0_2$e/ha/yr (high), assuming that the planted stock will be on average 18 years old in 2028. Although these figures are not directly comparable with the 9.21t$C0_2$e/ha/yr over 22 years at Bron Haul, it would appear that sequestration rates in the Bron Haul woodland are exceeding the highest predicted in that study. One explanation of this finding is that complex species mixtures have been found to exhibit increased growth rates when compared to monocultures (Grossman et al., 2017). The C-SORT model fails to take this into account. Instead it uses single species yield class models summed in proportion to species representation.

3.4.3 Careful thinning is needed to maintain species diversity

The differences in average tCO_2e sequestered by species reflect the vigour of the various species planted under the prevailing site conditions and silvicultural regime at Bron Haul. Figure 3.1 suggests that the conifer element has been the most useful for sequestering CO_2 and that oak has been least useful. However, there are some large oak individuals and the poor contribution of oak overall is partly due to the failure of the thinning regime to ensure that oak is not outcompeted. Oak is a light demanding species and once over-topped it loses vigour and eventually dies. The decline of oak seen in subcompartment 3 illustrates that planting complex mixtures of tree species will not inevitably give rise to diverse woodlands. The rapid height increment of larch has allowed it to out-compete its immediate neighbours.

Without careful management growth increment will be concentrated in those species that compete most vigorously and these species will dominate. The maintenance of tree species diversity within a mixed woodland requires regular, well targeted thinning.

3.4.4 Carbon sequestered in timber already harvested

Since planting, there have been two rounds of thinning in most of the Bron Haul woods. In subcompartment 3 these took place in 2009 and 2015. In the first thinning operation an estimated $20m^3$/ha was harvested as firewood and in the second round $30m^3$/ha a total of $50m^3$/ha. Actual volumes removed were not recorded. The thinning figures are estimates taken from BWW and Glastir management plans. If it is assumed that, when burnt, the firewood displaced fossil fuels then further GHG savings can be achieved. A UNFAO paper in 2015 concluded that net reductions in GHG emissions of between 50% and 150% could be achieved when wood is burnt in place of fossil fuel (FAO, 2016). If the central figure of 100% is taken, using firewood to replace other forms of heating represents a saving of CO_2 emissions equal to that embodied in the wood. If the specific gravity figure for alder from table 5.3.1 of the FC carbon protocol is used (0.42) then the dry weight of the timber removed in these two thinning cycles can be estimated at 21 tonnes. Therefore, firewood harvested as thinnings has embodied 10.5 tonnes of carbon or $38.5tCO_2$. This equates to the sequestration of $1.75tC0_2e$/ha/yr over the 22 years in Coed Ivan.

CHAPTER 4 Timber Potential of Bron Haul woodland

4.1 Introduction

4.1.1 Trends in afforestation

Forest expansion in the UK in the 20th century was dominated by the planting of commercial conifers, this mainly comprising sitka spruce. Investors and the commercial forestry sector, supported by the large sawmills, are content with this model. However, by the end of the century within the political sphere, it was realised that clearfell forest management, narrowly focused on the objective of timber production was no longer appropriate. Resolution H1 of the general guidelines for the sustainable management of forests in Europe (Forest Europe, 1993), stated that '…the conservation and appropriate enhancement of biological diversity in all types of forest is an essential element in their sustainable management'. The UN conference on the environment and development (1992) recognised that sustainable management required that the ecological, social, spiritual and cultural needs of present and future generations was considered alongside short-term economic benefits. The acceptance of these guidelines in the Woodlands for Wales strategy (Welsh Government, 2018c) means that all the new woodland planting in Wales should be 'genuinely multi-purpose'. Because of this, large scale expansion of the area of conifers in Wales has stopped.

Three quarters of the new woodland planted in Wales under the WGS (i.e. since 1988) has been broadleaf, with 13,300ha of broadleaf and 4,300 of conifer (Forestry Research, 2018). Planting densities ranged from 1100 to 2250 stems/ha allowed for broadleaf species. The higher planting density was to encourage the production of quality timber, incentivised by enhanced grant rates. However, much of the planting was at lower densities, with management objectives focused on the biodiversity and amenity benefits of woodland. Within the timber industry, it is widely believed that much of the post-1988 planting has not been managed for timber production, and that grey squirrels are greatly decreasing the value of the timber that has been grown (Oliver Combe, Tim Kirk, Andrew Bronwin, Charles Dutton, and Ian Barrington personal communications, 2019). A valuation of the Welsh forest resource (Saraev et al., 2017) found that although broadleaf woodland constitutes 45.5% of the timber resource in Wales, in 2015 it yielded only 1.5% of the timber harvested. Despite government policy, Wales is failing to produce quality broadleaf timber in any significant quantity.

4.1.2 Growing commercial broadleaf under continuous cover forestry

Achieving the multiple benefits of afforestation depends on the development of silvicultural systems which place ecological processes at the heart of timber production. The avoidance of clear-felling and the maintenance of a forest canopy at all times has led to the name continuous cover forestry (CCF), sometimes also called irregular forestry systems, to describe this type of silviculture. CCF encourages the development of diversity of structure and species composition to achieve recreational, landscape and environmental benefits and to safeguard forest soils, with the attendant positive impacts on timber production, water, and air quality.

Association Futaie Irreguliere (AFI) network

Although still in its infancy in the UK, CCF using predominantly broadleaf, site native species is well established in France, where the Association Futaie Irreguliere (AFI), founded in 1990, have established permanent reference plots in a network of over 80 research woodlands (Susse et al., 2011). All plots within the network are monitored on a 5-yearly cycle, with data being collected on a wide range of silvicultural, ecological, and economic parameters. The sites studied cover a wide range of species, climates, and soil types.

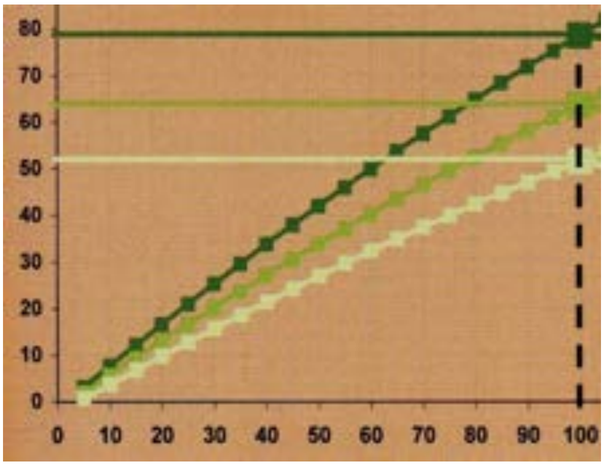
Central to AFI silviculture is identification of 'stems with a future' at the pole or small wood stage (12.5-27.5cm dbh). Stems are visually assessed for quality based on straightness, length of knot-free stem, and vigour. They are given a grade A, B, C, or D where A is fine quality timber suited to veneer or furniture making and D is suitable only for firewood. The best stems are then favoured by thinning to concentrate the increment potential of the forest into high quality timber production. These will be harvested when they reach their optimum economic size. Light levels within the stand are maintained such that there is plentiful germination of tree seeds, providing a ready supply of natural regeneration which can be recruited into the canopy as mature stems are harvested.

Experience in the AFI network has shown that the optimum basal area for CCF is between 12 and 18m^2/ha. The convention for measuring basal area used by the AFI only includes trees once they have achieved a dbh of 17.5cm, these stands would typically contain an additional 2 or 3m^2/ha of stems between 7cm and 17.5cm dbh (Susse et al., 2011). This would therefore equate to a basal areas measured using UK methodology of 14m^2-21m^2/ha. Under these conditions they have found that diameter increment is independent of the diameter distribution of the stand, i.e. the diameter increments of a given tree tends to remain constant throughout its productive life, if other conditions remain unchanged.

Institut pour la Développement Forestier (IDF) Active Silviculture

A slightly different approach to CCF, focusing principally on oak, is taken by the IDF, which they describe as active silviculture. The active silviculture of oak is described by Lemaire in 'Oak: fine timber in 100 years' (Lemaire, 2014). The main motive for Lemaire and the IDF in France is in cutting the length of rotation for oak from over 150 years, under traditional silviculture, to around 100 years. This was to promote the economic argument for growing oak, in the face of competition from the coniferisation of French forests.

Rather than concentrating on the basal area of the stand, the emphasis is on identifying around 70 potential 'winners' per hectare at an early stage (<20yrs) and ensuring that all neighbouring trees that threaten to impinge on the crown of these winners are removed before competition occurs. This halo thinning is replaced by basal area thinning to 14-18m^2/ha when the winners reach about 16m top height. By that stage, thinnings will be valuable trees in their own right. A minimum ratio of crown diameter to height of 1:2 is maintained in the future trees. Similar to the findings of the AFI, the IDF observe an almost constant rate of dbh increment (figure 4.1).



Age (years)

Figure 4.1 Relationship between dbh and age under active silviculture on sites of varying fertility; dark-light green = high-low fertility. (Adapted from Lemaire, 2014, p63)

Forestry Commission Free Growth

The active silviculture approach was influenced by the free grown oak experiment at Crumblands Wood in Monmouthshire. This stand of oak, planted in 1931, began its free growth management in 1951 with the aim of testing the possibility of growing high-quality oak in Wales to 60cm dbh in less than a century (Kerr & Forster, 2018). Each of the selected oaks (73/ha) was halo thinned so as to keep an area equal to ¼ of the crown diameter as a competition free buffer around each trees crown. Halo thinning ceased when the chosen stems reached a mean dbh of 39cm. The Crumblands experiment found that within the extensive plots the rate of diameter increment of the chosen trees was constant (figure 4.2).

The results from Crumblands were positive, with the first oaks achieving their target diameter in 2018, 87 years after planting. In their conclusions, Kerr & Forster suggests that other fast-growing broadleaved species might be more appropriate for free growth because they are less prone to the production of epicormic growth, which reduces the market value of the timber of oak.

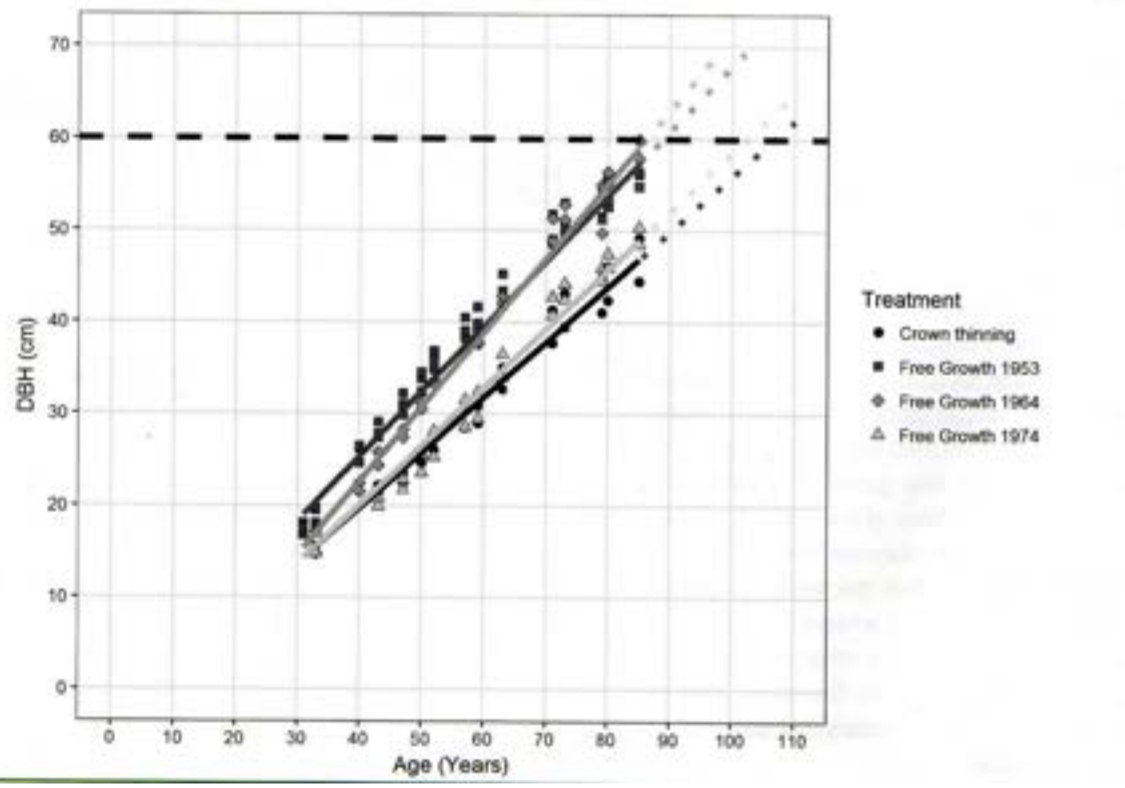


Figure 4.2 Relationship between dbh and age in extensive plots of free-grown oak. (Taken from Kerr & Forster, 2018).

The silvicultural approach being applied in the woodland at Bron Haul is consistent with the systems described above. Early thinning has mostly allowed for unchecked growth and combined with formative and high pruning, has promoted many stems of good form with well-developed crown structure, providing a good choice of 'stems with a future'.

4.1.3 Current market for broadleaf timber in the UK

Commercial timber milling in the UK is dominated by a few large mills with infrastructure for processing uniform conifer stems and supplying in large quantities to established markets. The processing capacity for broadleaf is more limited and mostly served by small mills.

There is an established market for good quality oak, and it is sought at large diameters with the best stems attracting prices of up to £515/m^3 (RFS, 2019). The choice of 60cm target dbh made in the FC Crumblands research and by the IDF reflects the compromise foresters are making between shortening time to harvest whilst presenting stems that are valued by the market. A weaker market exists for beech at similar sizes. Wild cherry and ash have only niche markets and can fetch up to £100m^3. However, wild cherry is a relatively short-lived species and is prone to butt rot once it reaches around 50 years old, and for this reason it is advised to grow it as quickly as possible. For the same reason saw millers prefer to buy a cherry of 40-60 cm diameter. The market for ash is described as very limited with high quality ash being exported for furniture making. Ash of 50cm or less is sought for this market. There is currently very little milling of sweet chestnut in the UK, its use is limited to cleaving for fencing material, and because of this smaller diameter timber is of value. (All timber pricing estimates were provided by Oliver Coombs, personal communication, 2019). Currently sweet chestnut thinnings provide all the fence posts used at Bron Haul.

This chapter will use the finding that a constant rate of diameter increment can be maintained in broadleaved trees grown under suitable CCF conditions to predict potential future timber harvest at Bron Haul.

4.2 Method

The assessment of stems with a future was limited to subcompartment 3 (Coed Ivan). The best available selection of stems that might realistically be expected to form a timber crop was chosen. This is a number of trees such that all might reasonably be expected to have sufficient space and resources to achieve a target dbh for sale as timber, if all the other competing trees in the compartment are removed as thinnings. For a mixed species wood in the UK, this number is not defined in the literature. However, from a review of sources (Lemaire, 2014; Kerr & Forster, 2018) considered in conjunction with research on the increased efficiency of resource use of multi species woodland (Liang et al., 2016; Smith et al., 2013) combined with differences in time to harvest between and within species, a final stocking rate of around 120 stems/ha was deemed realistic. These stems would be distributed evenly, though not regularly, across the site. The target diameter chosen for oak and beech was 60cm and for ash, cherry and sweet chestnut, 50cm. As stems achieve their target diameter and are harvested, this will create gaps in the canopy which will encourage natural regeneration, allowing the development of a continuous cover management regime.

The dbh of every tree in subcompartment 3 was measured as part of the inventory for the carbon protocol (chapter 3). From this data, the basal area in subcompartment 3 is presently 20.7 m^2/ha. This is at the upper limit of the target basal area for continuous cover management and indicates that the area is due for a thinning to reduce basal area by around 5m^2/ha.

4.2.1 Selecting stems with a future

The selection process started by choosing a vigorous, high-quality stem near the edge of subcompartment 3. This tree was designated as a stem with a future and numbered #1 with permanent orange paint, and a visual assessment of the quality of the stem was recorded using the A-D quality criteria defined in the AFI. The dbh and the timber height were measured (photograph 3.2), and the position of the tree was recorded as a waypoint using a Garmin ETREX30 GPS unit. Working from this first tree the best stem at least 7m and no more than 12m away was identified, marked, measured, and recorded in the same way. As well as stem quality and vigour, consideration was given to maintaining as wide a species mix and distribution as was possible.

4.2.2 Growth rates from annual ring width

As established in section 4.1.2, it is reasonable to assume that once a broadleaved tree is established it will continue on a set trajectory of diameter increment as long as it is subject to suitable, consistent management and climatic conditions. This allows for the possibility of creating a predictive graph relating rate of diameter increment in the future to the current dbh in the 5 primary timber species growing in Bron Haul woods. This procedure is not appropriate for the larch element as conifer species, managed under CCF regimes, exhibit accelerating rates of diameter increment. Measurements of increment in trees that have been felled in thinning operations in neighbouring compartments will be used to predict the growth rates of the stems with a future in subcompartment 3. These thinnings are in stands planted between 1995 and 1999, whilst subcompartment 3 was planted in 1997. The thinnings are therefore contemporary with the stems with a future $\pm$2 years.

The data used in this study is from tree rings cut perpendicular to the stem, from thinnings felled at Bron Haul during the winter of 2018. Prior to felling, the trees were marked at breast height; 1.3m above the ground level on the uphill side. Once felled, the ring was cut perpendicular to the stem at this mark with a chain saw. The ring was labelled with species, compartment code and a unique number.

In the workshop a rotary milling machine, set to remove 1mm of material, was used on one face of each disc to remove saw marks and to make it easier to see the annual growth rings. On all of the 5 species examined the growth rings were easily visible (photograph 4.1). Each disc was then measured on 2 diameters drawn at right angles to each other and passing through the pith of the log. This is an over-bark measurement to allow comparison with the dbh of standing trees measured during inventory. The same diameters were then marked where they intersected the 10^{th} annual growth ring counted from the underside of the bark (photograph 4.1). Measurements were them made, using a ruler, of the breast height diameter increment, to the nearest 1mm, made by each tree during the last 10 years. This yielded four sets of readings for each disc examined. Averaging these measurements gave an estimate of increment, allowing for the stem not being cylindrical. All data were recorded and remained associated with the numbered disc.

A graph was then prepared for each of the 5 species using the mean annual diameter increments (figure 4.3) and a line of best fit was drawn on each. This was used to derive a formula for each species which gives a relationship between current dbh and average annual diameter increment. Using this formula, it was determined from the current dbh, how many years it will take for each of the selected stems, growing at this constant rate, to achieve a target diameter for harvesting. This information was then used to create a predictive graph of when stems of each species may be ready for harvest (figure 4.4).

Photograph 4.1 Section through chestnut stem at breast height

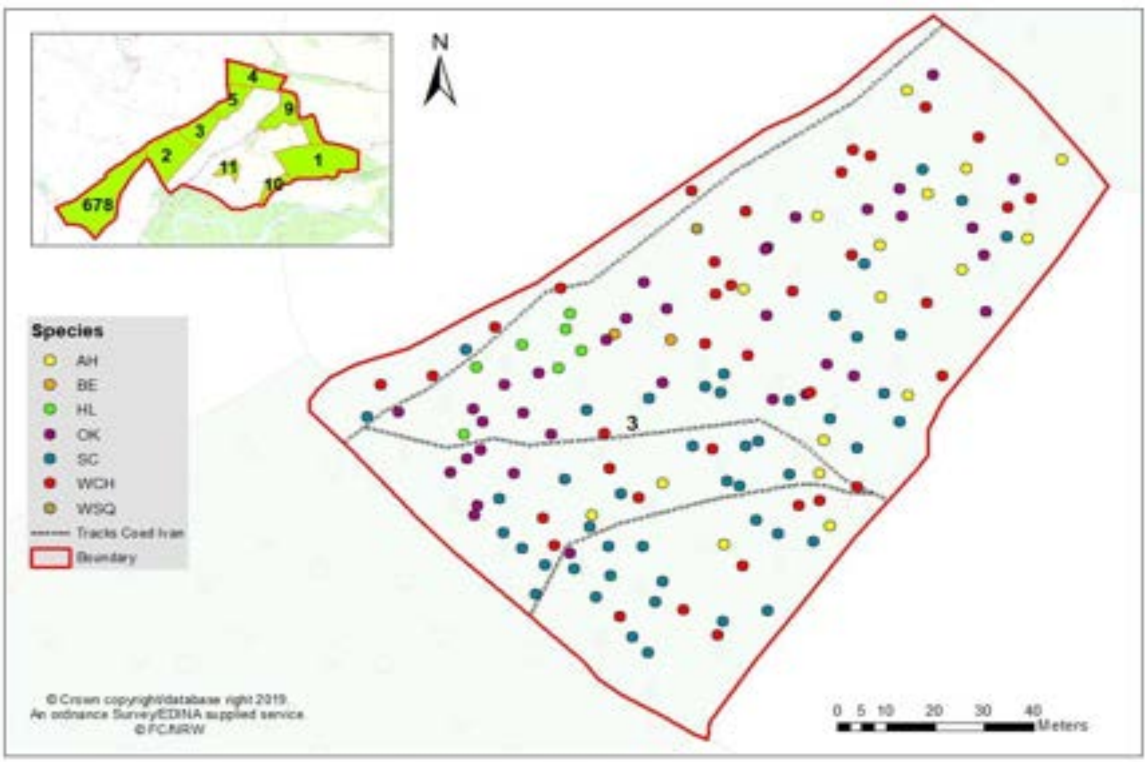
4.3 Results

4.3.1 Predicting annual increment from current dbh in 22-year-old stems

For each broadleaf timber species, the equation for the best straight-line fit is shown in figure 4.3. This formula provides an estimate of annual diameter increment for individual trees of known dbh at 22 years old.

4.3.2 Distribution of stems with a future

Map 4.1 shows the distribution of the chosen stems with a future in subcompartment 3. It can be seen that that they are evenly, (although not regularly,) distributed across the site. The species mix was not planted evenly across the subcompartment. This explains the distribution of some species, most obviously larch in the north-western corner. However, the predominance of cherry and sweet chestnut in the south-western corner is also influenced by this area being probably the most fertile part of the subcompartment. It appears that the oak here has been unable to compete with faster growing species which have been better able to exploit the conditions. Ash is distributed fairly evenly across the subcompartment. There is a total of 145 selected stems in the 1.21ha. that is 120 stems/ha which was the target final stocking rate.



Map 4.1 Position of stems with a future in subcompartment 3 (Coed Ivan). AH=ash, BE= beech, HL=hybrid larch, OK=oak, SC=sweet chestnut, WCH=wild cherry, and WSQ= Wellingtonia (sequoia).

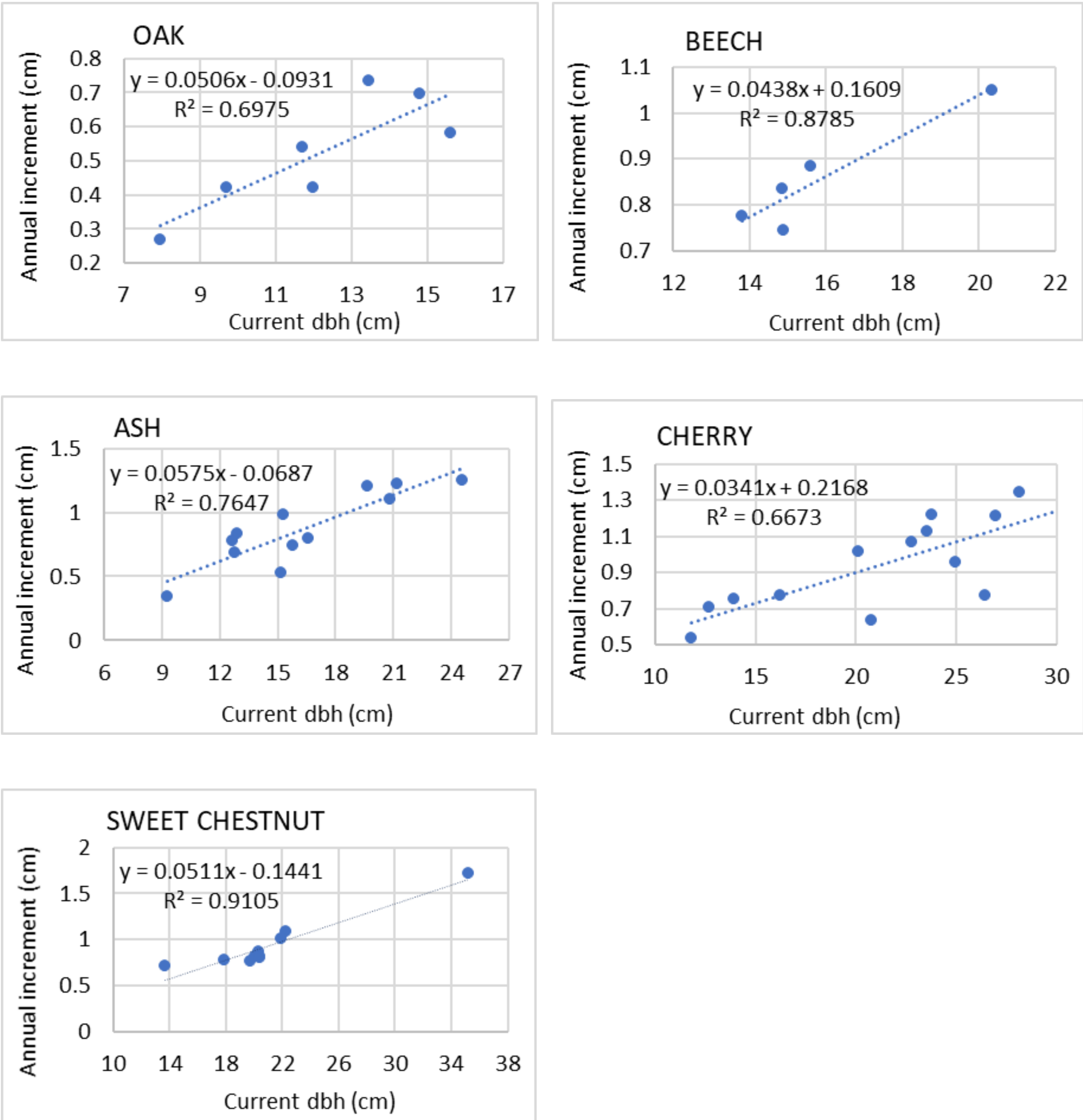


Figure 4.3 Graphs relating annual increment to current dbh for five broadleaf species in subcompartment 3 at Bron Haul.

4.3.3 Predicting future harvest dates

Figure 4.4 shows the predicted dates to harvesting diameter when the target diameter for cherry, ash and sweet chestnut is 50cm, and for oak and beech, 60cm. The first wild cherry, sweet chestnut, and ash reach 50cm dbh in the early 2030s. Of the stems with a future identified only two are beech and these are both predicted to reach 60cm dbh in the 2050s. By the end of the 2060s, if trees are harvested as they reach target diameter, then only six sweet chestnuts and two cherry will be left amongst the oaks of the first generation of trees. The first oaks are predicted to reach the target diameter are in the late 2060s, only 70 years after planting, though 21 of the 35 oaks which are amongst the selected stems with a future are not predicted to achieve a dbh of 60cms until the 22nd century.

The volume of timber in a stem of a given dbh is dependent on the timber height of the stem and the form factor. These cannot be established until the tree is ready for harvest. However, for broadleaf species, a generalised estimate is that for a stem of dbh 50cm volume is $1.9m^3$ and for dbh of 60cm volume is $2.6m^3$ (Hart ,1991).

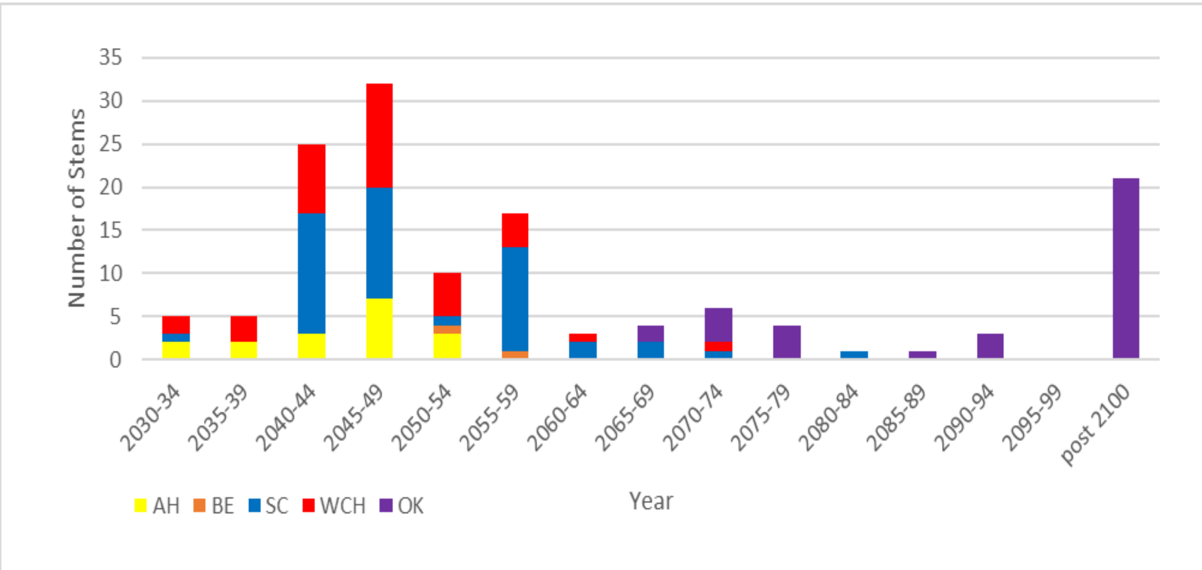


Figure 4.4 Predicted year of reaching target diameter for trees in subcompartment 3 (60cm for oak and beech, 50cm for other species).

4.3.4 Quality class of selected stems

Figure 4.5 shows the proportion of the selected Stems with a future which lie in each of the quality classes. The vast majority of stems are visually assessed as either class A or B, i.e. planking quality or better. Trees of quality class C and D would only be selected if there was no better stem in the vicinity.

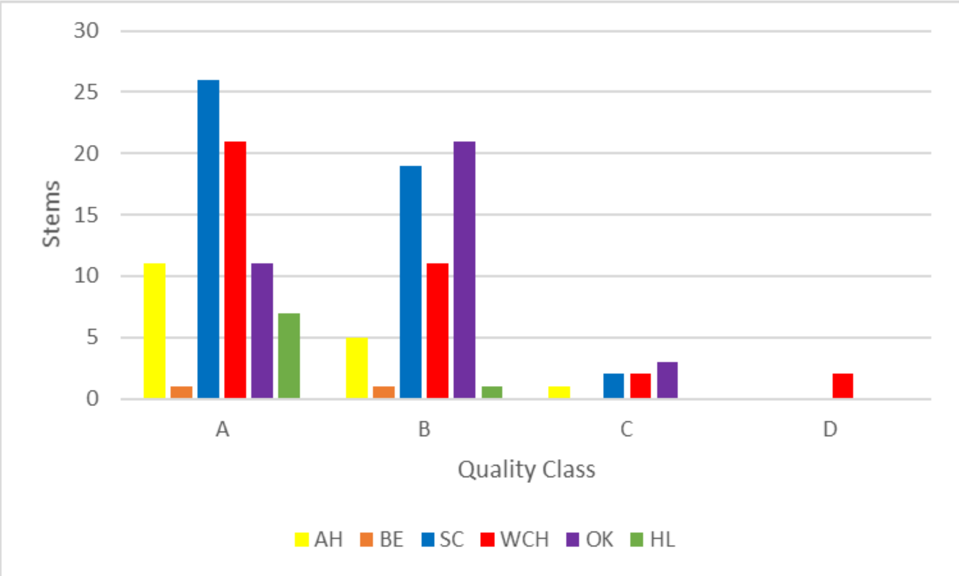


Figure 4.5 Quality class distribution of stems with a future.

4.4 Discussion

Subcompartment 3 of the Bron Haul woods is stocked with a good proportion of high-quality stems distributed among a range of tree species. If current management conditions continue it has the potential to provide an ongoing harvest of timber suitable for enduring end uses such as construction and furniture making (Hart,1991). This has been achieved through;

- Planting an intimate mix of site suitable species
- Formative and high pruning of many stems
- Timely and frequent thinning
- Rigorous control of grey squirrels

Figure 4.4 shows when the first generation of trees in subcompartment 3 might be expected to reach a harvestable size. Bron Haul woodland is predicted to start producing high quality saw logs 34 years after planting. This compares favourably with commercial softwood plantations. From then on, harvesting will be ongoing on a single-stem selection basis where the removal of crop trees also provides space to promote neighbouring stems to grow on or to create larger gaps in the canopy to allow restocking by natural regeneration. In figure 4.4 the rate of timber harvest is shown to decline in the 2060s. However, by this time the second generation of wild cherry, sweet chestnut and ash (if it is still present) should be reaching harvestable size and the woodland should be approaching a condition where it has diversity not only in species but also in structure and age distribution.

4.4.1 Accuracy of predictions

The predictive graphs produced in this section are designed to give only an indication of when timber may be ready for harvesting. They contain inaccuracies for several reasons;

- Any change in management aims or objectives will alter the outcomes. These may come about either in response to external factors such as species loss or through financial considerations such as price fluctuations between timber types. A factor which may become influential is the near future is the mechanisms that WG may introduce to replace CAP payments as support for the rural economy.

- Growth rates are affected by year-on-year changes in temperature and rainfall. Climate change is increasingly likely to affect the growth rate of trees (Ray 2008).

- Changes in the atmospheric concentration of CO_2 and other pollutants is expected to have increasing effects on tree growth. Effects on tree growth may be positive as is predicted in some studies in response to rising CO_2 (Norby, 2005) or negative for example as predicted with rising with O_3 (Norby & Zak 2011).

4.4.2 Influence of predictions on management decisions

Although a quarter of the stems with a future identified are oak (35/145) this masks the fact that oak, despite being favoured in previous thinning operations, is struggling to compete with more vigorous species present. It can be seen from figure 4.4 that only 14 of these oaks are predicted to achieve their target diameter before the year 2100. This is not because the site is unsuited to oak, as the best oaks are on schedule to be ready for harvest only 70 years after planting; quicker than any in the Crumblands trial. The slow growth of many of the oaks present indicates an urgent need for halo thinning to promote crown expansion and height increment. Currently the average top height of the oak in subcompartment 3 is 8.8m compared to around 12m for the other species (table 3.3). This further illustrates the difficulty of growing oak in intimate mixtures, especially if a vigorous nurse crop, such as alder as in this case, is used. It may be that a reassessment of the stems with a future to deselect the least vigorous oaks is required.

4.4.3 Resilience

Species diversity confers a degree of resilience to the woodland. Two of the species present in this subcompartment are under immediate existential threat from specific diseases; ash to *Hymenoscyphus fraxinius* (ash dieback), and larch to *Phytophera ramorum*. As can be seen from map 4.1 the distribution of these trees combined with their relative scarcity (12% for ash and 3% for larch, table 3.2) mean that if they are lost to disease the impact on the woodland, though damaging, will not be disastrous. In most cases adjacent stems of similar quality, but an alternative species, could be recruited. It is also hoped that the mixed nature of the stand, combined with the high standard of management, gives all species an increased chance of remaining healthy (Kerr, personal communication, 2018). Species diversity also confers a degree of economic resilience. A loss of one or even two species could be tolerated if they do not make up too great a proportion of the potential crop in any given period (figure. 4.4).

Shortening the time taken for broadleaf woodland to achieve harvestable size helps introduce resilience to climate change into broadleaf woodland. Under predicted rates of climate change, particularly under high, or even moderate emissions scenarios, (Forestry Commission, Environmental Site Classification) it is possible that conditions will change so rapidly that over a single rotation a given species may become unsuited to its site. The maturing of a crop allows an opportunity for the introduction of trees of the same species, grown from seed from a more southerly provenance, or the replacement of a species for which the climate has become unsuitable for one better able to cope with conditions during the next rotation.

It was decided that some ash would be retained as stems with a future despite doubts about the future of the species in the UK. The threat to ash is two-fold; ash die back, with recent research reporting varying levels of incidence of the disease being observed between UK regions (Sollars et al., 2017), and emerald ash borer (*Agrilus planipennis*) which has not, as yet, been reported in the UK (CABI, 2016), but is considered by some as a major threat to ash trees. The retention of apparently healthy ash trees should allow for tolerant individuals to be identified and for these to be selected as the seed source for regeneration (Skovsgaard et al., 2017).

CHAPTER 5 Synthesis and Conclusions

5.1 Lessons for land-use policy

5.1.1 The end of the CAP after Brexit allows political freedom for sustainable land management policy in Wales

The afforestation of land at Bron Haul has cost the WG little more than would have been spent on agricultural payments (figure 2.1). In return, the public has received a raft of ecosystem services including GHG sequestration, enhanced landscape, increased opportunities for biodiversity (photograph 5.1), improved water quality and soil stabilisation (Saraev et al., 2017). Land-use in Wales has been dominated by the CAP; a system of perverse subsidies in which large amounts of public money are paid to perpetuate an unprofitable livestock industry (figure 2.2), which provides a suite of public disbenefits, including GHG emissions, eutrophication of water, soil loss and decreasing biodiversity. The expansion of broadleaf woodland, with its attendant benefits, is frustrated because the WG cannot afford to compete with the vast expenditure of the CAP (€28bn to the UK over the period 2014-2020) (EU Website). Brexit provides an opportunity for the transition to a system within the land-use sector where public money is only spent where demonstrable public benefits (ecosystem services) will be the result. The latest SoNaRR (NRW, 2016) states that woodland expansion contributes to all 7 of the wellbeing goals in the Wellbeing of Future Generation (Wales) Act 2015.

Photograph 5.1 Y Fron Subcompartment 2

Wild cherry planted on the woodland margins enhances biodiversity and landscape value.

5.1.2 The multiple benefits of displacing ruminant grazing with afforestation

Reduction of methane emissions at Bron Haul

Planting woodland has displaced sheep from the Bron Haul land. The sheep quota allocated to Bron Haul was for 200 sheep to graze 21ha, equating to 9.5 sheep/ha. The land-use and climate change report (Welsh Government, 2010) quantifies methane emissions from sheep at 8.19kg/sheep/yr. Therefore, at Bron Haul there has been a reduction in methane emissions of 77.81kg/ha/yr on the afforested land, or 1.63tCO_2e/ha/year when standardised based on the climate forcing potential of CH_4 being about 21 times greater than CO_2.

Soil Carbon

Across the UK only 5% of terrestrial carbon is in biomass. Around 95% is held in the soil as organic compounds derived from decomposing plant tissue from leaf and stem litter, and from roots and root exudates. Consideration of the effect of afforestation on soil carbon stocks has changed what is considered good practice in choosing planting sites. The majority of soil carbon is in deep peats where tree planting will lower the water table and bring about huge losses of soil carbon as soils dry out (Sloane et al., 2018; Ostle et al., 2009). Therefore, although peat uplands have historically been favoured for afforestation by sitka spruce, this practice is now not approved and planting on deep peat must be avoided in the future.

Permanent grassland, where management practices remain constant, is described as in carbon equilibrium (Li et al., 2012). However, in a long term (16 year) trial in the north of England, De Deyn et al. (2011) found that continued fertiliser application led to loss of soil carbon, whereas cessation of fertiliser application led to increased species diversity and an increase in soil carbon stocks. In farms neighbouring Bron Haul, it is normal practice to apply high nitrogen fertiliser to grassland at least annually to maintain grassland productivity, suggesting a long-term depletion of soil carbon as a result of prevalent farming practices.

In a meta-analysis of carbon fluxes in land-use change studies, Guo & Gifford (2002) found that conversion of permanent grassland to broadleaf woodland left soil carbon stocks unchanged, whilst planting conifers led to a decrease in soil carbon of 12-15%. In a similar study, Li et al. (2012) found soil carbon unchanged where grassland was converted to coniferous forest and increased where hardwoods were planted. This was especially evident at greater depths in the soil profile. They hypothesised that broadleaf species contributed to soil carbon more through root turnover than through surface deposition of litter.

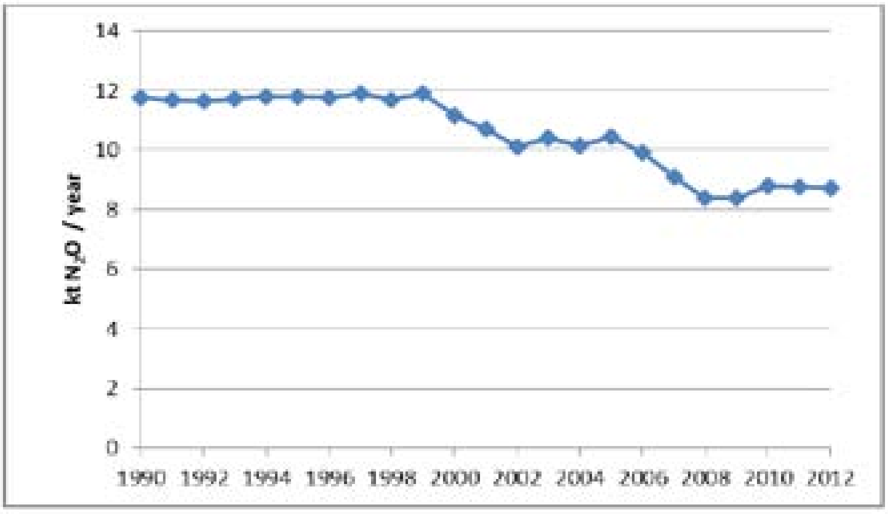
Increases in soil carbon were most obvious on time scales over 35 years (Li et al., 2012). This finding was supported by Fornara et al. (2018) who found soil carbon in woodlands was more recalcitrant because it was prevalent in microaggregates of less than 250μm whereas in grassland soil carbon was held predominantly in macroaggregates (>2mm). In a long-term study in a temperate region of Australia, reforestation with native species was found to show significant increases in soil carbon only after 45 years, though a shift to more recalcitrant soil carbon was evident after 30 years (Cunningham et al., 2015).

Although it is difficult to quantify the change in soil carbon when grassland is afforested, the climate change and agriculture report (Prosser et al., 2008) used IPPC figures to suggest an increase in the equilibrium carbon content of 74t$C0_2$e/ha when grassland is afforested and that this would take place over 100 years, with a sequestration rate of 0.74tCO_2e/ha/yr.

Displacement of Agricultural N_2O

Deposits of nitrogen fertiliser, manure and urine on agricultural land were responsible for 8,400tN_2O being released from Welsh soil in 2012, that being 79% of all N_2O emissions in Wales (figure 3.2). N_2O has a climate forcing potential 298 times that of CO_2. 8,400tN_2O is therefore equivalent to 2.5mtCO_2e or 2.5% of Wales' total GHG emissions in 2012.

This study does not attempt to quantify the N_20 emissions that would have occurred on the Bron Haul land if it had not been afforested. It is however clear from the above that continued livestock farming and nitrogen fertiliser application at Bron Haul would have been responsible for GHG emissions through N_20 emissions from the soil.



(Source: UK Agriculture Greenhouse Gas Emissions Inventory)

Figure 5.1 Trends in N_2O emissions from agricultural sources in Wales (1990-2012). Adapted from the climate change and land-use review (ADAS, 2014)

Table 5.1 GHG benefits of afforestation at Bron Haul after 22 years

GHG benefits of afforestation		**$tC0_2e$/ha/yr**
Carbon sequestered by woodland	Embodied in plant biomass	9.21
	In harvested timber	1.75
	In soil carbon	0.74
Displaced agricultural emissions	Methane from enteric digestion	1.63
	N_20 from fertiliser and animal waste application to soil	Not quantified in this study, but considerable
Total		**13.33**

The carbon benefit of planting woodland on formerly sheep grazed land at Bron Haul, over 22 years, averages 13.33t$C0_2$e/ha/yr (table 5.1). If woodland is not planted on grazed land, then this figure can be thought of as the carbon storage opportunity cost of not planting trees (Searchinger et al., 2018). When public money is spent to support or promote other land-uses then the justification for this expenditure must account for this lost opportunity.

In its most recent report on 2nd May 2019, the Westminster climate change committee recommended that Wales should aim for a 95% reduction in GHG emissions by 2050 (CCC 2019). To achieve this target, Wales is urged to maximise afforestation as the proven method of removing GHG from the atmosphere.

5.1.3 Land-use policy based on a single objective prevents management for multiple ecosystem services

It has been suggested that payments for eco-system services, such as carbon sequestration in woodlands, may be a mechanism for directing financial support to the rural economy once CAP funding is withdrawn (Welsh Government, 2018b). Carbon sequestered in woodland is a proven mechanism for removing GHGs from the atmosphere, and as such is a public good. It is also relatively straight forward to quantify with an agreed protocol (Jenkins, 2018). However, it is recognised that the current trend of focusing on the provision of timber as the sole ecosystem service from forestry, and the consequent planting of sitka spruce as monocrops, has led to the many other ecosystem functions of forests being ignored (Millennium Ecosystem Assessment, 2003). The same would be true if carbon sequestration in biomass was the sole objective of woodland management. Current systems of land management, focussed on maximising the provisioning service of land, have contributed to climate change and environmental decline. The response needs to be a sustainable, holistic approach to land management that achieves its provisioning role whilst addressing climate change and improving soil health, water quality, biodiversity and the local economy (UN FAO 2016).

This dissertation illustrates that continuous cover management of broadleaf woodland can deliver these objectives in Wales. It adds to the growing body of evidence that such silvicultural approaches are not only environmentally beneficial, but are also economically robust (Susse et al., 2011). Maintaining the basal area of the trees within the levels advocated by continuous cover practitioners, such as the AFI, ensures relatively high levels of light reaching the forest floor which promotes biodiversity and soil health. The permanent presence of trees in non-clearfell systems means the ecosystem services provided by the woodland are uninterrupted. The focus on the production of quality timber enhances the carbon sequestering role of the woodland as carbon can be retained for many years in enduring products whilst providing renewable raw materials to support employment in local manufacturing. Additionally, it is creating a woodland structure with intrinsic resilience, which is of increasing importance as climate change progresses. If payments for ecosystem services are to become an important mechanism for supporting the rural economy, it must avoid distorting woodland management towards more easily measured parameters and fail to recognise the diversity of ecosystem services that woodland can provide.

5.1.4 The sustainable economics of continuous cover forestry

Figures 4.4 and 4.5 show that producing high quality hardwood from broadleaf woodland planted on formerly sheep grazed grassland in Wales is possible. The economic argument for doing so in terms of established woodland being self-funding will now be considered.

Commercial forestry in the UK is dominated by conifer plantations that are managed on rotations of around 40 years, often with little intervention between establishment and clear-felling. Income is concentrated in the felling year, followed by a brief period of expenditure in restocking and establishment. The simplicity of this system in terms of input and product makes for straightforward economic analysis and, as such, it is a familiar mode of operation within the commercial forestry sector. Conversely, growing timber in complex mixes under continuous cover is unconventional and poorly understood outside a small community of enthusiasts. Revenues are small but frequent and the product is varied.

In the French context, where continuous cover forestry is widely practiced, a suitable infrastructure for dealing with its products is in place. Economic data from the AFI network, collected from the 45 irregular forests which have been monitored for the longest time, show that all are making ongoing profits independent of subsidies. On average, annual revenue from timber sales was €214/ha with total costs of €55/ha giving an average net profit of

€160/ha/yr (2008 prices) across the AFI network (Susse et al., 2011). This demonstrates the validity of the type of woodland management being practiced at Bron Haul as a long-term commercial venture, and that it could contribute to a prosperous Wales. However, this will be dependent on a suitable local market. If forest management based on mostly site native, predominantly broadleaf, woodland is to become part of the forestry sector in Wales, in line with the goals of the Wellbeing of Future Generations (Wales) Act 2015 for a resilient Wales, then supply chains to utilise the specialist timber produced will need to be developed. Funding for this could be accessed through the economic resilience scheme proposed in the Brexit and our land consultation (Welsh Government, 2018b). There is no shortage of potential demand. The UK is the world's second largest importer of forest products with net imports of US$8 billion in 2016. This is at a time when global deforestation is running at a rate of 3.3 million ha/year (data for 2010-2015, Forest Research, 2018). The expansion of Welsh forestry would be a positive move towards sustainable self-sufficiency in timber and contribute to the requirement under the Wellbeing of Future Generations (Wales) Act 2015, to Wales becoming a globally responsible nation.

5.1.5 Afforestation and dietary change

The report to the Westminster climate change committee entitled Land-use: reducing emissions and preparing for climate change (CCC, 2018) highlights that the planting of woodland on grazing land will reduce meat production and therefore, as long as this is not substituted by imports, have the potential to bring about a co-benefit on public health by reducing meat and dairy in UK diets (Springmann et al., 2016). The current assumption is that red meat and dairy consumption will decrease by 20%. If the current move by consumers to embrace vegetarian and vegan diets can be encouraged by governments then even greater reductions, with the associated GHG and health benefits, can be achieved (Edenhofer et al., 2014). The climate change committee recommend a reduction of grassland and rough grazing of 26-36% across the UK accompanied by the planting of up to 1.5 million hectares of new woodland (Watson, 2019). Wales has the opportunity to make a major contribution towards this target, with 75% of the agricultural land in Wales being permanent grassland pasture; an area of 1.326 million hectares (Armstrong, 2016).

Conclusions

Bron Haul provides an example of how the planting and management of multi-use, broadleaf woodland can contribute to the Welsh Government’s vision for a more sustainable and globally responsible Wales. It shows that:

- The CAP has been a barrier to farmers contributing to the Welsh Governments tree planting targets (section 2.4.3, figure 2.1).

- Carbon sequestration in biomass is an important ecosystem service that can be provided by well-managed, broadleaf woodland (section 3.4.4, figure 3.2). It is especially significant if it is combined with a change in land-use away from ruminant agriculture (section 5.1.2, table 5.1). However, carbon sequestration is only one of the eco-system services that woodland can provide, and it must not be considered in isolation.

- Broadleaf woodland has the potential to provide a valuable timber resource for future generations (figures 4.4 and 4.5). This benefit will only be achieved if markets are developed and skills fostered throughout the supply chain. This would be an appropriate use of the economic resilience scheme proposed in Brexit and Our Land.

- Used together, pillars 1 and 2 of reformed rural support payments could change land-use and deliver benefits under all the wellbeing goals in the Wellbeing of Future Generations (Wales) Act 2015, through promoting well managed, diverse, broadleaf woodland.

- On 1st May 2019 the UK parliament declared a climate change emergency. In the light of this the carbon efficiency of land-use must be considered. Multi-use forestry should displace livestock farming as the default land-use in Wales (table 5.1), and it must do so urgently.

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Appendix I Ethical Checklist

College of Natural Sciences

PRIFYSGOL
BANGOR
UNIVERSITY

RESEARCH PROJECT ETHICAL ISSUES CHECKLIST UNDERGRADUATE, OR TAUGHT POSTGRADUATE

Students should complete this ethical checklist for all research projects. If you answer 'no' in ALL of sections A B and C below, please keep this form on file as it may need to be referred to when you submit your thesis or results for publication. If you answer 'yes' in ANY of sections A, B, or C below, further details of your project will be required. Please complete sections 1, 2 or 3 as appropriate.

To assist with record keeping, please name your checklist files according to the following format: Ethics_surname_year

A. Research involving people and human biological samples	**YES**	**NO**
Does the proposed research involve people or human biological samples?		no
Does the proposed research involve live vertebrates or cephalopods? (if working with live invertebrates other than cephalopods please provide a brief description of your work in section 2)		no
C. Research conducted overseas and fieldwork	**YES**	**NO**

Will the proposed research be conducted overseas or use experimental material from other countries?		**no**
Does the proposed research involve fieldwork where permission from landowners or other authorities may be required?		**no**

Project title: MSc Dissertation David Brown	
Proposed start date: 12/11/18	
Proposed end date:31/8/19	
Funding body (if applicable):	**na**
Name of student (applicant):	**David Brown**
Email address:	**Afp85b@bangor.ac.uk**
Supervisor's name:	**Tim Pagella**
Supervisor's signature:	

Please note that it is your responsibility to follow the University's Research Ethics Policy and any relevant academic or professional guidelines in the conduct of your study. This includes providing appropriate information sheets and consent forms, and ensuring confidentiality in the storage and use of data. It is also your responsibility to ensure that you have all necessary permits to conduct your research. Any significant change to the project over the course of the research MUST be notified to your supervisor who will advise whether you need to complete updated forms for review.

Appendix II Risk Assessment

BANGOR

School of the Environment, Natural Resources and Geography

Risk Assessment Form

Location / Building / Area:	Bron Haul woodlands. LL22 9DY SH970732	**Activity (Summary):**	Collection of woodland inventory data: Measuring trees using calipers and Vertex, The cross cutting of trees using a chainsaw (to obtain cross-sections)
Date of Assessment:	10/11/2018		
Academic supervisor	Tim Pagella	**Name of student:**	David Brown
Signature:		**Signature:**	D.C. Brown

What are the dangers/hazards?	Who might be harmed and how?	What are you already doing to prevent harm?	What further action is necessary?	Action by whom	Training on equipment/procedures completed To be signed by trainer (supervisor/ technician)
Bad weather	The student and assistant	Always wear suitable clothing and footwear	Check forecast before going into woods	The student and assistant	
Trips and falls	The student and assistant	Wear suitable footwear	Workers point out specific hazards encountered on site	The student and assistant	
Chainsaw	The student and assistant	Both operators are fully trained and wear full PPE		The student and assistant	
Laser line	The student and assistant	All workers informed of the dangers to eyes of using a laser line	Laser never pointed in the direction of another person	The student and assistant	