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European Innovation Partnership (EIP) Wales

Small scale birch tapping in Wales:

Final project report

March 2023

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Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig:
Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
European Agricultural Fund for Rural Development:
Europe Investing in Rural Areas

Llywodraeth Cymru
Welsh Government

Final project report: EIP Wales project – 'Comparing on-site preservation techniques for fresh Welsh birch sap for use in artisan products by local businesses.' (Jan 2020 – Jun 2022)

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March 2023

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EIP Wales, which is delivered by Menter a Busnes, has received funding through the Welsh Government Rural Communities - Rural Development Programme 2014 2020, which is funded by the European Agricultural Fund for Rural Development and the Welsh Government.

The purpose of EIP Wales was to fund agricultural projects across Wales that encouraged the collaboration between farmers and others that work within the sector. Bringing people from both practical and scientific backgrounds creates a great opportunity to draw from different experiences, benefit from the latest knowledge and introduce new ideas whilst tackling problems. Since 2017, EIP Wales has funded 46 projects across Wales, working with over 200 farmers, and a multitude of individuals, businesses and academics working across the agricultural sector.

Acknowledgements: This project would not have happened without the enthusiasm and hard work of the Operational Group members who undertook to tap their trees. This report is a testament to the hard work of Llais y Goedwig; Wild Spirit Bushcraft, Llyn Parc Mawr Community Woodland; Abergavenny Community Woodland, Cwmffrwd and Lower Pen y Graig farms. Thanks are also due to Lafan, the EIP Wales team and Farming Connect who actively supported and promoted the project at every stage including navigating the strictures of covid restrictions. Thanks also to Bryn Harris who assisted with the literature review.

Executive summary

The 2002 forest inventory of Wales reveals that 12,579 ha of woodland in Wales is dominated by birch. Of this area, 78% is privately owned much of it in the form of small farm woodlands many of which are under-managed. Commercialisation of birch products could potentially be a useful income for small woodland owners and help invigorate farm woodland management. Under the previous Dewis Gwyllt project (run by Llais y Goedwig), artisanal production of birch syrup from sap was trialled and found to produce a viable product. However, birch sap is highly perishable and since the ratio of syrup to sap is 1:124 the difficulties of handling and storing large volumes of sap present a constraint on production.

The aim of the EIP Wales project was to trial three methods for on-farm artisanal preservation of fresh sap and determine the relative costs and benefits of each. A second aspect was monitoring of the tapped trees to learn more about sap production and the impacts of tap wounding on the trees to inform the development of best tapping practices and guidelines for sustainable tapping regimes. An underspend at the end of the project added two further outputs: a manual on management of birch woodland for sap and guidance for setting up a birch sap start-up business. At the end of the project guidance on good practice was prepared covering tapping, on-site preservation, woodland management, marketing and business planning for a small-scale artisanal birch syrup enterprise.

The project ran from January 2020 to Sept 2022. Covid 19 restrictions on face-to-face training compromised some aspects of data integrity but generally the project progressed unimpeded.

Key findings were:

- Birch sap yield is generally positively correlated with tree size as indicated by stem diameter. However, yields of individual trees, even of a similar size, varied from 0.4 litres to more than 10 litres with no apparent correlation to obvious characteristics of the tree or micro-site.

- It is recommended that tapping be restricted to trees between 20 and 45 cm in diameter. Small trees have low yield and the tap hole is a large in relation to the size of the tree while older trees are more susceptible to rot entering wounds as growth slows.

- Plots of the daily yields for individual trees suggests there is a low level of synchronicity in the timing of sap runs within the stand. So as sap yield is declining for some trees it maybe increasing or remaining constantly high or low in others. It is supposed that the source of variation is either underground in root relationships with soil, genetics or idiosyncrasy. In practice, overall sap yield can be dominated by the production from a small number of trees and it is difficult to predict which trees will be high yielding.

- The sap run in 2022 was lower in volume, sugar content, and of shorter duration (number of days of clear sap run) than 2021. The winter of 2021 was around two degrees colder than 2022 which likely suited birch as it is a cold-adapted species. In both seasons the sap flow was in March with peak flows on the north coast of Wales being around ten days later than flows on the south coast.

- A tree that is yielding sap should give around 2 litres of sap per day with a sugar concentration of 0.7 ^{o}Brix. Sap at this concentration will give a syrup yield of 1:124. Back of the envelope calculations suggest around 30 trees would yield about 6 litres of syrup which, at the right price, would yield a marginal profit for a few hours work a day in March.

- Wound healing can be rapid with around half the trees showing visible closure of the tap hole after one summer's growth. Observations of tap holes with slower healing indicate care is needed in installing and removing taps to avoid damage to the cambium around the hole.

- Internal staining arises from ingress of air oxidising the wood and infection. After one year staining affected 50x the volume of the tap hole which is comparable to sugar maple and low for other studies on birch. However, it can take several years for staining to develop to its full extent so this needs to be monitored over several years.

- A tapping model developed in Vermont was used to estimate the proportion of the tapping zone rendered non-conductive by tapping for four trees which were felled and sectioned. To sustain repeated tapping, the volume of stained wood rendered non-conductive by tapping should be less than 10% of tapping zone volume. Three of these trees grew fast enough to support annual tapping while the slowest growing failed. Threshold growth rates for sustainable tapping were derived for a range of trees sizes. Comparing these to estimated growth rates for the trees tapped by the EIP project indicated that 44% of the trees in these stands may not be growing fast enough to support annual tapping.

- It is suggested that tap wound closure is used as an indicator a tree has grown enough to support further tapping. Around half the trees in a stand could be tapped after a year while others may need two years. Any tree where the tap hole is open after three years is probably not heathy enough to tap.

- Reverse osmosis (RO) is the cheapest and quickest means of concentrating fresh sap but does require an initial purchase of specialist equipment. Although RO is not able to increase sugar content beyond 6 °Brix, this will have removed around 80% of the water. For anyone tapping more than a handful of trees it would be worth investing in RO and freezing the concentrate for subsequent further batch processing.

- Catering urns are cheap and can be obtained second hand. The narrow, deep shape of an urn is not ideal for evaporation and concentrating sap in an urn is a slow process. However, the urn can be left untended for several hours. Heating the sap with electricity is relatively expensive but saves on time and for small volumes the urn can be used for the whole process from fresh sap to syrup.

- Evaporating sap in gastronorm pans on an outdoor wood burning stove was found to be most efficient for processing larger volumes of sap. A wood stove is cheap and easy to construct but does require a suitable safe outdoor space, full-time tending and a supply of fuelwood. If fuelwood is purchased then running costs can be high, however, if free or cheap fuelwood is available then this will likely be the cheapest method for concentrating sap after RO.

- All three methods of on-site processing of sap worked and it is difficult to identify an outright 'best' or most 'efficient' method. Which method would be cheapest and/or most efficient depends on the scale of production, and what fuel, facilities, and pre-existing equipment are available to the tapper. Input/output figures have been provided to enable a tapper to make their own judgement on the method they wish to employ.

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Introduction

In the past, birch tapping was an established practice in the UK as evidenced by the many pages devoted to instruction for sustainable sap production and use in the description of forest trees and forestry by John Evelyn in 1662. Interestingly, Evelyn speculated that the promotion of birch water might increase interest in the silviculture of the undervalued birch. Furthermore, he goes on to describe in detail procedures for tapping to maximise sap production and preserve the health of the tree. In this respect not much has changed in 360 years. In Wales there are records of tapping continuing until the 1940’s, and records of tapping in Montgomery (Svanberg et al 2012) so birch tapping is not new to Wales. Nevertheless, traditional practices lapsed a long time ago and presently there is no tapping in Wales beyond bushcraft and foraging activities.

There is 13,000 ha of woodland in Wales which has birch as principal species with the majority (85%) of this being privately owned (Maxwell 2022). Much of this resource is denigrated as ‘scrub’ as birch is considered as little use besides besoms, horse jumps and firewood. Much of the birch is on farms and adding value to birch has potential for income diversification and as an incentive for improved woodland management.

Sap is highly perishable and is difficult for small operators to handle. Previous work by the Dewis Gwyllt project (https://www.dewisgwyllt.co.uk/product-research/birch-syrup/) demonstrated that syrup was feasible as a small-scale artisanal product. Maple syrup is well known from North America and there is increasing interest in birch syrup there. However, syrup production is was not an established tradition in Europe, Svanberg et al (2012) only recorded historical birch syrup production for Finland, Estonia, Poland and Romania. Although there has been some recent development of commercial birch syrup production from Scotland birch syrup is a novel product for Wales, UK and Europe.

It is against this background that the European innovation programme (EIP) Wales project set about refining guidance on the sustainable tapping and artisanal production of birch syrup as a novel product for Wales.

1.1 Operational group

EIP projects are undertaken at the behest of the Operational Group (OG) of Farming Connect members. The membership of the OG for the birch project is given Table 1. The EIP Wales innovation broker for the OG was Geraint Hughes, of Lafan Consulting, and the technical consultants were Dr Jenny Wong and Bryan Dickinson of Wild Resources Ltd (WRL).

Table 1: Operational group membership

Operational group	Location	Birch stand tapped in EIP project	Role in OG
Wild Spirit	Merthyr Mawr	Candleston	Trials in 2021 & 2022
Llyn Parc Mawr Community Woodland Group	Newborough	Sub-compartment 13B & 13E of Newborough Forest	Trials in 2021 & 2022
Lower Pen y Graig Farm	Llanfoist	Woodland used by Abergavenny Community Woodland Group	Trial in 2022
Cwmffrwd Farm	Glanamman	Cwmffrwd	Trials 2021 & 2022
Llais y Goedwig	Non-farming member		Lead applicant
Natural Resources Wales	Non-farming member		Manager of Newborough Forest

1.2 Aims of the project

The EIP project was to:

- Trial and compare three sap preservation techniques (outdoor evaporation using a wood stove, reverse osmosis, and catering urn) in terms of cost, ease of use, time, quality of concentrated product.
- Deliver on-site training in best practice tapping techniques and immediate post-tapping preservation and sap storage.
- Optimise the harvesting system to site conditions, OG member capability, and desired end-product.
- Monitor the sap quantity and quality to establish how yield varies with species, site type, tree size and climatic factors.
- Prepare training materials, guidance, and standards for birch sap production.
- Quantify soft-benefits to OG members of involvement in birch sap production.
- Examine social return on birch sap preservation and syrup processing activities with participants and volunteers, linking in with Social Investment Cymru.

Project activities began in October 2020 and were completed in June 2022 with reporting completed in September 2022. This was a period in which the imposition of Covid restrictions meant it was not possible for face-to-face meetings. This meant OG meetings were held online and the technical consultants were unable to meet OG members on site to undertake training or properly tailor the trials to the context of each OG member. In these difficult circumstances the OGs did an exemplary job of collecting sap and undertaking trials which enabled the project to largely achieve its objectives. However, the lack of in-person practical demonstrations of the tapping procedures did inevitably result in some inconsistencies in the application of the protocols between the OG members in the first season.

1.3 Project preparation

At the start of the project, WRL were provided with an EIP scoping literature review on birch sap quality and processing prepared by Stiles (2019) of the Institute of Biological Environmental and Rural Sciences (IBERS). The conclusion of Stiles' review was that "birch sap can be effectively harvested and processed into a sweet syrup, in a manner similar to maple syrup production. Utilising birch trees for this purpose however, presents certain challenges as the sap material produced is less rich in sugar, and requires more processing or reduction to achieve the desired end product, and the trees themselves are highly susceptible to damage, should management be inappropriate or too intensive. Caution is therefore advised in terms of effectively managing tree stock to ensure no adverse, long-term damage is done to individual trees." This informed the design of the study and in particular investigations into the impacts of tapping on tree health. During the project the literature review was expanded and incorporated into this report.

1.4 Social impact assessment

One of the aims of the project was to investigate the soft-benefits of birch tapping with a particular focus on the OGs which were volunteer community woodland groups (CWGs). The intention was that this would be achieved by adding birch tapping activities to the Social Value Assessment that was being undertaken as part of the Llais y Goedwig Enabling Natural Resources and Wellbeing (ENRaW) Project. The plan was for the CWGs in the OG to run social value assessments alongside activities and community events as part of the tapping and processing trials.

As the project progressed and the impact of Covid on community groups and the potential for activity involving more than one or a handful or people became apparent, we had one of our CWGs drop out of the project altogether, and another cancel activity during the first tapping season. As described in earlier sections, it was also not possible to do any community or pubic facing activity during the first EIP tapping season.

Alongside this, the Social Value aspects of the ENRaW project were significantly decreased due to Covid, with Social Value Cymru providing training to CWGs so they could do their own assessments as opposed to a project-wide social value analysis that was to have incorporated the EIP project.

We did manage to incorporate some Social Value work into the project evaluations of both the ENRaW and Dewis Gwyllt projects and have included relevant excerpts below regarding real and perceived benefits of participating in income generating/diversification activity.

In addition, the easing up of restrictions in 2022 did allow a limited number of events to go ahead: a community boil down at Llyn Parc Mawr Community Woodland and an open boil-down day at Ynys Uchaf for Coetir Mynydd.

Dewis Gwyllt – a supply chain project on non-wood forest product harvesting and product development opportunities. That portion of the project on birch syrup production was relevant to the work of the EIP project. This was because the concentrate produced by the trials was passed to the Dewis Gwyllt project who incorporated it into further work on the supply chain i.e. finishing of syrup, market research and sales. All OG members benefited from this and have received income from sap sales mediated by the Dewis Gwyllt project. The evaluation of the Dewis Gwyllt project gathered the following statements specifically about birch tapping from participants which includes the contributions from the EIP project as from the perspective of the OGs the two projects worked together seamlessly:

Presentation of birch tapping to Llyn Parc Mawr volunteers at trial of wood-fired stove (16 April 2022)

> "The main benefit identified by all parties was the learning and knowledge gained through the different project activities. And while woodland groups / owners and businesses learned different things, the project has gained a valuable insight into the overall potential of these supply chains and the barriers that need overcoming to progress things further."
>
> "Woodland owners / managers have identified new opportunities and potential in their woodland, which in turn has led to improved management practices and potential increase in production, which itself increases the supply for businesses."
>
> "On the woodland group and owners side, the combination of increased knowledge, new skills, published materials, and established networks has brought people together and improved the overall capacity of the networks to sustainably manage their woodlands and work collaboratively.
>
> These collaborative networks, both formal and informal, also enable individuals and small group to collectively address bigger global issues such as the climate and/or nature emergencies."
>
> "Many of these activities are things that groups and individuals would never have embarked on without the time, resources, and knowledge of the Dewis Gwyllt (EIP) project. The new skills and processes provide new and different reasons to engage local communities and attract more volunteers which is another unexpected and beneficial outcome.
>
> It's also clear that participants have thoroughly enjoyed and gained wellbeing benefits from their participation."
>
> "Groups recognise that the newly acquired skills and knowledge will live on, and nearly all are certain that they will be able to act on this knowledge over the next few years which will positively impact both their groups and their woodlands."

1.5 Dissemination

Two publications were anticipated at the beginning of the project: a report and a manual. Savings made because covid restrictions limited expenditure on travel lead to the commissioning of two additional pieces of work: one on business planning and one on woodland management for sap. At the end of the project these were all rolled up into three publications:

Small scale birch tapping in Wales: Final project report

Small scale birch tapping in Wales: A manual for artisanal tappers

Birch sap start up support

All project reports and videos are available on the EIP project webpages: https://businesswales.gov.wales/farmingconnect/business/european-innovation-partnership-eip-wales/approved-eip-wales-projects/comparing-site

The project was disseminated on several public media including:

- "Birch syrup – Tapping into a new Welsh food product" in Farming Connect magazine pages 12-13 of issue 30, Nov/Dec 2020
- Farming Connect webinar on birch tapping on the 1/12/2021.

- Birch tapping featured on BBC Wales' "Country Focus" programme broadcast on the 14/11/2021 and again on 11/08/2022.
- Farming connect video "EIP Wales: 'Dewis Bedw' Welsh birch sap – published on Farming Connect YouTube channel May 2022
- https://www.youtube.com/watch?v=J4AvSftJxy8&t=3s
- FCTV update on EIP (published on YouTube September 2022) https://youtu.be/Nw4vRE_1VaU

Face-to-face public events could only take place in 2022 and the planned tapping demonstration days could not be held. However, in 2022 the OG hosted two public drop-in events at the delayed wood-fired trails at:

- Llyn Parc Mawr Community woodland on the 16 April 2022 and
- Ynys Uchaf (WRL offices) for Coetir Mynydd members on the 22 April 2022.

A demonstration for Farming Connect was held at Denmark Farm on the 9th March 2023.

The EIP project also featured at the Llais Y Goedwig Celebration 26-27 March 2022. There was a lot of interest in tapping and use of birch sap and syrup and several took away leaflets and thought they might give it a try.

As agreed, the findings of the EIP project were amalgamated with the Dewis Gwyllt material on birch syrup and part of the Dewis Gwyllt portion of the Llais y Goedwig stand at the:

- Royal Welsh Agricultural Show (18-21 July 2022) and
- Eisteddfod (30 July – 6 August 2022).

1.6 Legacy

An Agrisgôp group was formed out of interest arising from the Farming Connect outreach with the OG as core members. The new Agrisgôp has had two meetings which have stood in for the later OG meetings. One of the new Agrisgôp members undertook trial tapping in 2022 and is considering continuing this in the future. Another did some tapping in 2021 and sold the sap fresh through a local health food shop. This was successful and is continuing with this.

Sap has been included as a named product in the draft UK Woodland Assurance Standard: UKWAS 5.0 with the reports and manuals prepared by the EIP project contributing to good practice standards. Once approved, UKWAS 5.0 will form the basis for FSC and PEFC certification for responsibly harvested birch syrup from UK woodlands.

Llais y Goedwig Birch Syrup Production Hub: The Head Office Kitchen at Unit 1, Eco Dyfi Park, Machynlleth has been successfully registered as a food business, receiving a five Star Food Hygiene Certificate. Three rounds of processing have taken place using sap from four different woodlands - producing market ready syrup, 2.95 litres of which has been sold (70% of income went to tappers / 30% to LlyG). – This was principally an initiative of Llais y Goedwig under the Dewis Gwyllt project but adopted the use of RO, urn and wood stove developed by the EIP project. This work will be continued in 2023 under their Goods from the Woods project.

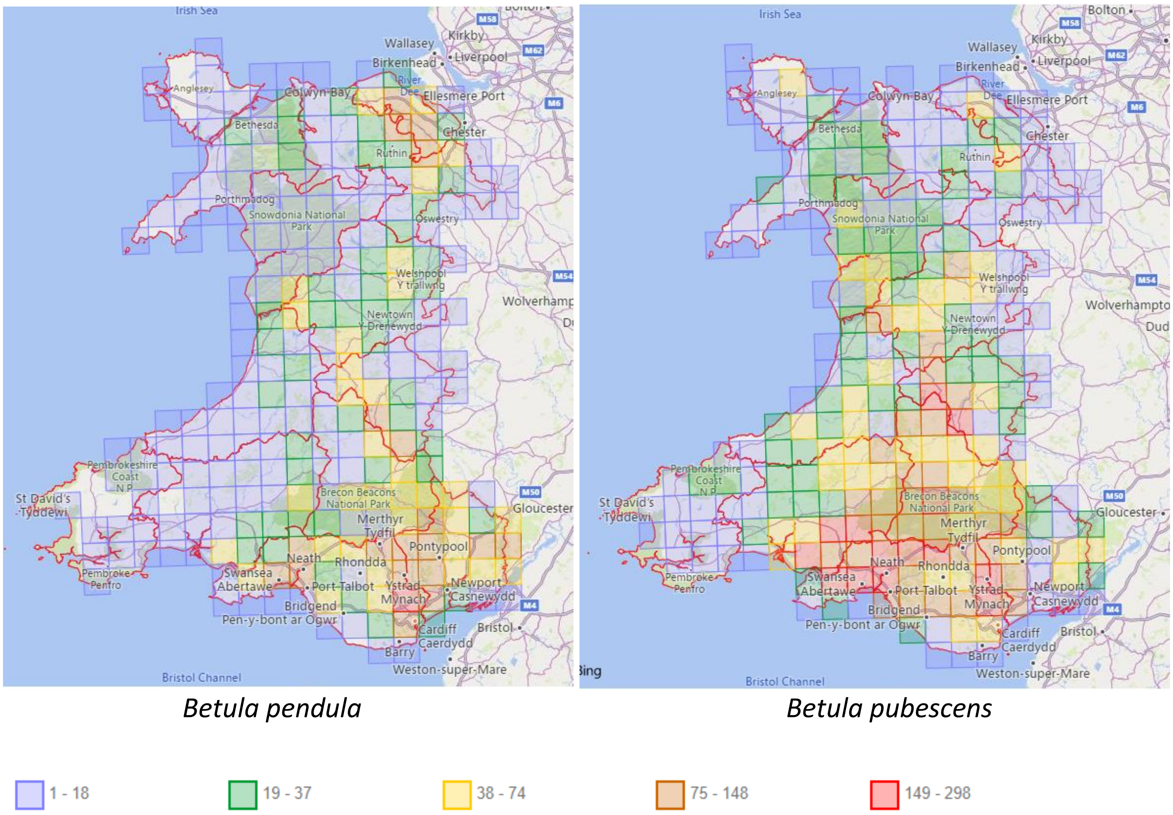
2 Birch as a source of sap

Birch is one of the commonest broadleaf trees in Britain and comprises 18% of broadleaf woodland cover in the National Forest Inventory[1]. There are two species of birch – the silver birch (*Betula pendula*) and downy birch (*Betula pubescens*) which are native in Wales. Although identification guides describe discrete sets of characters for each species in the field separation of the two species is problematic with many trees displaying a mix of characteristics (Amphlett 2021). At the present time there are no reliable DNA tests that can separate the two birch species or confirm hybrids (Stuart A'Hara, Forest Research and Annika Perry, Centre for Ecology and Hydrology – pers comm).

The two species are very similar though *B. pendula* is generally considered to prefer drier soils and be faster growing and have better form with *B. pubsecens* better able to tolerate acidic, waterlogged conditions and be slower growing (Atkinson 1992, Cameron 1996, Hytönen et al. 2013). Conditions in upland Wales therefore favour *B. pubescens* and it is recorded as being in higher densities across more of Wales than *B. pendula* (Figure 1Figure 1).

Although birch is grown as a high-quality timber in northern Europe it is seldom planted or actively managed for timber in Wales. Birch is therefore most often found in 'scrub' arising from natural regeneration and is unmanaged. In terms of the autecology of the species in the British Isles, Atikinson (1992) is the definitive monograph on birch while Lewington (2018) delves more into ethnography i.e. the uses and cultural history of the species.

Figure 1: Distribution of Betula species in Wales - Aderyn records for 1950-2020



Betula pendula *Betula pubescens*

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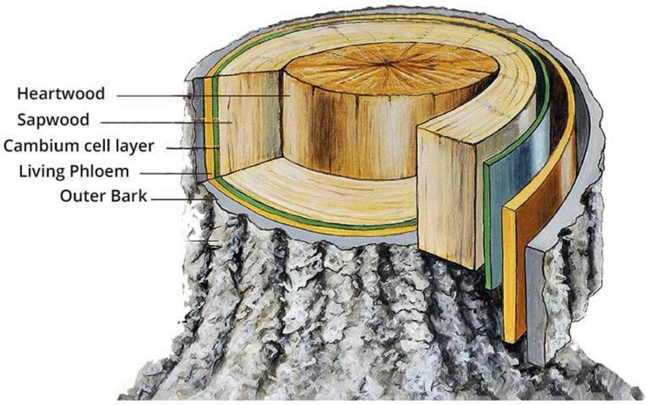
[1] https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/

2.1 Spring sap run

The sap in a tree flows in live xylem vessels in the outer portions of the trunk (Figure 2) and can react to wounding while the heartwood is old xylem which is 'dead' and liable to rot.

Figure 2 Internal structure of a tree trunk



From: https://www.gotreequotes.com/anatomy-of-a-tree/

Birch trees prepare for spring budburst and subsequent leaf expansion with a flow of sap, stored sugars and nutrients from the roots up to the leaf buds (Patch 2004). The trees draw water into the roots using active osmosis which pressurises the sap within the tree (Hölttä et al 2018). It is this internal pressure which gives rise to a flow of sap from spiles placed in the tree. Once the buds burst and leaves open the pressure is released and sap flow ceases. The season for tapping is therefore period of about three weeks in the early spring when sap pressure is at a maximum and a flow of sap from taps is both possible and rich in sugars and minerals. This period is known as the 'sap run'. Predicting the start of the sap run is problematic as it depends on antecedent weather conditions (especially the depth of snow in the preceding winter) (van den Berg et al 2018). There are complex relationships between chilling, photoperiod as described by Caffarra et al (2011) for the timing of budburst in *B. pubescens.*

Studies in Finland (Salo 2000, Miina & Kurttila 2022), USA (van den Berg et al 2018) and Canada (Maher 2005) indicate that sap flow is higher in slow springs with low day and night temperatures than faster, warmer springs. These differences can be dramatic: Miina & Kurttila (2022) found the warmer 2020 had half the yield of the cooler 2019 while van den Berg et al (2018) found warmer years could have two to three times less sap than cooler years.

2.2 Sap flows

All studies agree that sap flow is highly variable between trees, years and sites (Kok et al 1978, Maher 2005, Salo 2000, Dixon-Warren 2010, Miina & Kurtilla 2022). There is some consistency in performance of the same tree from one year to the next with Maher (2005) suggesting there is a 50% chance a tree will produce similar quantities from one year to the next.

Variation between trees is often noted as confounding the determination of systematic differences between soil types, altitude and other site characteristics. Nevertheless, Zajączkowska et al (2019) showed that trees from the edge of a stand produce more sap than those in the interior which suggests access to light and competition are significant. Though Kallio (2013) was of the opinion that between tree variability is possibility related to genetic factors and tree age as they found no consistent differences between other environmental factors.. Mingaila et al (2020) observed *B. pendula* as having higher yields than *B. pubescens* in Lithuania but there are generally too few comparable studies to confirm any systematic difference between the European species. While work in Canada found no differences in overall sap yield between their birch species (Skinner 2018, Dixon-Warren 2010).

Total sap production has been reported as positively correlated with tree diameter (Enescu 2017, Miina & Kurttila 2022) or height (Mingaila et al 2020). Though even this is modified by weather conditions as the relationship between size and yield is more marked in dry than wet years (Maher 2005). In drier climates, several studies have shown that sap yield is related to water availability (Maher 2005, Farrell 2017).

Kok et al (1978) noted that not all trees commenced and finished sap production simultaneously with the average flow per tree being 16 days though the overall sap season was 21 days. These differences in timing are likely the reason that Kallio & Ahtonen (1987a) considered that tree variability was so extreme that it was pointless to calculate mean sap flows for single trees. Nevertheless, across a stand the highest daily yields are often observed at the start of the sap run with a peak of 5-9 days then falling to end of season (Salo 2000).

2.3 Sap composition

Sap is mainly water but it does also contain sugars, acids and minerals. For syrup production it is the sugar which is of most interest.

2.3.1 Sugars

All birch species for which data has been presented have an average sugar concentration of around 1% (Dixon-Warren 2010 for North American species; Kallio & Ahtonen 1987a, Łuczaj et al. 2014 for European species). Variation in sugar content is high, with Zajączkowska et al (2019) reporting sugar contents between 0.25% to 2.25%. Birch sap is made up of equal parts glucose and fructose with trace amounts of sucrose (Kallio et al 1985, Kūka et al 2013, Grabek-Lejko et al 2017). The sugar content of birch is about half that of sugar maple (Farrell 2010) and the composition is very different as sugar maple is nearly all sucrose. This means that birch sap is not a substitute for sugar maple but a distinctly different product.

There are several studies which examine variation in sugar content between the two birch species. Several studies reported higher sugar concentrations in *B. pendula* than *B. pubescens* (e.g. Essiamah 1980, Kallio & Ahtonen 1987a) with Grabek-Lejko et al (2017) reporting 30% less sugar in *B. pubescens* than *B. pendula*. However, the converse with *B. pendula* having a lower concentration than *B. pubescens* has also been reported (Ozolinčius et al 2016).

Studies which looked for seasonal variation in sugar content generally showed highest yields at the beginning (Ozolinčius et al 2016) or middle of the season (Kallio & Ahtonen 1987a & b). Bilek et al (2016) and found little difference between sugar content between sites though Grabek-Lejko et al (2017) found some variation between in sap composition between habitats though these did include suburban and industrial sites which might be expected to have higher exposure to pollutants. Kallio & Ahtonen (1987a) also point out that sugar content depends on energy reserves stored the previous year i.e. conditions in the summer proceeding tapping.

A few studies examined sugar content for more than one year (e.g. Maher 2005) and found little variation between consecutive years. This all suggests sugar content is conservative and there are few reasons to select sites or trees to increase sugar yields though it maybe worth examining variation by species if both are available at a site.

Syrup productivity is often expressed as the syrup: sap volume ratio. Taking the figures in Table 6 as a guide we might expect ratios between 1:86 for higher concentrations to 1:108 for lower concentration sap. Beaumont (2010) gives a simple ready reckoner for estimating the syrup:sap ratio (box) which suggests a ratio of 1:124 which is perhaps more realistic given likely losses during handling especially repeated decanting between stages.

Ready reckoner for syrup:sap ratio (Beaumont 2010)

This rule is valid only up to 5° Brix. Assume syrup is to be 66 Brix – a constant 87.1 is divided by the sugar content of the sap to give the volume of sap needed.

Example:
Constant: 87.1 (constant to produce syrup at 66° Brix)
Sugar content: 0.7 ° Brix
87.1 divided by 0.7 = 124.43
Ratio of syrup to sap = 1:124

2.3.2 Acids

The flavour of birch syrup produced from early, middle or late season sap are sufficient for differentiation in marketing (Dixon-Warren 2010). These differences may arise from the quantity of acid in the sap which appears to be consistently higher at the beginning of the sap flow (Kallio & Ahtonen 1987b, Kallio 2013, Ozolinčius et al 2016) as it is the ratio of sugars to acid which determines taste.

2.3.3 Minerals

There is considerable interest in the mineral content of birch sap mostly arising from the consumption of fresh sap as a spring tonic in eastern Europe. The minerals most of interest from a dietary perspective are: zinc, copper and manganese (Staniszewski et al 2020). Bilek et al (2016) compared mineral content of tree saps across eight European species which showed that the two birches have similar concentrations of zinc and copper at concentrations to be comparable with mineralised water (Grabek-Lejko et al 2017) but not at levels that would breach drinking water standards (Staniszewski et al 2020). Several of these studies explored environmental controls on mineral content and found variation related to: pollution levels (Grabek-Lejko et al 2017), soil type (Kallio & Ahtonen 1987a, Ozolinčius et al 2016, Mingaila et al 2020) and relationships to tree age, timing of collection and sap production rate (Bilek et al 2017, Staniszewski et al 2020). Although all of these have some influence on mineral content as with sap volume and sugar between-tree variation is high so the general recommendation was to pool sap from as many trees as possible to standardise the product (Staniszewski et al 2020).

2.4 Perishability

Sap is highly perishable and goes 'milky' or 'buddy' if left for more than 24 hours in the collection bottle and flow from the tree also goes off at the end of the sap flow (e.g. Helfferich 2003, Dixon-Warren 2010). Weber (2006) working on *B. pendula* in Germany showed that the sap is rapidly colonised by a consortium of yeasts followed by fungi, and it is the yeasts that cause the sap to become milky and go off. This seems to be a universal feature though is likely to be more rapid in warmer ambient temperatures. The end of the sap run is often marked by the sap spoiling rather than drying up. Once the tap is removed the sap will continue to seep until the leaves open and can result in large blooms of yeast on the tree. This is temporary and disappears once the sap flow stops and does not appear to affect the tree (Farrell 2010).

2.5 Impact of tapping on the tree

Concern that tapping might impair the growth and survival of the trees has always been something of concern to tappers – it certainly gets a mention by John Evelyn in 1662. Tapping a tree has two impacts on tree health; (a) depriving the tree of a proportion of its sap which contains sugars and minerals intended to fuel growth and (b) creates a small wound into the sap wood.

The wound created by the tap is the most significant consideration in the sustainability of birch sap tapping. This is because tapping may introduce pathogens into the tree which could develop into pockets of rot within the trunk. This would compromise the long term health of the tree and likely shorten its lifespan. When a wound is deep enough to reach through the bark into sap wood (refer to Figure 2) the sap drains from the xylem vessels and air enters along with a host of micro-organisms. The cells around the wound react to the damage by releasing chemicals to inhibit infection and secretions to seal off the damaged wood in a process known as 'compartmentalisation'. Birch is diffuse porous and wounds are closed with gels (rather than resin) and compartmentalisation is weak (Fay & Berker 2018). This means birch is susceptible to decay (Tsen et al 2015) and has low tolerance to tap wounding compared to other species including sugar maple (Farrell 2010). However, decay will not develop from all wounds as compartmentalisation response varies between trees and appears to be genetically controlled and quick healing of wounds is related to vigour of the tree, not treatment of the hole (Walters & Shigo 1987).

The reaction of a tree to wounding is well documented mostly in connection with pruning (e.g. Shigo 1984) but also for tap wounds in sugar maple (Walter & Shigo 1978) and for the cores taken for tree ring analysis (van Mantgem & Stephenson 2005, Fay & de Berker 2018, Tsen et al 2015). Various wound treatments have been used in an attempt to minimise the risk of infection with many of these reviewed by Tsen et al (2015). Use of hard plugs, i.e. wooden dowels were shown to be of no benefit and had some negative aspects such as damage to cambial tissue from hammering, protruding plugs prevent cambial overgrowth and expansion of dowels as they weathered can crack surrounding wood. Wound treatment with ethanol had only a temporary effect. Tsen et al (2015) reported no benefit from use of untreated wax plugs while Salo (2000) found brown discolouration associated with rot in holes which were capped with beeswax. Walters & Shigo (1978) reported that wound sterilisation with paraformaldehyde exacerbated die-off of cambial tissue around the hole and was associated with elliptical wounds much larger than the original taphole. Nevalainen (2005) compared plugged and unplugged holes and although results were inconclusive this study appeared to show that open holes were associated with the smallest internal stains. As Salo (2000) points out, the microbiota is able to infect the area around the tap hole during tapping and any treatments at the cessation of tapping are irrelevant and only likely to further irritate the wound. Current advice from aboricultural practice is that the best long term outcome for the tree is to leave increment bore holes open to allow natural wound healing.

Trees grow from the cambium which is just under the bark and over time the cut edges of the cambium will form a callus which will close off the hole. The damage caused by increment boring to the centre of mature trees to assess their age has been investigated in several studies (e.g. Tsen et al 2015, Fay & Berker 2018) but there are few studies of tap wound closure in young trees.

Nevalainen (2005) studied 45 60-year-old *B. pendula* trees examined two and five years after sap tapping in Finland. Here the tap hole resulted in very narrow, strongly flattened, conical-shaped discolouration column emanating up and down from the hole which was found to be an oxidation reaction which is common in mature birch. The extent of staining after two years was 4.7 cm wide and 109 cm high and after five years was 6.6 cm wide and 245 cm high. Observations by Hörnfeldt et al (2010) of internal staining ‘false heartwood’ arising from tapping birch also noted that the red staining can continue extending over time.

Nevalainen (2005) compared plugged and unplugged holes but results were inconclusive but appear to show that open holes were associated with the smallest stains. Samples taken from the stained wood contained 486 microbial cultures but only three decay fungi and there was no indication that taps had been infected by agents of decay. Salo (2000) also examined microbiota of brown stained birch wood and found it to be made up of bacteria, yeasts and fungi wone of which were pathogens and of relevance only in terms of discolouration of the wood.

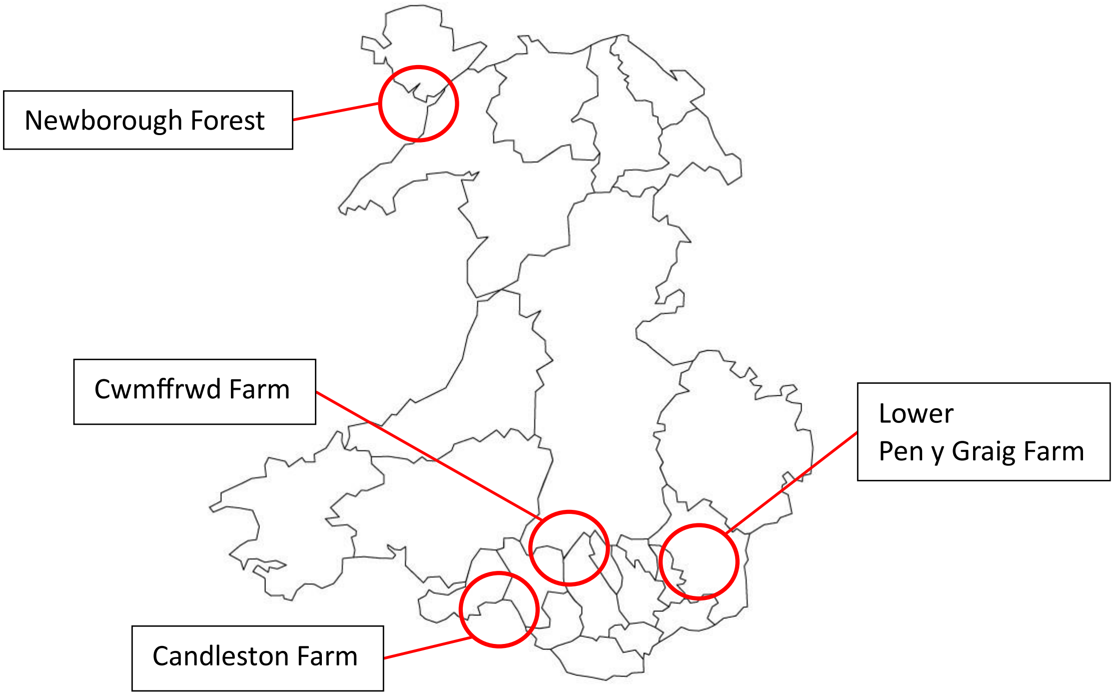
However, bad tapping practices can have a devasting effect on tree health. Trummer & Malone (2008) dissected 21 trees tapped some ten years previously with very poor practices and left untended. These trees had “red heart” in a streak 1.9 m long inside the tree. In addition, 33% and 50% of trees also had dark streaks/black staining extending roughly 30 cm from the tap hole associated with decay. Trees which had been corked or had taps left in situ had canker fungus around the wound. Based on these observations Trummer & Malone (2009) suggested improvements to best practice guidelines which led to the Alaska Birch Syrup Association prohibiting the use of plugs in tap wounds (ABSA 2008).

3 Birch tapping trials in Wales

3.1 Birch tapping trial sites

Four sites were offered by the OG group members for trial tapping with a geographical spread across Wales (Figure 3).

Figure 3: Location of sites of trials of birch sap tapping



3.1.1 Site and stand descriptions

Site level data collection and descriptions were compiled by WRL to ensure consistency. All four project sites were visited and measurements from all 84 trees recorded. Methods used in the description of the stands and trees is given in Appendix 1. Table 2 contains a summary of the results for each of the four EIP sites.

Reliably separating the two birch species proved to be problematic as the trees on the sites often had a mix of characters indicating *Betula pubescens* (e.g. leaf morphology) with others indicating *Betula pendula* (e.g. bark character). A simple scoring system based on individual characters was devised and used to indicate the predominant ‘species’ for each site.

Table 2: Summary description of trial sites

Site	Candleston	Cwmffrwd	Newborough	Lower Pen y Graig
Location	S. Wales	S. Wales	N. Wales	S. Wales
Site description	Dense birch regeneration in pine plantation	Birch regeneration since WW2	Birch regeneration in failed pine plantation	Birch regeneration in mixed hazel & oak woodland
Soils	Sandy soil with rich humus layer.	Rocky scree with some rich humus.	Sandy soil, occasionally waterlogged.	Rocky scree with some rich humus.
Average infiltration rate (cm/hour)	57.6 (3 pits)	75.6 (1 pit)	57.1 (4 pits)	11.7 (2 pits)
Permeability class	Very rapid	Very rapid	Very rapid	Moderately rapid
Ground vegetation	Brambles, nettles, Himalayan balsam, ferns	Bramble, bluebell	Brambles, grass	Bramble, bluebell

Site	Candleston	Cwmffrwd	Newborough	Lower Pen y Graig
Site slope and Aspect	Flat site	Steep slope facing SE	Flat site	Steep slope facing NNE
Distance from nearest coast (km)	1.8	22.7	0.5	32.6
Altitude (m)	50	175	5	230
Average basal area (m^2/ha)	28.9	21.8	38.0	18.4
Birch species	Mainly *B pubescens*	Mainly *B pubescens*	Mix of hybrids / *B pendula*	Mostly *B pendula*
Approximate age of trees (years)	31 From ring counts of two felled trees	30 From ring counts of two felled trees	30 From NRW records	25 / 40+
Yield class	8-10	8-10	8	8
For trees in trial:				
Average diameter at 1.3 m (cm)	23.5	27.9	24.5	31.2
Average height (m)	16.9	16.9	16.1	15.8
Average canopy volume (m^3)	128	194	123	210

Soil pits were dug at each site in 2022 to provide a visual assessment of soil conditions using standard methods (Ball et al 2013, Johannes & Boivin 2016) and perform 'falling head' water infiltration tests using methods using timed observations of falling water levels in a pit (SEMCOG 2008, O'Green 2013). Infiltration measurements were made on up to four 25 cm x 25 cm pits, 30 cm deep dug at each site and filled with water. Measurements of the decreasing water level were taken at regular intervals to calculate the average infiltration rate in cm/hour.

Estimates of the growth potential of each site were made from standard forestry yield models for the UK. These are most accurate for conifers and birch is rather overlooked and lumped in with sycamore and ash. Yield class (YC) is the volume of wood added to stand per year m^3/ha when it is growing at the fastest rate the site can support. YC is predicted from the top height (average height of largest diameter trees) against age and is an index of site potential. The trees at all four sites were the same height so yield class was differentiated only on the age of the stand. Since the stands all originated from natural regeneration stand age was estimated using available information. For Newborough age was taken from the NRW sub-compartment records and for Lower Pen y Graig from the recollections of the farmer for the smaller trees. The heights and ages were then used to estimate yield class from tables given in Hamilton & Christie (1971).

Direct measures of tree growth were taken by counting tree rings for a sample of felled trees: two each at Cwmffrwd and Candleston. It was not possible to fell trees at the NRW site at Newborough, and no trees were felled at Lower Pen y Graig.

Basal area was measured using a standard forestry angle gauge at each tapped tree. The stand basal area is taken as the average of the basal area measured for all trial trees. The basal area of a stand is a measure of the density of the trees given as the sum of cross-sectional area at 1.3 m height of all trees in m^2/ha.

Canopy volume was calculated from measurements of canopy extent in the four cardinal directions and the depth of green crown as an ellipsoid.

3.1.2 Weather records

Three members of the OG were provided with basic weather stations (Youshiko YC9387 5 in 1) to record hourly rainfall, temperature, humidity, pressure, windspeed & direction. Weather stations were delivered and installed as close as possible to the tapping sites by the OGs. Data was stored remotely using 'Weathercloud' and downloaded regularly. Data collection commenced at Newborough on 15/12/20, Candleston on 17/01/21 and for the late entrant Cwmffrwd on the 11/03/21. Most stations worked well, but there were some issues with internet connections that meant there were gaps in the data. Alternative weather data to fill these gaps were located from nearby weather stations at Porthcawl (for Candleston), Brynamman (for Cwmffrwd) and Bodorgan (for Newborough). Tapping at Lower Pen y Graig was only possible in 2022 so no station was provided, and all weather records for this site were obtained from a nearby station at Gilwern. Summary data relevant to the timing of the sap run and overall yields is given in Table 3.

Table 3: Summary weather data for tapping season

Site	2021 tapping season			2022 tapping season		
	Average daily temp Nov 20-Mar 21 (°C)	Number of frost days Nov 20 -Mar 21	Rainfall Jan-Mar 2021 (mm)	Average daily temp Nov 21-Mar 22 (°C)	Number of frost days Nov 21 -Mar 22	Rainfall Jan-Mar 2022 (mm)
Newborough – Newborough	6.7	17	337	8.3	4	306
Merthyr Mawr - Candleston	6.5	17	449	8.1	8	675
Glanamman - Cwmffrwd	6.0	26	801	7.0	29	528
Llanfoist - Lower Pen y Graig				6.3	19	187

3.2 Methods

The EIP project undertook to tap 10 trees at each size in 2021 with five of these tapped for a second time in 2022 with the addition of five new trees. As shown in Table 2 this was achieved at three OG sites but not at Lower Pen y Graig. Altogether, 91 healthy trees over 20 cm diameter suitable for tapping were identified, measured and tagged at the four sites and of these, 49 were tapped either in one or both years (Table 4). These provided more than enough sap to carry out the processing trials. The remaining 42 trees were left untapped as controls. All the trees identified were tagged and mapped.

Table 4: Records for tapped trees at each site

Birch Tapping	Candleston		Cwmffrwd		Newborough		Lower Pen y Graig	
	2021	2022	2021	2022	2021	2022	2021	2022
Number of trees selected & tagged	25		32		27		-	8
Number of trees tapped	10	10	10	10	13	10	-	8
Number of trees tapped twice		7		7		7	-	-
Number of untapped control trees	15	12	22	19	14	11	-	-

Each OG visited their trees each day to collect sap and record the sugar content (measured using a portable Brix meter), quantity (weight), and appearance of the sap produced by each tree. A record of the overall time spent collecting the sap each day was also made. Towards the end of the season the sap can become cloudy/milky and may smell yeasty. Milky sap was discarded and usually tapping was brought to a close when more sap was being discarded than collected. The late delivery of a sugar meter at Cwmffrwd in 2021 and difficult conditions (heavy, cold rain) during the tapping at Lower Pen y Graig meant that there are relatively few sugar records for these sites and years.

3.2.1 Tree selection

The trees selected for the project were greater than 20 cm diameter, healthy and spread through a level and accessible area of the woodland. All trees were tagged and measured and divided into those that would be tapped and the control trees that would be kept untapped.

3.2.2 Tapping

The trees were tapped according to the protocol given in the Dewis Gwyllt project leaflet "How to tap birch" https://www.dewisgwyllt.co.uk/2022/05/18/how-to-tap-birch/ which itself is based on standard practices outlined in Trummer & Malone (2009), ABSA (2008), Mitchell (2007), Dixon-Warren (2010), Farrell (2013) and Beaumont (2010). The instructions and data recording sheets for sap collection sent to the OGs is given in Appendix 2.

There were some practical considerations which meant it was not possible to examine all the factors which may affect sap yield. A case in point for this is aspect: Bilek et al (2016) suggest tapping on south side of trees while Enescu (2017) preferred the north both indicating that aspect maybe a factor in sap yields if not a consistent one. At the OG sites it was found that this was overridden by the need to place taps away from prevailing wind and sun flecks.

All data were sent to WRL, checked and entered into an Access database. All statistical tests were performed with JASP (version 0.16.4 Sep 29 2022) from the University of Amsterdam (https://jasp-stats.org/download/).

Over the course of the EIP project a large amount of daily records of sap volume and sugar concentration were collected. The reduced support from WRL because of covid restrictions together with the constraints of fitting tapping into daily routines resulted in some inconsistencies in the data collected:

- Overflowing collection bottles: This was mainly an issue in 2021 when collection bottles were found to be completely full and overflowing. This occurred for one tree (#255) at Candleston which overflowed on five of 25 days, four of the 10 trees tapped at Cwmffrwd overflowed on the majority of days. No full bottles were recorded at Newborough. In 2022 yields were overall lower and the collection bottle only overflowed for one tree for a few days at Cwmffrwd. Cwmffrwd sap yield data was therefore excluded from statistical analyses of between year and site differences in sap yield since it was obvious the yields were truncated at 5 litres per day.

- Sensitivity of the refractometer: the sap sugar content is right at the lower limit of the range and sensitivity of the meter. The readings are sensitive to ambient temperature and in the cold, outdoor conditions needed constant checking and re-calibration with pure water. This rendered measurements fiddly and time consuming and it was not always possible to obtain readings every day. This was compounded by late delivery of the refractometer to Cwmffrwd in 2021.

- Restricted participation in study: Lower Pen y Graig data is only available for late in the 2022 season and for a small number of trees. Yields started low and declined across the collection period such that it appeared to represent the tail end of the sap flow season. Since these data are limited and likely unrepresentative they were omitted from statistical analyses.

For site and year comparisons statistical analyses were restricted to Candleston and Newborough and for site comparisons to the 2022 data for Candleston, Cwmffrwd and Newborough.

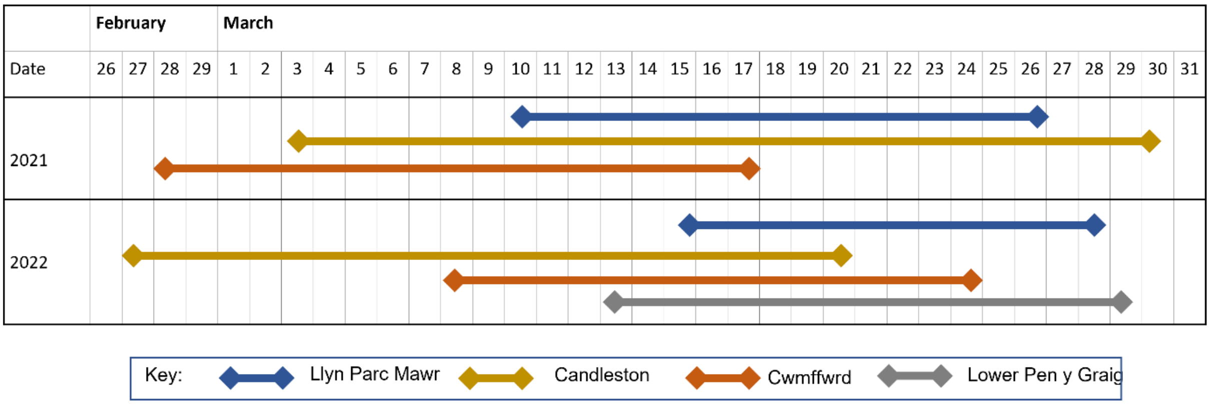
Tree level analyses were restricted to trees which did not overflow the five litre collection bottles for sap flow and to those with at least one refractometer reading for sugar content.

3.2.3 Timing of sap collection

Given the sap run is short it is important to identify the start of the season and this is problematic as there are few useful clues to internal processes within the tree. Either clues are taken from experience (e.g. snow melt as in Finland Tschirpke 2006) or by the expedient of placing test taps in three trees – when two of the three taps start flowing the rest of the taps are placed (Dixon-Warren 2010). However, we can also draw on phenological records of bud burst (Abernethy et al 2017) which indicate that average bud burst between 2000-2016 in Wales was 5th April in south Wales and 8th April in north Wales. This suggests the sap run should be in March and this was confirmed by prior experience with test tapping done under the Dewis Gwyllt project in 2019 and 2020.

The exact timing of tapping was at the discretion of the OGs who used a combination of experience and test taps. Figure 4 gives the timing of sap collection at each site in 2021 and 2022.

Figure 4: Timing of sap collection



3.2.4 Growth rates for 2021

We hadn't envisaged being able to measure annual growth over the short duration of the project. However, having measured the trees at the start of the project it was decided that since WRL staff would be making several site visits the trees would be remeasured when time on site permitted and as close to the end of the project as possible. Inspection of these data to weed out anomalies, such as trees covered with ivy, revealed size differences comparable to expected annual growth (as confirmed by ring counts on the felled trees). Nevertheless, there are a number of problems estimating growth from over-bark diameter measurements just one year apart. It is only really possible to make useful estimates for trees where annual growth is greater than sampling errors on the measurements. In many instances this was not the case and errors meant the second measurement could be smaller than the first giving apparent negative growth. Excluding such records would have introduce bias towards faster growing trees so all data were included in the analysis. It is also possible for trees to shrink, as trees will swell and contract with moisture content. The average growth rates for each site are given in Table 5. Note that these data give Newborough as growing faster than Cwmffrwdd and Candleston rather than slowest as suggested by the yield class in Table 2 which may reflect the higher expected growth rates for *B. pendula* (Nieuwenhuis & Barrett 2002) which is present at Newborough over the commoner *B. pubescens*.

Table 5: Estimates of average growth for 2021

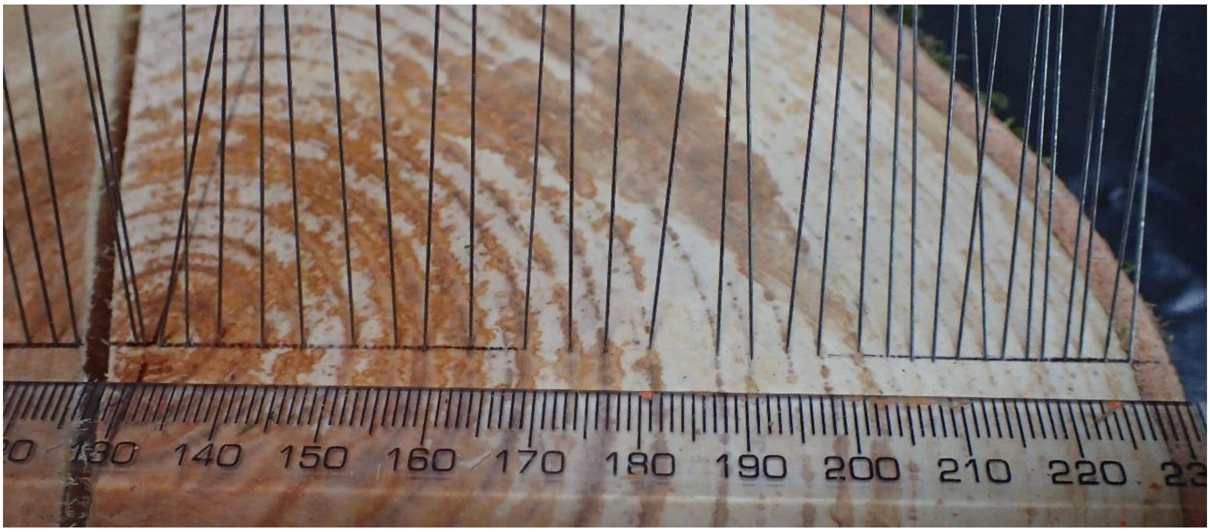
	Candleston	Cwmffrwd	Newborough
Number of trees with diameter measurements 2021 & 2022	25	27	23
Mean diameter increment in 2021 (cm/yr)	0.204	0.218	0.344
Mean cross-sectional area increment (cm^2/yr)	9.352	7.818	13.154

3.2.5 Felled and sectioned trees

After the second tapping season a small number of trees at Candleston and Cwmffrwd were felled and sectioned to examine growth and progress of internal staining and healing of the tap holes. At Cwmffrwd two trees were felled, selected from the tapped trees to minimise disturbance to the remaining stand. Tree Cwmf234 had been tapped in both 2021 and 2022 while tree Cwmf244 had been tapped in 2022. At Candleston one tree CF260 which had been tapped twice was felled and a control tree which had fallen in a storm CF273 was also sectioned. The intention was to also fell trees at Newborough but gaining permission for this in a heavily used public woodland was problematic.

The felled trees were cross cut into disks at the base, every metre up the trunk and at 1.3 m. All disks were sanded and ring counts made using a binocular microscope for difficult sections. For the disk at

1.3 m ring widths were measured on scans of the disk using digital image software. The age of the tree was taken as the ring count of the lowest disk.



Tree CF260 – Measuring ring widths on cross section at 1.3 m

4 Sap production

4.1 Daily sap flows

Table 6 gives a summary of the daily sap flow data.

Table 6: Summary data for collected sap

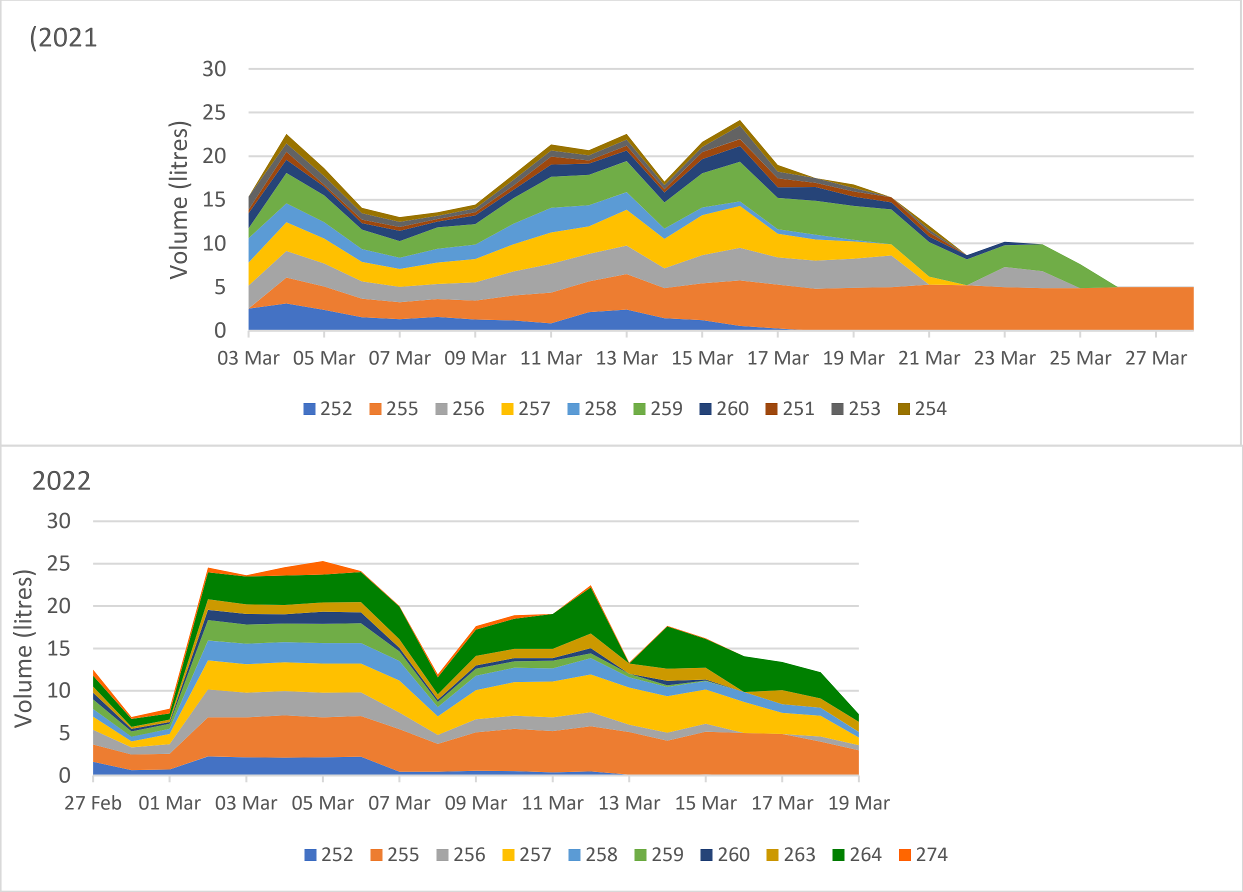
Birch tapping records	Candleston		Cwmffrwd		Newborough		Lower Pen y Graig	
	2021	2022	2021	2022	2021	2022	2021	2022
Individual daily sap volume records	210	200	144	150	221	139	-	128
Number of sugar content records	139	95	30	144	219	139	-	100
Maximum tapping period (days)	28	22	17	17	17	14	-	17
Total volume of sap collected (litres)	395.1	369.7	366.0	321.0	410.1	202.6	-	75.9
Total volume of usable (clear) sap (litres)	378.6	352.7	329.8[+]	306.9	400.6	201.1	-	72.3
Average daily sap production per tree (litres)	1.8	1.8	2.4	2.1	1.9	1.5	-	0.6
Average sugar content (°Brix)	0.77	0.61	1.03*	0.70	0.77	0.66	-	0.72
Min sugar (°Brix)	0.2	0.2	0.9	0.6	0.1	0.1		0.1
Max sugar (°Brix)	1.3	1.2	1.2	1.0	1.4	1.4		1.4

[+] 5 litre bottles consistently overflowed * sugar meter only available for part of sap run

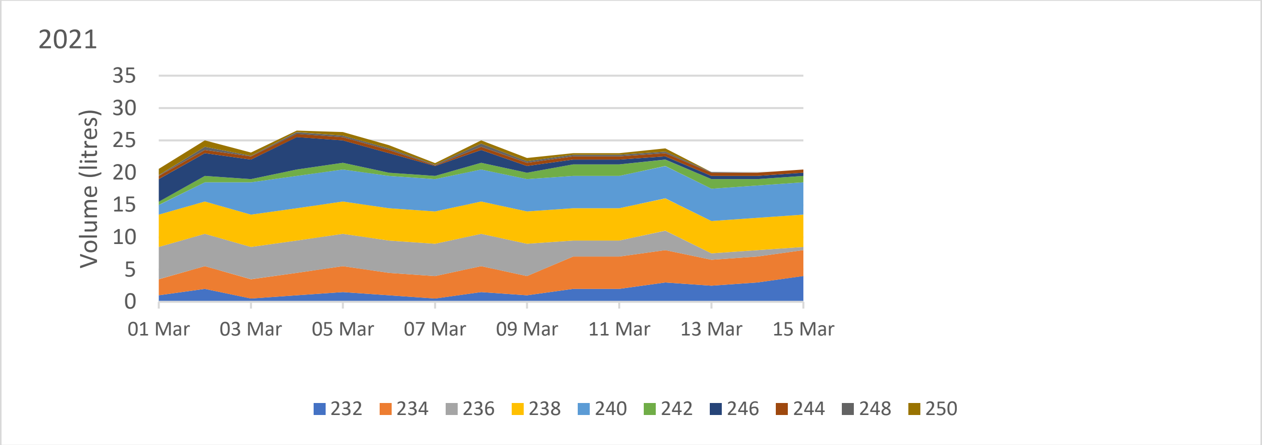
To examine the pattern of sap flow across the season at each site cumulative daily usable sap yields for each site and tree were plotted as cumulative charts (Figure 5). The impact of the cap on maximum yields caused by the five litre bottles overflowing in the 2021 data is evident for tree 255 at Candleston (Figure 5 (a)) trees 234, 236, 238 and 240 at Cwmffrwd (Figure 5 (b) and tree 345 at Newborough (Figure 5 (c). Overall total yields at all sites were higher in 2021 than 2022 with more trees overflowing and what appears to be a longer sap flow season. ANOVA of daily sap volume for Candleston and Newborough showed a significance difference between the two sites (*p=0.18*) and between years (*p=0.001*) though there was no distinction with site x year (*p=0.881*). Candleston had an average sap yield of 1.950 litres (*SE% = 4.7%*) which was higher than Newborough at 1.703 litres (*SE% = 3.5%*). However, considering the number of overflowing bottles at Cwmffrwd and the very low yields at Lower Pen y Graig a ranking of sites in terms of sap volume would be: Cwmffrwd, Candleston, Newborough, Lower Pen y Graig.

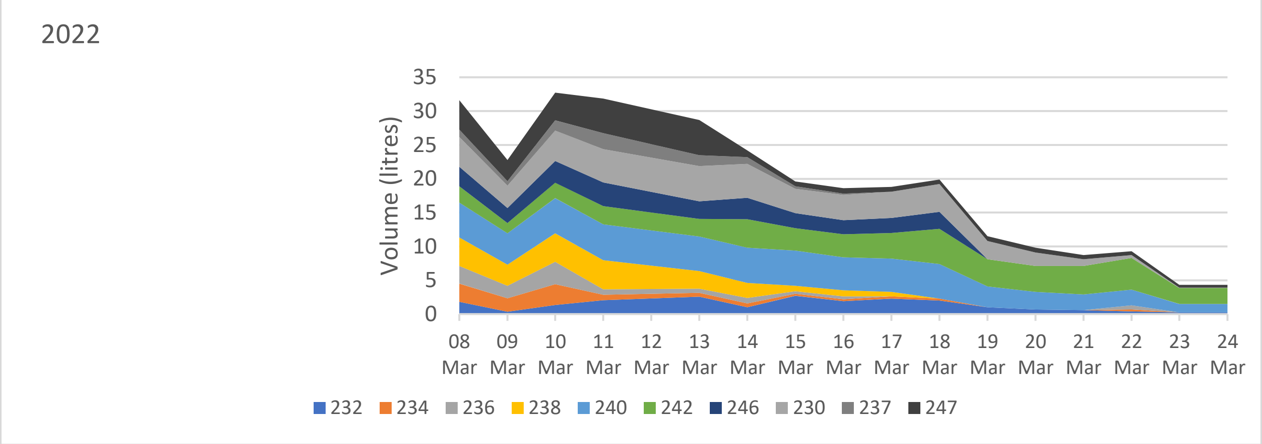
Figure 5: Daily sap yield for all tapped trees

(a) Candleston

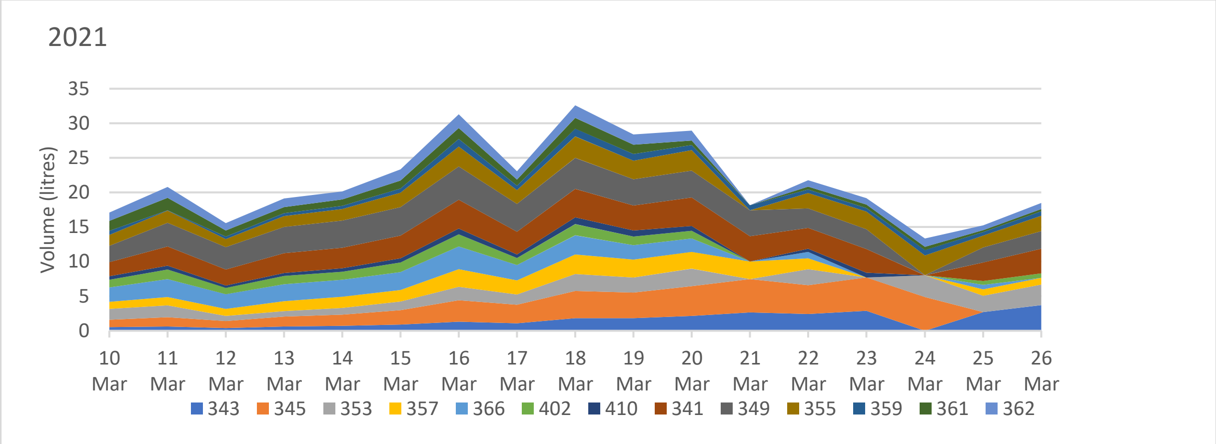


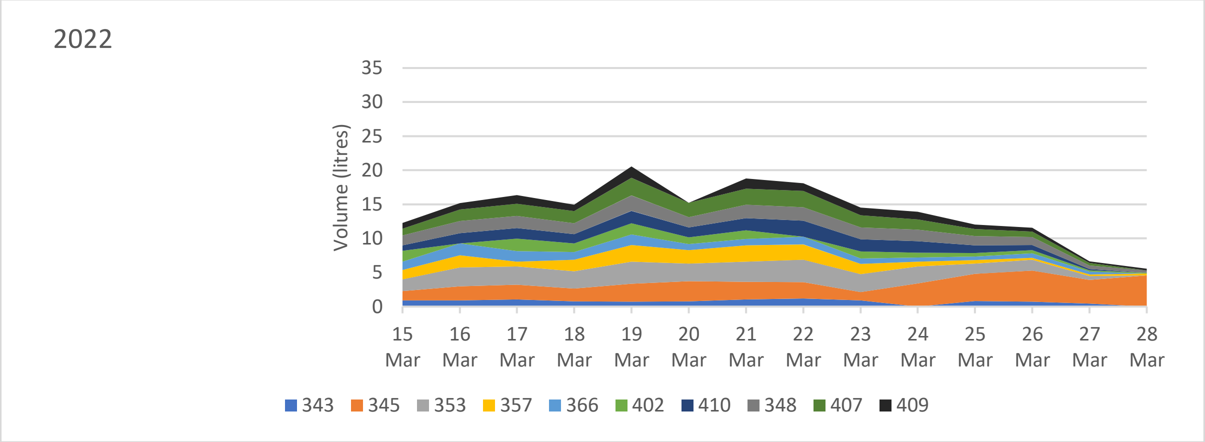
(b) Cwmffrwd



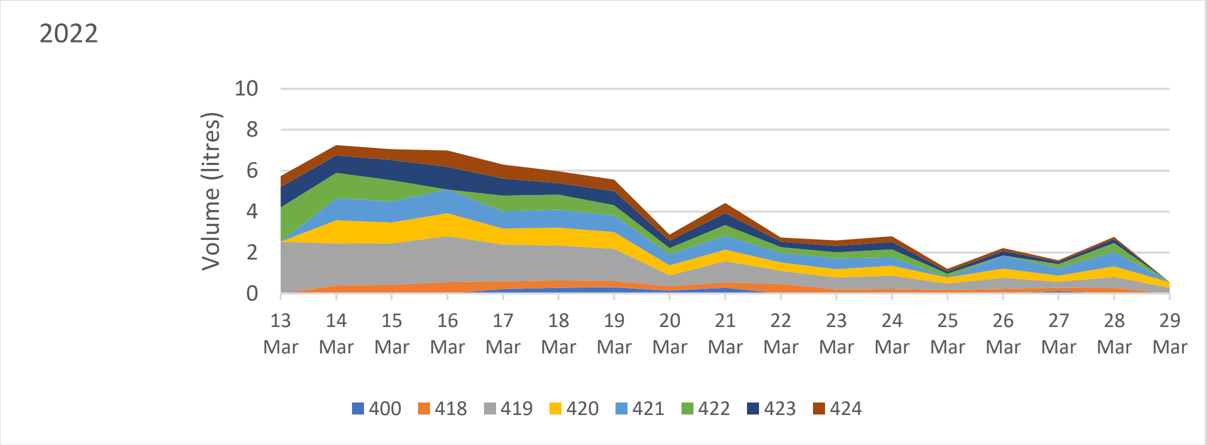


(c) Newborough





(d) Lower Pen y Graig



Soil and stand characteristics (Table 2) do not give any obvious clues to what may control site productivity for sap. Based on the observations of Maher (2005) and Farrell (2017) we might expect sap volume to respond to winter soil water availability. However, rainfall amounts in the 2021 and 2022 season were broadly similar (Table 3). Furthermore, under current rainfall regimes we generally expect that total sap production would not be constrained by rainfall in Wales[2] though this may become an issue in the future if climate change brings about an increase in droughts.

For Newborough and Candleston, 2021 had average yield of 1.945 litres (*SE% = 3.5%)* some 22% higher than the average for 2022 of 1.594 litres (*SE% = 4.8%*). 2021 was somewhat cooler than 2022 (Table 3). This mirrors observations in Finland (Salo 2000) and Alaska (Maher 2005) of higher yields in colder, wetter years but the differences are not so marked in Wales. This is not unexpected given that Wales has only short periods (if any) below freezing and generous rainfall[3]. However, there may be an impact on timing – sap flow is perhaps earlier in warmer years and there maybe more synchronicity between trees in colder years.

The daily data is somewhat saw-toothed and it is tempting to suggest these are related to weather conditions. However, setting sap flows against daily temperature and rainfall from the site weather stations did not reveal any simple relationships.

Despite many observers noting a relationship between sap yield and tree diameter (Aher 2055 and Miina & Kurttila 2022) we didn’t find any relationship with tree diameter in the EIP data. However, the size range was limited with few trees more than 30 cm diameter. Interestingly Maher (2005) noted that the weak relationship they observed between diameter and yield was influenced by weather conditions – size was more significant predictor of yield in drier years when large diameter trees maybe better able to obtaining moisture than smaller trees.

A notable feature of sap production is the large variation in yield between individual trees with some trees giving only a trickle while others give large amounts. Some of this could be due to asynchrony with trees following individual timing for the sap run which Kok at al (1978) also observed in Canada.

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[2] Contrast Finland with mean annual precipitation between 600-700 mm and Wales with between 1000-3000 mm.

[3] Compare the 600-750 mm mean annual precipitation for southern and central Finland with the 1000-3000+ means for Wales.

Overall yield does not appear to be related to species, size, competition (as indicated by basal area measured for each tree) or estimated growth rate. It maybe that yield is controlled by below ground interactions or is simply natural genetic variability between trees. Regardless tree yield does appear likely to be consistent between years (cf tree 255 with high yield and tree 260 with low yield at Candleston, tree 240 with high yield at Cwmffrwd and tree 353 with low yield at Newborough. However, consistency between years is far from certain (cf tree 234 at Cwmffrwd and tree 259 at Candleston) and statistical analyses found no differences between the sap yield per day by site or year.

A further feature is that the yield on the first day gives a reasonable indicator of total yields. There were 12 trees which gave less than 1 litre on the first day – of these only two (tree 343 in 2021 and tree 407 in 2022 at Newborough) went on to give more than 20 litres over the season. It may therefore be more efficient to remove taps from trees with low initial yield and to install them on new trees to seek out the higher yielding trees. Once located, high yielding trees should be marked for subsequent tapping.

4.1.1 Estimating sap yields

To be able to plan an enterprise based on sap it is helpful to be able to estimate what to expect in terms of sap yield from a site. There have been several attempts to develop sap yield models based on regression of sap volume against tree diameter. The one developed for *B. neoalaskana* in Alaska (Maher 2005) was adapted for use in Finland by Kurttila et al (2018) though based on rather sparce data due to the “protection of undisclosed know-how and business information”. To rectify this Miina & Kurttila (2022) initiated a large-scale citizen science collection of birch sap in 2019 and 2020. This resulted in data for 225 trees from 74 stands which gave means of 47.8 litres of sap per tree of mean diameter of 19.2 cm, mean height of 16.0 m, and mean stand age of 40 years with no distinction made between the birch species. A regression of sap yield against tree, stand characteristics, region and year revealed sap yield of a tree had a positive relationship with tree diameter while average total sap yield was related to mean height, mean diameter, stand age and stand basal area. With the EIP data we did not observe any of these relationships but our dataset is small (three stands compared to 72 in Finland. In common with other studies Miina & Kurttila (2022) found between tree variability within a stand was large compared to the effect of any of the differences between stands which means any model would have wide confidence intervals.

Until there is more accumulated experience of birch tapping in Wales it is not possible to provide a yield equation. In the interim the data derived from the pooled EIP data gives averages of 2 litres /tree /day for a tree between 20 and 35 cm diameter with a sugar content of 0.71°Brix with a pragmatic syrup to sap ratio of 1:124. These figures can be used as a first approximation of what you can expect from tapping. Improving on this requires that tappers keep records of yields from their trees.

4.2 Variation in sugar content

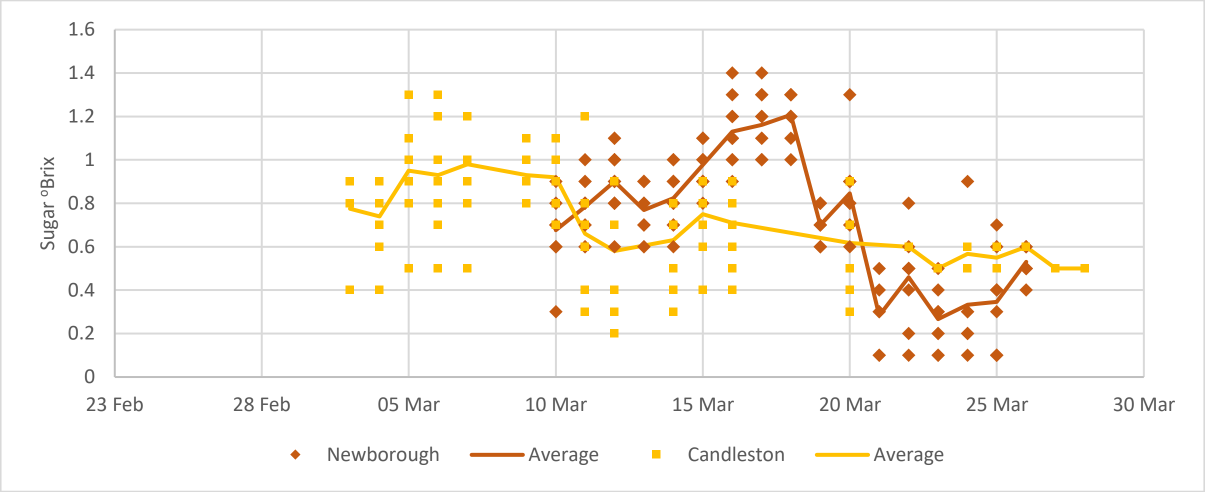
Syrup yield is a function of both sap volume and sugar content with sugar content being the most important of the two as sap with higher sugar content will require less evaporation. Sugar content varied from 0.1 °Brix to 1.7 Brix with a mean of 0.771 Brix (Table 4). These figures are much the same as reported for other species of *Betula* (Maher 2005) and *B. pubsecens* and *B. pendula* elsewhere in Europe (Ahtonen 1987a, Kallio et al 1985, Łuczaj et al 2014).

4.2.1 Variation over sap run

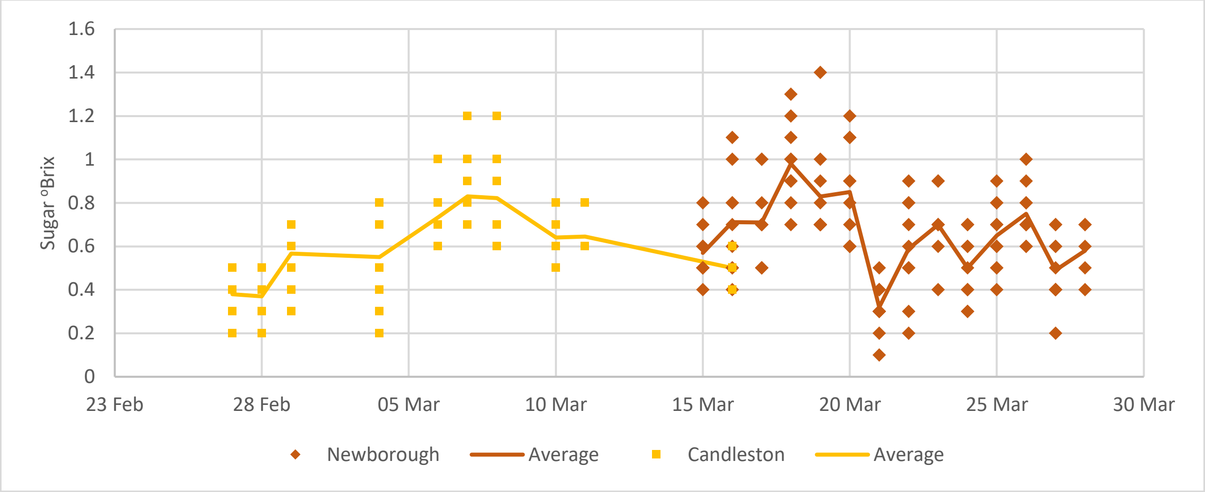
Figure 6 gives the variation in sugar content across the tapping periods for Candleston and Newborough for both years.

Figure 6: Variation in sugar content during sap flow season for Candleston and Newborough

(a) 2021



(b) 2022



In Figure 6 it appears that all trees at both sites and years follow a similar pattern in sugar content with a maximum in what appears to be the middle of the sap run. The periods of maximum sap volume and sugar content are roughly aligned at Newborough (c.f. Figure 6 (b) with Figure 5 (c)) but are asynchronous at Candleston (c.f. Figure 6 (a) with Figure 5 (a)) which suggests there may be different controls on the build-up of root pressure in the tree and mobilisation of sugars. This is something that would need further detailed investigation to disentangle.

For commercial tapping it is probably enough to know that there is a period of maximum productivity for syrup for a period of about five days in the middle of the season. In both years the period of maximum sugar content at Candleston was between 5-10 March and at Newborough between the 15-20 March. Both sites are at sea level, on sand with Newborough 190 km due north of Candleston which suggests a northward progression of the peak in sugar content of roughly 0.75 km per hour or a 10 day lag.

Based on data for 2000 to 2016 Abernethy et al (2017) report budburst occurring on the 5th April in south Wales and 8 April in north Wales. This equates to a northward progressing of silver birch budburst of 2.6 km per hour across the UK. This is many times faster than our observed northward progression of sap flow but budburst is correlated with average March temperatures with bud burst advancing by just over 4 days for every 1°C rise in average March temperatures (Abernethy et al 2017). March is when the sap is flowing so release of sugars and budburst though sequential are likely responding to different environmental triggers. Using the 2016 phenological data and correction with mean March temperatures against the mean temperatures reported in Table 3 we estimate that budburst in 2021 would have been around 5th April and in 2022 which was 1.5°C warmer around the 30 March. Sap flow ceases at budburst and the earlier date corresponds well with the drying up of the sap run at the end of March experienced at all sites in 2022 (Figure 5) and also at the most southerly Candleston in 2021.

Total sugar productivity (taken as sap volume * sugar %) in 2021 was generally higher in 2021 than 2022. The winter temperatures in 2022 were warmer than 2021 which likely had some impact on sugar mobilisation but since the stored sugars are made in the last two months of the previous growing season (i.e. August-September) it maybe that we need to look further back to understand sugar yields. This is not possible for the EIP data as we have no weather records for summer 2020 to compare with summer 2021 – the summers before tapping in spring 2021 and 2022.

The availability of diameter measurements spanning the 2021 growing season (April-October) meant it was possible to compare tree growth in 2021 with sugar content in sap flow in 2022 for individual trees. Average sugar content per tree was tested against two indices of growth potential. The tree basal area increment (BAI) in cm^2 was the difference in diameter measurements expressed as the increase in cross-sectional area of the trunk at 1.3 m. The basal area in m^2/ha of the stand in the vicinity of the tree is a measure of competition experienced by the tree. The pooled data from Candleston, Cwmffrwd and Newborough point to a correlation between BAI and basal area ($r=-0.300$ $p=0.022$) and a weak relationship between basal area and sugar content ($r=-0.196$ $p=0.109$). This suggests that sugar content is highest in trees with least competition which are growing fastest.

4.3 Practical observations

The decision to tap was left to the discretion of the OG and to follow general advice to install a couple of test taps and commence tapping once they started running (Mitchell 2007, ABSA 2008). The OG at Candleston decided to commence tapping once the daffodils started opening, she took as signalling the start of spring, while those at other sites either installed test taps or commenced tapping in early March when it fitted best with their schedule. Despite this, comparison of Figure 5 with Figure 6 indicates that with one exception the tapping periods all included a period of peak sap and sugar productivity. For Lower Pen y Graig, tapping started so late it was obvious they had only picked up the tail end of the sap flow season (Figure 5 d)).

Tapping individual trees ends when the sap starts to be cloudy in the bottle. This generally starts some 12 days after tapping and is related to contamination of the tap hole and collection equipment and can occur when the sap is still flowing strongly. There is variation between trees with some giving a clear flow for a long time and contamination is also likely to be earlier in warmer years. For this reason it is advisable not to pre-empt the start of the season.

Cloudiness was the main signal for cessation of tapping in 2021 which was a warm year. Conversely tapping may cease when the tree dries up at budburst and gives an amount too small (less than 1 litre) to be worth collecting as was seen in the cooler 2022. These effects are most noticeable at Cwmffrwd (Figure 5 (b)) and Newborough (Figure 5 (c)).

The level of site-level synchronicity between sap productivity between years shown in Figure 6 suggests that if a pre-determined date for tapping is useful for scheduling then as long as tapping starts by the 5th March in south Wales and proceeds one day later for every 20 km further north (not later than 15th March for the north coast) then a tapping period of two to three weeks should overlap with the sap run.

To engage in birch sap tapping It should be feasible to set aside three weeks in March for tapping.

The key observations regarding the timing of the sap run from the combined experience of the Dewis Gwyllt, EIP projects and WRL tapping trials (2019-2023) are:

- Test taps can be used to detect the start of the sap run – but intuition, especially if based on previous tapping at the site can be just as reliable.
- It takes around 7-10 days for the peak in sap flow to progress from the south to north coasts of Wales (approximately 1 day later for every 20 km further north).
- If you need to fix dates for tapping then starting in first week of March in south and second week in March in north will probably catch the main part of the season.
- The sap run will start earlier in warmer years compared to cooler years.
- The sap run is likely to be shorter and end with sap going off in warm years.
- The sap run may be longer, with trees running dry in cooler years.
- Expect overall yields to be higher in cooler than warmer years.

In terms of the performance of individual trees expect:

- Each tree to have its own trajectory through the season – some will have peak flow early, others late and some will continuously produce large amounts - or only a trickle.
- Sap in collection bottles will start being milky, a sign it is going off, from around 12 days – while others can remain clear for 20+ days. To keep sap clear, be scrupulous in sterilising all equipment, use a sharp drill bit and rinse out the hole before inserting spile. Shading the bottles in sunny weather may also help keep sap cool.
- Consider moving taps to new trees based on their behaviour – i.e. abandoning a tree after several days of very low flows, perhaps putting taps in new trees mid-way through the season if flows are good but sap is starting to go milky.

Predicting yields with any accuracy is not yet possible as there are insufficient data for any form of modelling and the extreme variability means predictive models may never be useful. In order to get a better feel for your trees and how they react to local weather and microsite conditions – consider the following:

- Tag your trees and keep notes of individual tree performance – this does not need to be every day but maybe twice in the season.
- Keep a record of total daily sap yield and sugar content.
- Make a note of any significant weather events e.g. heavy rain, temperature, presence of snow on the ground, periods of warm sunshine etc.

5 Sustainable tapping

This section considers the impact of tap wounds on the trees. Tapping creates wounds in the tree and it would be disingenuous to say that it has no impact on the trees. What we need to know is the severity of the impact, how long it takes the tree to recover and whether there is any lasting damage. It is unreasonable to expect no damage but it should be commensurate with the value of the product and managed by adopting good practices and ideally managing the stand. However, do bear in mind that we are making small holes in trees which may reduce its lifespan compared to felling them for firewood!

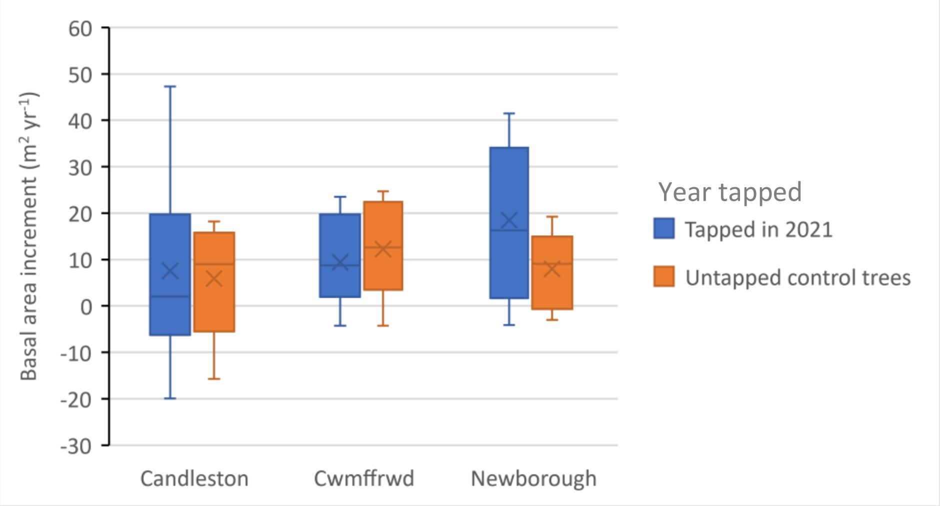
5.1 Impact of tapping on growth potential

A primary question when considering sustainability is whether the loss of sap or tree wounding has any impact on yields or vigour of the tree in subsequent years. The EIP study was designed with a set of control trees to examine the impact of tapping on tree health (see Table 4). The control trees were tagged and a number of measures of health recorded in March 2021. These trees were then remeasured in April 2022. Health is difficult to record when trees have no leaves and subjective measures e.g. crown density in a closed woodland were too imprecise to give meaningful results.

Using the growth data derived from diameter measurements in 2021 and 2022 it was possible to test whether trees tapped in 2021 had any discernible impact on growth of the trees the summer after tapping. The current annual increment (CAI) for 2021 for tapped and untapped trees by site is given in Figure 7. Although it may appear there are differences between growth rates between sites – as shown in Figure 7 there is a lot of overlap in growth rates for the individual trees and an ANOVA test reveals there are no significant differences between growth rates with tapping (*p=0.464*) between sites (*p=0.599*) or tapping * site (*p=0.661*).

The impact of tapping on tree health maybe expressed as changes in sap flow and sugar content. Both of these parameters were compared for trees tapped in 2022 which were being tapped for the first time and those which had been tapped in 2021. There were no significant differences between previously tapped and untapped trees in terms of sap yield (*p=0.722*) and sugar content (*p=0.130*).

Figure 7: Growth as basal area increment for2022 for trees tapped in 2021 and untapped controls

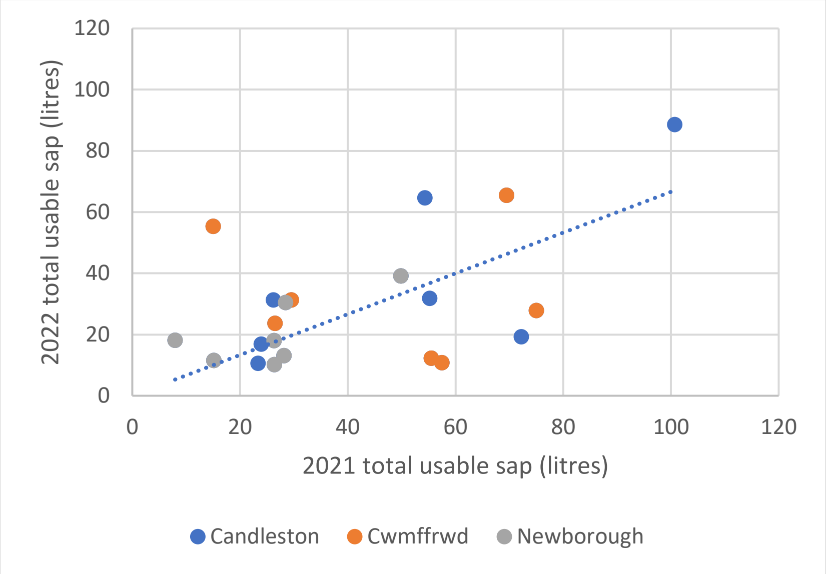


These results are encouraging but are far from conclusive as tree health generally takes several years to decline and the number of trees tapped for the first time in 2022 is small. A better method of monitoring tree health is to track the progress of healing or decay at tap wound sites.

5.1.1 Tapping in second year

An important question for commercial tapping is whether a single tree can be repeatedly tapped and if so, how frequently. Figure 8 shows the yields in 2022 compared to that for 2021 for trees which were tapped twice. Generally, notwithstanding the overall lower yields in 2022, individual trees gave similar yields in each year. But there are also trees which have quite different yields from year to year. The preliminary conclusion from this is that tapping in a second year may not affect sap yields overmuch and it would be worth marking high yielding trees for tapping in subsequent years as suggested by Maher (2005).

Figure 8: Sap yield from second tapping



5.2 Response to tap wounds

To ensure tapping is sustainable long-term it is axiomatic that tree health should not be unduly compromised - some increase in risk of mortality is inevitable but should be small.

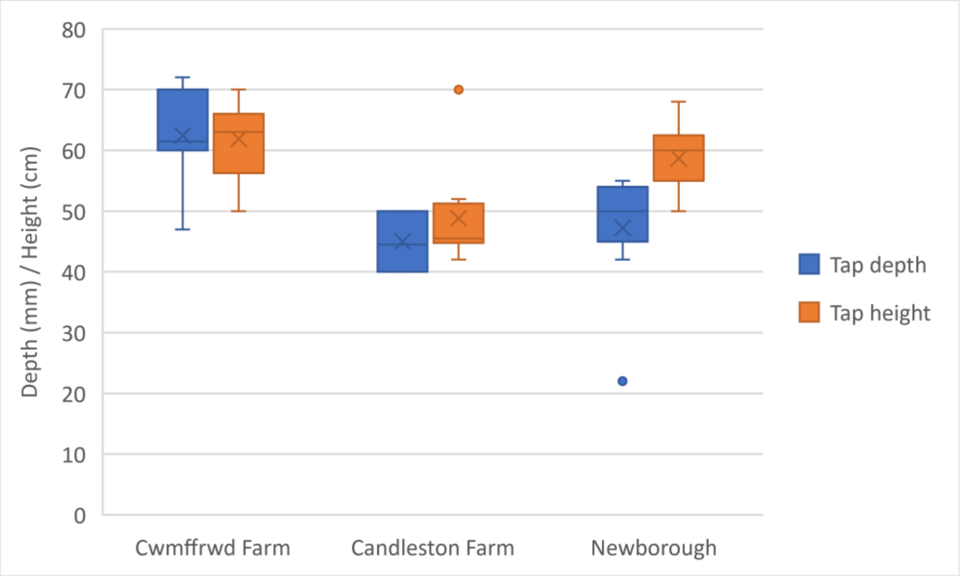
Each OG had been given instructions on how to go about tapping and had recorded some basic details on the depth and positioning of the drill holes. Once harvesting was complete, the plastic spiles were removed and the holes left open to allow natural healing after earlier observations confirmed the long-lasting damage inflicted by placing bungs in the holes.

Visual inspections of the tap holes was carried out in July 2021 (approximately five months after initial tapping), and again in April 2022 (2 months after 2022 tapping and 14 months after 2021 tapping). All the tap holes were photographed and examined to measure the maximum hole depth using sterile, flexible probes of 1 mm and 2.5 mm diameters. A range of measurements and condition scoring was used to record and describe wound healing.

Physical damage and visible staining from the tap wounds were also recorded from a number of trees by sectioning across the tap holes.

There was some variation in both the height that tap-holes were placed up the tree stems, and also the depth of the drill holes. A target depth of 40 mm was proposed but when measured later, all holes were deeper than this, significantly so at Cwmffrwd (Figure 9) which may contribute to higher sap yields at this site in 2021 (Figure 5). The aspect of the tap-holes also varied considerably between sites, with many more trees tapped on the north-facing side at Newborough, and none at Candleston. The angle of the tap-holes should be downwards to assist water drainage and this was not always found to be the case. It is possible that these, and many other factors may have affected the speed of wound healing.

Figure 9: Variation in tap depth and height between sites in 2021



5.2.1 Wound healing

The degree of wound healing was assessed visually 4-5 months after initial tapping and again after 14 months. The tap hole closes over at the cambium layer (between the bark and wood) towards the outside. As the wound heals the appearance of the hole gradually changes. Initially the hole is fully open, then a sign of a “rim” develops around the hole. This rim gradually increases in thickness, this is more rapid from the sides so the hole takes on a “cat’s eye” appearance and becomes a vertical slit. The final stage is when the hole is fully sealed, sometimes with a slightly puckered “belly button” appearance. Figure 10 shows a near completely healed tap wound two years after tapping. Note that the hole is dry and black with minimal staining extending into surrounding wood.

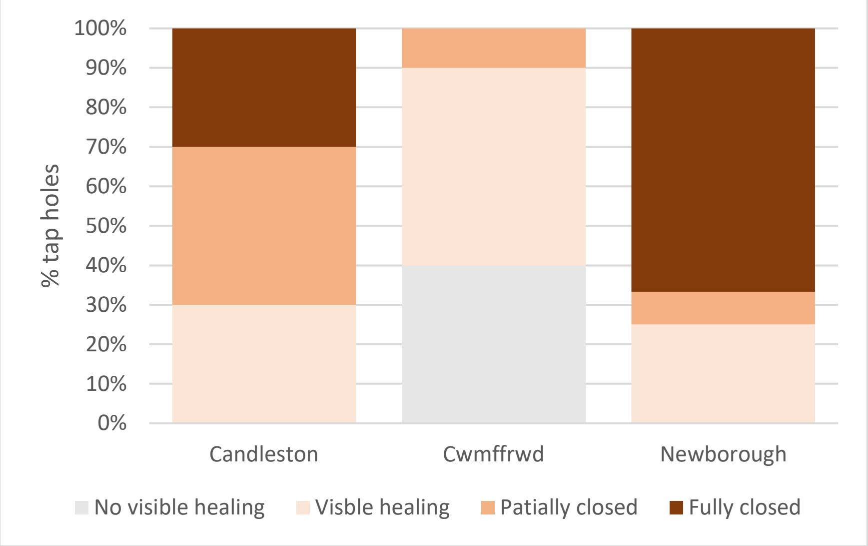
Figure 10: Advanced closure of two year old tap wound

“Belly button” closure on outside

Horizontal cross-section

The results given in Figure 11 indicate the response of the trees to wounding in April 2022 following tapping in early March 2021 (equates to one growing season).

Figure 11: Visible tap wound closure one year after tapping



The degree of healing response varied considerably between sites, with tap-holes at the Newborough site apparently showing the most advanced healing. It would be expected that fast growing trees would be able to close wounds quickly and Newborough also appeared to have the fastest growing trees (see Table 5). There were also marked differences between sites in terms of the cleanliness of the tap holes. About half of the tap holes at Candleston and Cwmffrwd contained slugs, wood lice and insect frass compared to just one at Newborough. Vegetation at Candleston was tall, dense and indicative of high nutrient status (nettles and Himalayan balsam) which perhaps served to keep the air at the level of the tap holes humid with plentiful food for slugs. More investigation into the potential relationship between tree growth rate, humidity, slugs, insect activity and wound healing would be desirable.

It was obvious from inspection from some of the wounds that there had been some collateral damage to the cambium around the hole (likely a result of pulling the bark away when withdrawing the drill or spile) which resulted in a larger-than-necessary wound hidden behind the bark as shown in (Figure 12). Nevertheless, there was clear evidence that wound healing was proceeding but wound closure would be delayed. This was particularly the issue at Cwmffrwd (Figure 6) were the OG had no previous experience of tapping and face to face training was not possible because of the covid restrictions. This is all useful evidence in support of guidance for sustainable tapping.

Figure 12: Tree with cambium damage beyond the tap hole

5.2.2 Propagation of non-conductive wood in tree

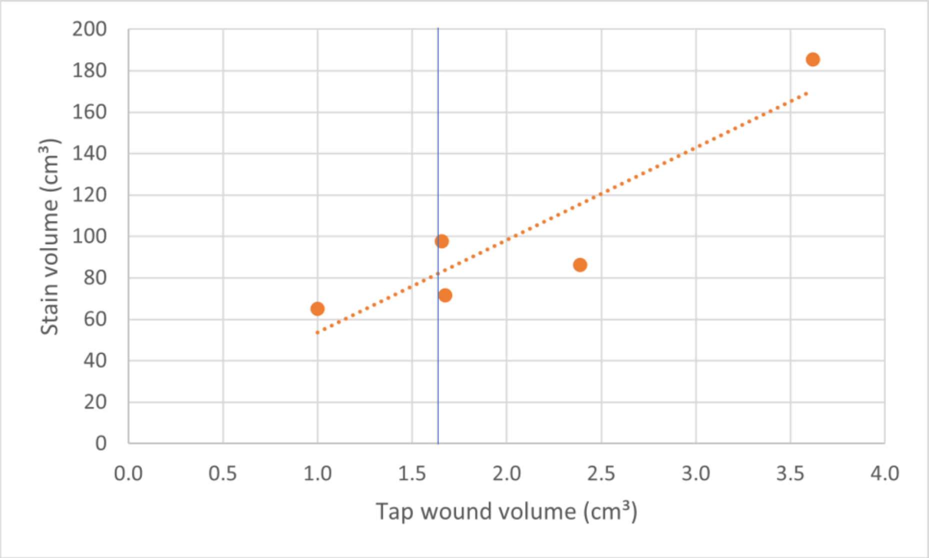
Three trees were felled (two with two tap holes, giving five taps) and sectioned to examine the extent of staining around the tap wound. Following the methods described by van den Berg et al (2018) one tap hole was sectioned vertically through the tap hole to examine the vertical extent of staining the other four were sectioned horizontally at 2 cm intervals through the stain. Figure 13 shows the typical pattern of staining with longer extension up the tree than down, and that the horizontal stain does not extend much beyond the footprint of the tap hole.

Figure 13: Cross sections through tap wounds

Vertical cross section (Tree 260) Horizontal cross sections at 2 cm intervals (Tree 234)

The total volume of stained wood was estimated for each tap hole by photographing the sections and using image processing software on the computer delineating and measuring the cross-sectional area of stain. As shown in Figure 14 the volume of stained wood is correlated with the volume of the tap wound – wider and deeper holes result in larger areas of staining.

Figure 14: Volume of wood staining initiated by tap wound



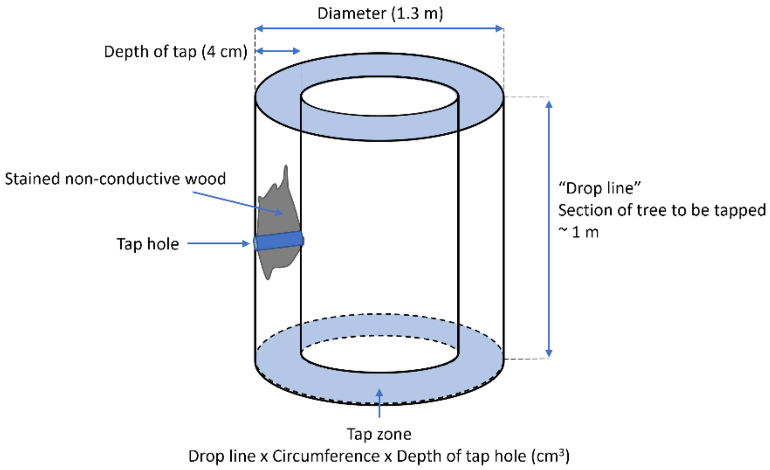
Blue line indicates a ‘standard’ tap hole of 8 mm diameter and 4 cm depth

5.3 Tapping models and intervals

Boring a hole into a tree cuts across the bark, cambium and severs the xylem vessels of the sap wood which carry sap which runs out of the hole under pressure. Air enters the severed vessels which become non-conductive i.e. can no longer transport sap through the tree. The entry of air causes the affected wood to darken as it is oxidised and a zone of wood around the hole have dark or reddish stains. These stains are a useful indicator of the extent of non-conductive wood (NCW) originating from the tap hole. Since tapping into NCW will not yield any sap, there has been considerable research on the consequences of the accumulation of NCW and its replacement by growth of new wood for multiple year tapping of sugar maple which has been used to develop a model for the propagation of NCW in tapped sugar maple trees (van den Berg & Perkins 2014). This model was then applied to *B. papyrifera* trees in Vermont (van der Berg et al 2018).

The tapping model is based on the premise that to keep pace with the development of NCW, the growth rate of new conductive wood should at the very least be greater than the generation of NCW. It is suggested that a useful rule is that the proportion of NCW should not be more than 10% of the available tap zone volume. The tap zone volume being the volume of wood that can be tapped and extends around the tree to the tap depth (4 cm) within the area that can easily be reached for tapping (say from 40 to 140 cm from the ground[4]). Figure 15 illustrates the tap zone assuming the trunk of the tree is cylindrical (it is actually a frustrum of a cone as tree trunks are tapered).

Figure 15: Relationship between tap hole, NCW and tap zone volume



The availability of conductive wood is dependent on (a) the volume of NCW associated with each tap hole, (b) the size of the tree, and for repeated tapping, (c) the tree's growth rate. The starting point for a model based on that developed by van den Berg et al 2018 for birch in Wales is to establish the values for parameters based on the data derived from the EIP trials. From Table 7 the multiplier for NCW is between 36 and 65 with an average of 50. This is comparable to sugar maple but much smaller than the average of 222 reported by van den Berg et al (2018). NCW continues to develop over time and the EIP data was just for one to two years, while for van den Berg et al this was measured after 10 years. Nevertheless, at least for the wounds which were rapidly healed over, it seems unlikely that the NCW will develop the 2 m high stain columns reported by van den Berg et al. To be conservative, we adopted the NCW multiplier of 75 as used by van den Berg et al (2018). Growth rates were derived from ring measurements on cross-sections of four trees (Table 7).

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[4] For sugar maple this is the depth of the 'drop line' which is restricted by the logistics of maintaining fall and suction pressure on piped collection using vacuum pumps.

Table 7: NCW and ring widths for four sectioned trees

Site	Tree	Tap	Tap hole volume (cm³)	NCW volume (cm³)	NCW multiplier	Tap zone volume (cm³)	NCW as % of tap zone	Diameter (cm)	Average width of last five rings (cm)
Cwmffrwd	234	2021	2.4	86.3	36	7186.8	1.2	19.83	0.139
		2022	1.0	65.1	65	6725.2	0.9		
	244	2022	3.6	185.4	51	6929.2	2.7	21.11	0.389
Candleston	260	2021	1.7	71.5	43	5970.2	1.2	16.58	0.183
		2022	1.7	97.7	59	5947.0	1.6		
	273	No tap						32.89	0.187
Average			2.1	101.2	51	6551.7	1.5	22.60	0.224

Model results are given in Figure 16 for these trees and indicate that NCW% will remain below 10% with the exception of tree 234. This is not surprising, as tree 234 has the slowest diameter growth and is relatively small. The size of the tree before tapping has an impact as shown by trees 260 and 273, which have similar growth rates but quite different reactions to tapping. Small trees start with a disadvantage of a smaller tap zone, though the tap hole and NCW will be the same as for larger trees. This means that growth rates to maintain NCW below 10% can be lower than that for smaller trees as shown in Figure 17. Applying these rates to the annual increment data, derived from the repeat diameter measurements, allows an evaluation of the number of trees at each site which have growth rates sufficient to support annual tapping as shown in Figure 18.

Figure 16: Model of annual tapping

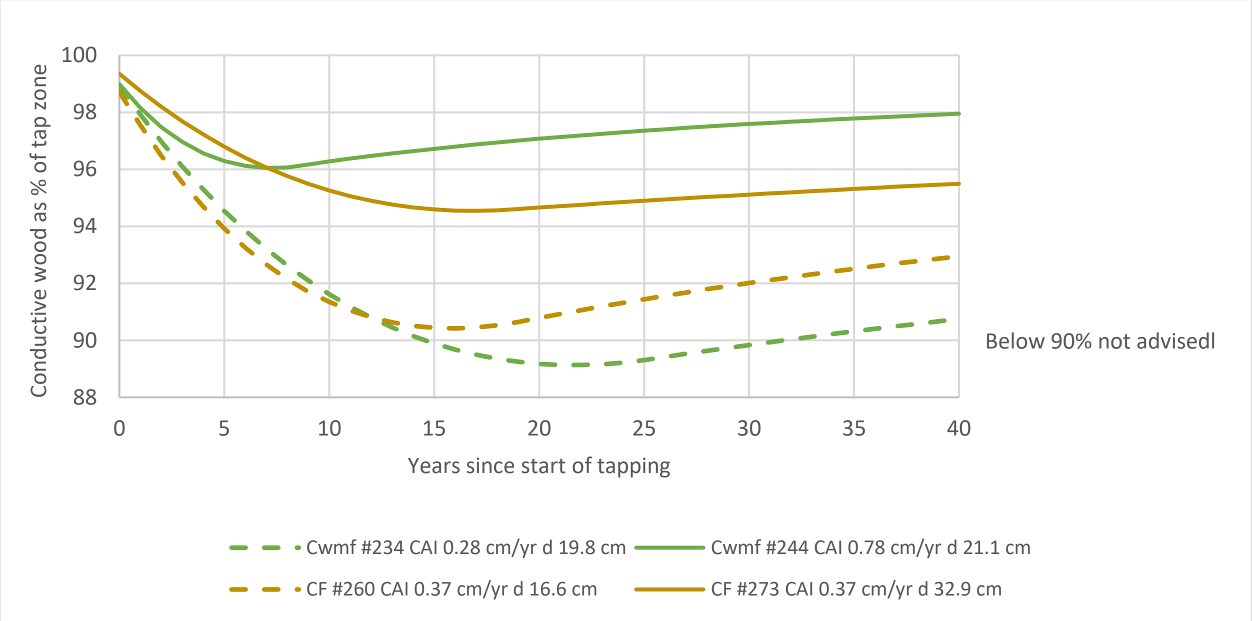


Figure 17: Threshold diameter increment to support sustainable annual tapping

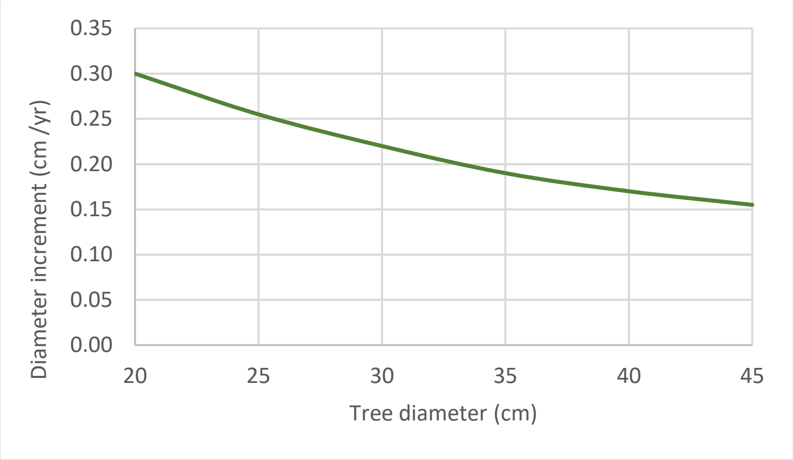
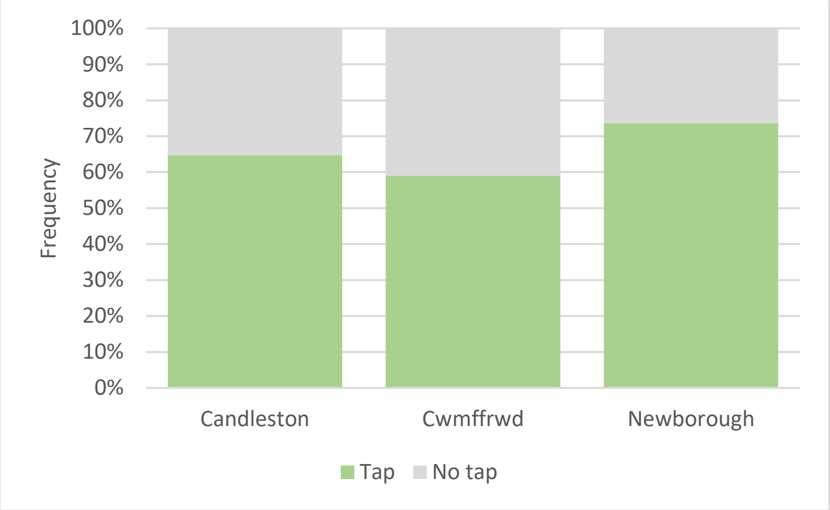


Figure 18: Proportion of trees with diameter increment capable of supporting annual tapping

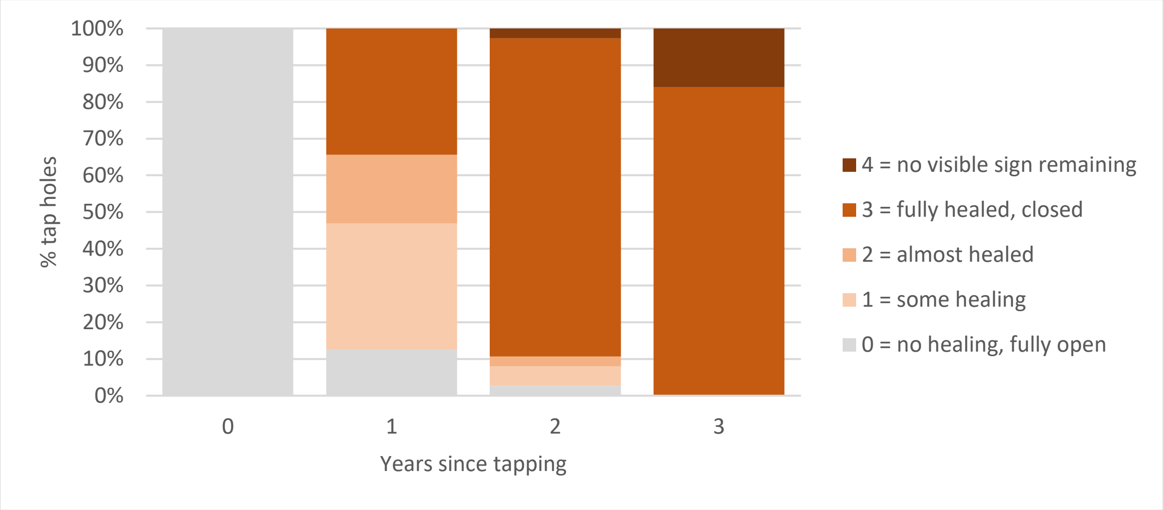


The model is relatively unsophisticated, simplifying growth to a constant rate rather than varying the growth rates as the tree matures and not accounting for differences in site type or species. However, the lack of species-specific yield studies for birch in Wales and generally in the UK mean the only way to improve on models would be to monitor growth over a number of years. Such data could then be used to create site-specific models to estimate yields and parametrise sustainable tapping regimes to properly underpin a birch sap industry in Wales.

For now - the model suggests that the yield class estimates of growth potential are not a wholly reliable guide to the sustainability of sap production; Newborough given YC8 has a greater proportion of fast-growing trees than Candleston and Cwmffrwd both given YC 10. To be able to assess sustainability of repeat tapping we therefore need individual tree growth rates, which is not very practical. We may also be able to achieve sustainable tapping of slower growing trees by tapping less frequently than every year.

The tap wound monitoring shows that trees vary in the progress of wound closure (Figure 11) and intuitively the fastest growing trees should close first. We can therefore use the progress of closure of the last tap hole as an indication that the tree has grown enough to be tapped again. Trees were tapped in 2019 and 2020 by the previous Dewis Gwyllt project and these trees were revisited and the tap holes inspected. The progress of wound closure derived from the Dewis Gwyllt and EIP trees is given in Figure 19, and shows that the majority of taps will be closed over the second year after tapping. Any tap which remain open beyond two years is likely moribund and should not be tapped.

Figure 19: Tap hole closure by year since tapping

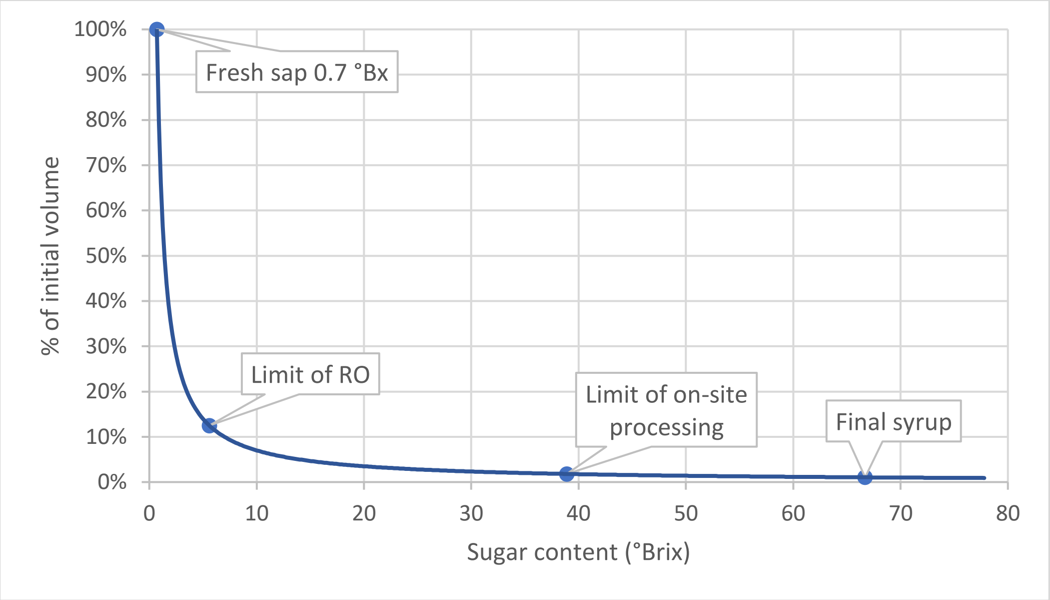


Taking Figure 11 as a guide, it seems likely that the proportion of trees which can be tapped annually will vary by site. Getting to know the site and trees will greatly assist the development of management strategies and forward projections of sustainable yields.

6 Processing sap to syrup

Processing fresh sap into syrup is usually a multi-stage process as initially large volumes of water need to be removed and at the later stages care is needed to keep temperatures low to prevent burning the sugars and spoiling the syrup. There are a number of manuals to production of syrup from north America (e.g. Beaumont 2010 and Farrell 2013). Many of these describe larger scale continuous commercial production that takes sap directly from the tree down a network of lines through reverse osmosis (RO) and on into evaporation pans. This is a costly set up and requires tapping of 1000’s of trees. This is inappropriate for the type of small scale on-farm production considered more appropriate for Wales. However, there are also artisanal processing systems which could be adapted for use in Wales described in a number of handbooks e.g. Casio (2020), Skinner (2018) and Dixon-Warren (2010). The EIP project therefore undertook to trial processing systems for fresh sap which could help stabilise the highly perishable fresh sap and reduce the volume for storage on-farm. The concentrate could then be sold on or taken to a commercial kitchen for further processing and finishing. Figure 20 shows the process of making syrup from sap. The processing trials undertaken by the project are concerned with the first stage processing from fresh sap to maximum of 38°Brix.

Figure 20: Turning sap to syrup



6.1 Methods

The EIP project planned to trial two types of processing systems by each group, but due to Covid restrictions and because Lower Pen y Graig joined the project late, this was not possible. However, Candleston and WRL were able to do additional trials in year one and sufficient trials were carried out by the end of year two. Table 8 gives a summary of all the processing trials that were performed.

Table 8: Summary of processing system trials

Processing equipment	**Number of tests and total volume processed**								
	Newborough		**Candleston**		**Cwmffrwd**		**Lower Pen y Graig**	**Additional tests by WRL**	
	2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2022**	**2021**	**2022**
Reverse osmosis	RB5	RB5	Pentair	Pentair		RB5		RB5	
N tests	28	14	11	13		14		5	
Volume (litres)	369	1981	222	306		2471		831	
Catering Urn			Adexa	Adexa	Buffalo		Adexa	Buffalo	Buffalo
N tests			6	2	7		2	11	1
Volume (litres)			1281	191	250		721	2621	12
Wood stove									
N tests		1	3	1		14		3	2
Volume (litres)		53	80	171		247		1461	1981

Three different types of processing equipment were tested:

1) Reverse Osmosis filtration (bespoke kit, utilising an adapted ‘Pentair’ water filter system and an ‘RB5’ off-the-peg system made by The ROBucket company imported from USA).
2) Large capacity (40 litres) Catering Urn (Adexa and Buffalo brands)
3) Outdoor, wood-fired stove (heating sap in two 45 litre 2/1 ‘Gastronorm’ brand stainless steel pans)

Processing was tested over a range of initial starting volumes of sap, sugar concentrations, raw and partially processed sap, and fresh and stored (frozen) sap.

For each trial, detailed notes were taken, including:

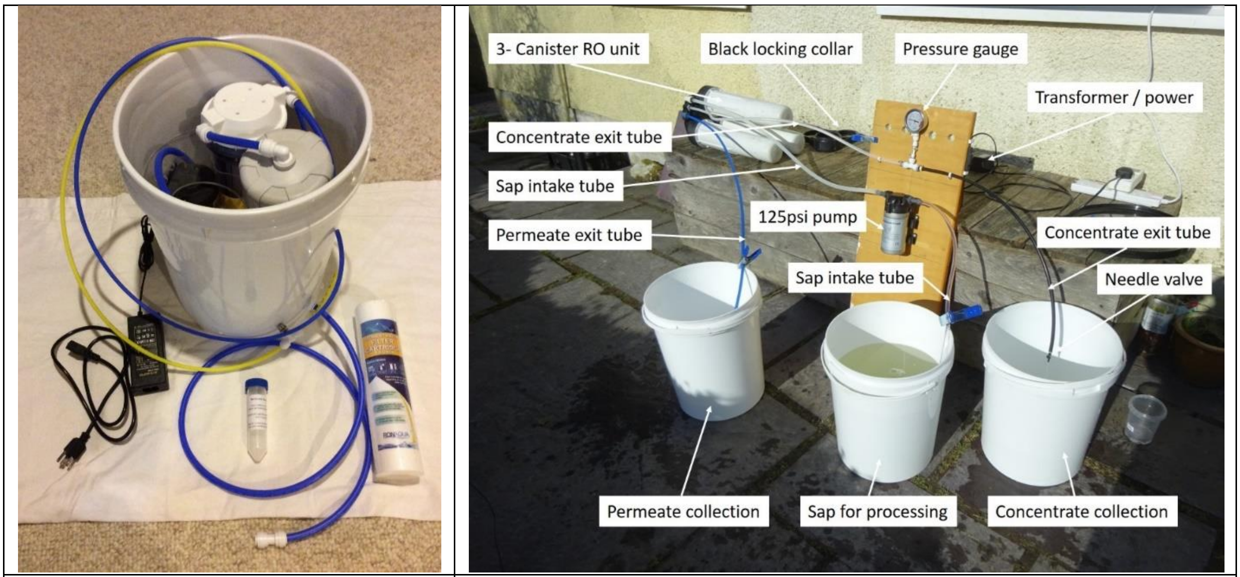
- Type of sap (fresh/frozen)
- Initial volume of sap and volume of concentrate produced
- Initial and final percentage sugar content (measured using a digital Brix% meter)
- Initial and final qualities of sap processed (notes on colour / smell etc)
- Length of time taken
- Estimated costs of fuel used (electricity / wood fuel)
- Notes on practicalities of using the different types of equipment

6.2 Reverse osmosis

RO is a well established method for concentrating fresh birch sap and has a number of specific studies. Kallio et al (1985) describes early trials of RO in Finland focussing on the effect of temperature and pressure on the concentration of sugars and minerals in the permeate. Later papers by Kallio (2013) and Bilek et al (2018) also report on concentration and composition of sap by RO. Wawer et al (2018) were more concerned with energy costs for RO and showed that it is a cost effective means of increasing sugar concentration to around 4% sugar. Unlike the other processes RO is a cold process which keeps the concentrate clear and so is a slightly different product. RO is now widely adopted by the maple and birch syrup processors and is a standard part of commercial processing.

There are a number of designs (e.g. Skinner 2018, Childs 2021) and self-help videos for home-made RO kits for use with maple sap. The intention was to commission the construction of such a kit using commercial filters and pumps. Using these resources a bespoke RO system was built from pre-used parts from a 'Pentair' domestic water purifier (Figure 21). These are commonly used for purifying aquarium water and by window-cleaners to remove impurities in cleaning water. This set-up has 3 x 2.6 litre chambers containing filter membranes. The first Carbon pre-filter was removed as per the Cornell University design, leaving 2 TLC-350 filters RO membranes. These filters are larger than the RB5 system and are capable of processing 150 litres per hour. The pump was also larger than the RB5 model (125 psi, 1.2 litres minute open flow)) and was not self-priming. A pressure gauge was also included to monitor the system. This system was supplied to Candleston.

Figure 21: Reverse osmosis kit



"RB5" RO kit

'Pentair' kit showing layout of pipes and collection buckets

During the early part of the project it was discovered that the RO Bucket LLC company in America was building off-the-peg RO kits in bucket specifically for use with maple sap. An “RB5” model was imported from the USA (Figure 21). This is the smallest model they produce and is designed for Maple syrup producers tapping 5-35 trees, and to process 5-8 gallons (23-36 Litres) of sap per hour. It has two filters: a basic 10” 5µm sediment pre-filter and an “8 gallon/hour” RO membrane. The pump is a self-priming 24v DC running off mains electric via a transformer. The only adaptation required was to add a UK-style plug.

The RO process was mainly tested with fresh sap which had been collected from trees 1 to 2 hours earlier. Fresh sap was emptied into a large bucket via an intake pipe that extracted sap via an electric pump. The sap was forced through the membrane(s) of the RO with pure water passing through the membrane into a ‘Permeate’ bucket, the sap, now with a higher concentration of sugar which didn’t pass through the membrane was collected in a third ‘Concentrate’ bucket. It was also possible to return the concentrate back into the first bucket and pass it back through the filters, thereby concentrating the sap further still. The RO system was also tested with a small number of samples of pre-concentrated sap.

For each run the initial volume of sap was measured and further measurements of the permeate and concentrate were taken during the run. Once the input bucket level fell to approximately 5 cm of the base of the bucket there was a risk air entering the system which could have damaged the pump, so processing was stopped at this point.

For each run the initial volume of sap was measured and further measurements of the permeate and concentrate were taken during the run. Once the input bucket level fell to approximately 5 cm of the base of the bucket there was a risk air entering the system which could have damaged the pump, so processing was stopped at this point.

Once the processing was complete, the concentrated sap was transferred into food-grade storage buckets before being frozen. The permeate liquid (purified water) was also stored and used to flush out the equipment before and after each processing session and in the case of Newborough used to flush out collection bottles and tap holes once the taps were removed.

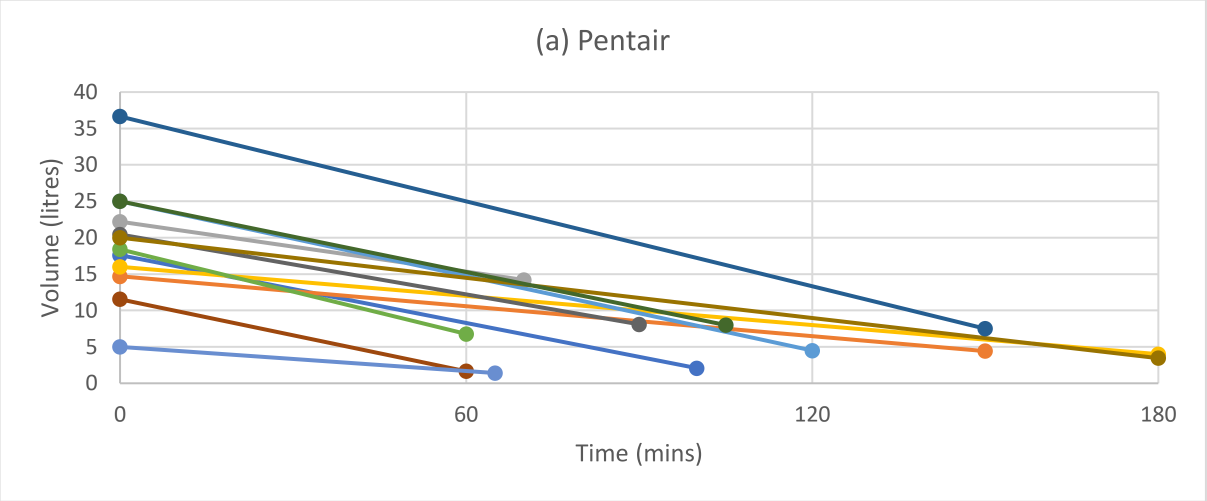
Energy consumption was derived from the power rating of the devices and/or a power consumption meter on the supply.

6.2.1 Sap concentration rates

After some basic training in how to use the equipment, the systems could easily be set up and run with minimal supervision. The main issues were ensuring the system was clean before any sap was run through, that all the intake/output pipes remained in the buckets, and the pump did not run dry.

During the project the OG’s recorded 56 trial runs through the RO systems; 43 through the RB5 and 13 through the Pentair. The OGs processed a range of volumes of fresh sap (5.0 to 36.7 litres) depending on what they had available and for different lengths of time (65 to 180 minutes) depending on how they preferred to use the equipment. Figure 22 gives the start and end volume against the duration of the run for all trials. The RO Bucket is especially designed for small volumes of sap and had faster pass-through rates for the Pentair. For a single pass (raw sap going once through RO) the average pass rate for the RO bucket was 10.4 litres per hour while for the Pentair the average was 9 litres per hour. Recycling the first pass concentrate back through the RO is a simple means of increasing the concentration but as the sugar content increases it becomes harder to force the water through the membrane. This is evident in Figure 22 with the longer runs have a lower volume reduction rate as the concentrate is recycled. For the RO Bucket recycling decreased the volume reduction rate to 8.3 litres per hour and for the one long run of the Pentair to 3.3 litres per hour. A single pass through on both machines raised the sugar content from an average of 0.6°Bx (note this included several samples with very low sugar content that in normal practice would not be considered worth processing – generally a cut off of 0.4 °Brix would be a sensible minimum threshold for processing) to 2.3 °Brix. Recycling can be done continuously by putting the concentrate back into the sap bucket or it can be done by saving the first run and running it through as a batch. In either case the final concentrate had an average of 4.9 °Brix which means an 87% reduction in volume.

Figure 22: Sap volume reduction vs time for reverse osmosis process



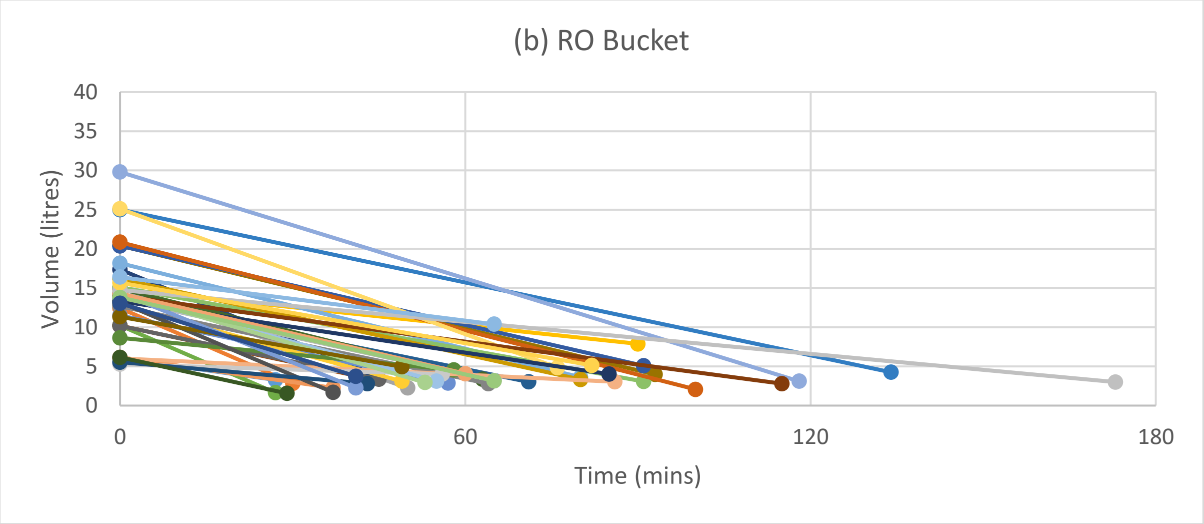
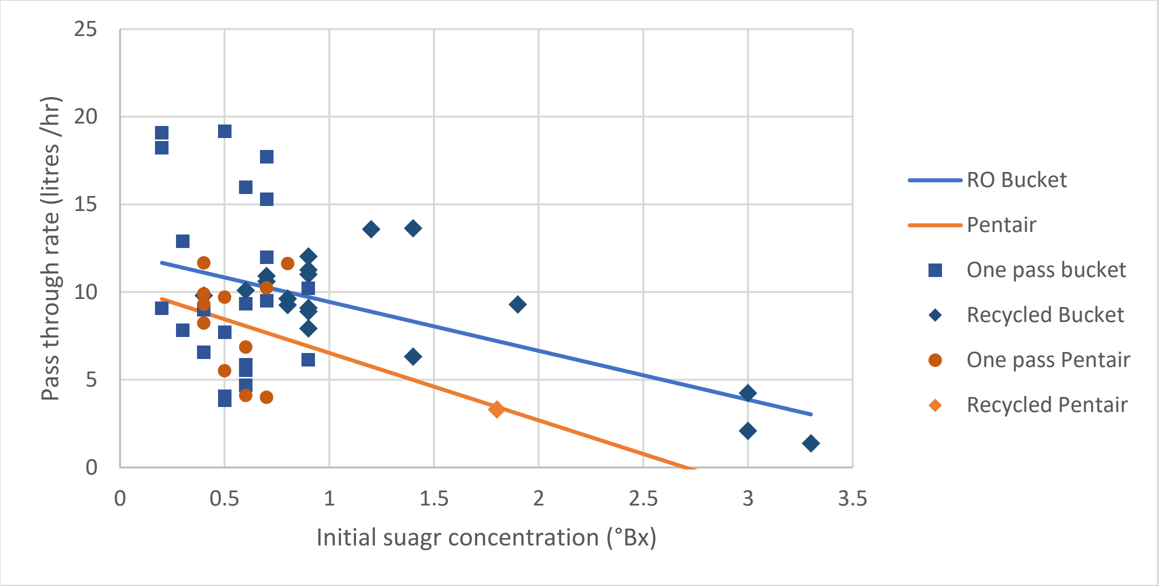


Figure 23 uses the variable starting sugar levels in the trials to demonstrate how initial sugar content influences the volume reduction rate. This can be used in planning to provide an estimate of how long passing a set volume through the equipment will take or how long recycling should be run to reach a target sugar content.

On average the OGs processed a starting volume of 16 litres of liquid sap at a time and ran the RO for 77 minutes (1 hour 17 mins) to reduce the initial sap volume down to 4.6 litres (a reduction of 69% i.e. to 31% of the start volume) (Figure 23). The average sugar content of the sap after processing was 2.3°Brix but by recycling concentrate several OG's achieved final sugar content of 4.9°Brix.

Figure 23: RO pass through rate against sugar content



In these trials most groups collected relatively small amounts of sap each day and the levels remaining in the concentrate bucket quickly became too low to recycle and keep the pump primed. When larger volumes of sap were available it was possible to continue recycling the sap until a final sugar concentration of 5°Bx was achieved. Processing of concentrated sap (up to 3.3°Bx sugars) appeared to take longer to reach a similar reduction in volume, though the number of tests was low.

There were indications that the Pentair system was slower at processing the sap than the RB5 system (Figure 23). The Pentair system was also less efficient at processing small volumes of sap as the three-chamber design meant that some sap was always left behind inside the equipment. This volume was more significant when small amounts of sap were processed.

Provided care is taken to ensure all containers were large enough to hold the amounts generated, and pipes were held in place well then the equipment requires little or no supervision whilst it is running. However, some cleaning of the equipment after each use is essential to prevent microbial build-up that could contaminate the sap. Flushing with permeate and rinsing the buckets usually took an additional 10 to 15 minutes each day.

At the end of the sap collection season a more thorough clean of equipment requiring a specific cleaning mixture was needed before the equipment was stored away. The pre-storage clean took between 1 and 2 hours.

6.2.2 Energy costs

Energy costs were directly related to the length of time that the RO units were run. However, the only energy consumption come from running the small electric pumps, the largest of which was rated at just 13.1W. Consequently, electricity consumption was negligible, usually at <£0.01 for each trial.

6.2.3 Observations

Both models of Reverse Osmosis equipment worked well and required only a small amount of training by the operators before the systems could be run with minimal supervision. These systems were clean and could be run indoors if necessary although some small spillages of sap or permeate are likely to occur, so outdoors might be preferable.

Processing moderate volumes (~40 litres) of sap should take less than 4 hours, but energy consumption is low, and very little supervision is needed provided care in setting up is taken and sufficiently large buckets are used to deal with the volume of permeate produced

In this trial, groups only tapped between 10 and 14 trees, so the volume of sap to be processed each day was only about 15 to 21 litres. Processing such small quantities using RO is inefficient, as a significant portion of the sap is left inside the equipment each day, and this must be discarded. Consequently, the larger the volumes to be processed, the better. Because only small amounts of sap were processed, few tests of recycling the concentrate could be carried out, however, there are indications that if processing could be continued then final sugar concentrations of >5% might be achieved, relatively easily. However, this may have an impact on how long the membranes would last before they needed replacing. Replacement membranes can be expensive (£45 for RB5, £114 each for Pentair) and care needs to be taken to preserve their functionality.

For comparison with other processing systems, with the reverse osmosis system, a 50% reduction of the initial sap volume would, on average, be achieved in 50 minutes for the 'RB5' and 70 minutes with the 'Pentair'. 30 litres of sap could be reduced by 70% in volume in between 90 minutes (RB5) and 100 minutes (Pentair). The average volume reduction rate was 9.5 minutes per litre.

6.3 Catering urn

Two models of large volume catering urns were tested (Figure 24):

1) 'Buffalo' brand 40 litre capacity catering urn. This is a manual fill electric steel urn with an internal element, rated at 2.6 kW, with a thermostat control temperature range from $39^{O}C$ to $100^{O}C$. Two units were purchased in early 2021 costing £136 and £161.
2) 'Adexa' brand 40 litre capacity catering urn. Also, a manual fill, electric urn with an internal element, rated at 3 kW, and with a temperature range of approximately $39^{O}C$ to $110^{O}C$. This model also has a visual level gauge showing how much liquid is inside. Purchase cost was £119 in 2021.

Both types of urn could be run on-site (i.e. in the birch woodland) using AC electricity produced by a portable generator, but this was not found to be necessary, as processing was usually done at the farm/home where mains electric was available. The 'Buffalo' urn was tested at Newborough and Cwmffrwd, and also by WRL at their offices in Mynydd Llandygai. The 'Adexa' urn was tested at Candleston and Lower Pen y Graig. Both urns were tested side by side by LlyG at their offices in Machynlleth.

Figure 24: Catering urns used in sap processing trials

Buffalo 40 litre urn

Adexa 40 litre urn with level gauge

As expected, sap processing produced large amounts of slightly sticky steam. In one case the urn was set up in the porch of the farmhouse and the drift of steam into the house during the hours long boiling was considered unacceptable. To dissipate the steam, it was recommended that the urn was operated outdoors (Figure 25) or under cover. Since the trials were in March the ambient outdoor temperature was quite low and was occasionally blustery or dank with high humidity. To counter this, for some trials an insulated jacket made from temperature-resistant foam was improvised to reduce heat loss from the exterior of the urn. WRL also trialled a battery-operated automatic pot stirrer (Figure 25), to agitate the sap in the urn in the expectation this would improve the rate of evaporation and reduce processing time.

The initial volume, sugar content, duration and end volume and sugar content were recorded for 29 trial runs. Energy consumption was derived from a power consumption meter placed between the urn's plug and the power socket.

Figure 25: Catering urns in use

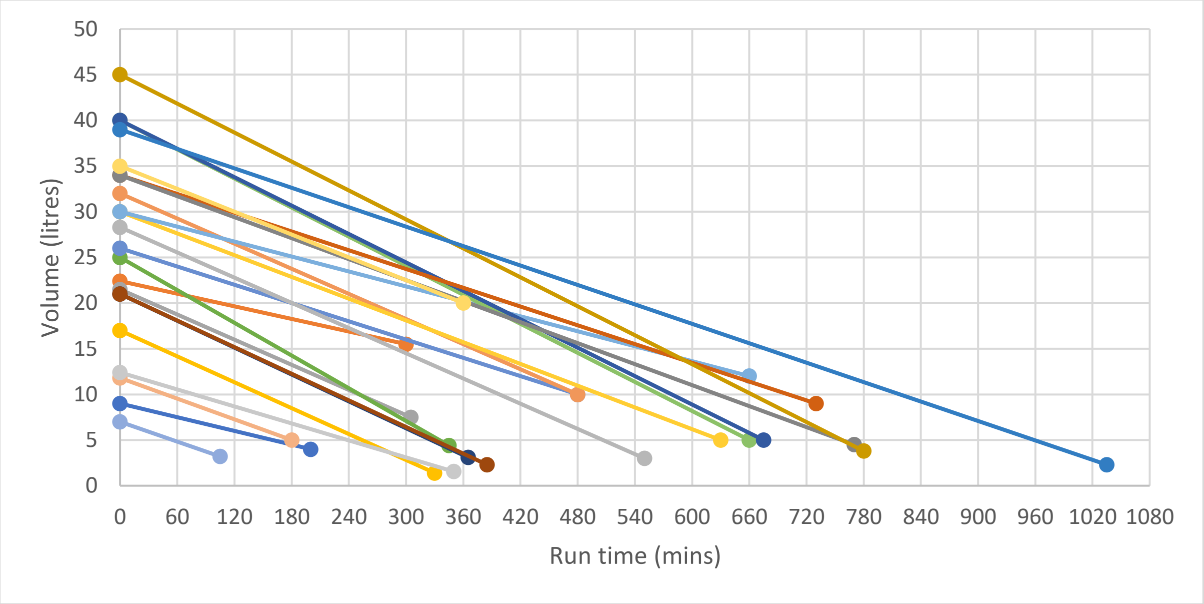
Urn in use

+ insulating jacket and battery-operated stirrer

6.3.1 Evaporation rates

Given on-site training in the use of the urn was not possible due to covid restrictions and the natural adaptation of processing to fit each OGs circumstances there was a fair amount of variation in the operation of the urn. For example, on some occasions the run commenced with defrosting sap, while for some sap fresh from the tree was placed in the urn. The starting sugar concentration would vary from fresh sap to concentrate from RO or output from previous runs. The duration of the boil down could also be set times or left to run until a target sugar concentration was achieved. Ambient conditions might also be warmer or cooler and there are differences in the maximum temperatures and power output of the two brands of urn. On top of this record keeping was in some instances imprecise. After screening out the seven trials which gave anomalous results we had 22 useful trial runs as shown in Figure 26. These are obviously not perfectly scientific trials but do mimic 'real life' scenarios and the generalised results are a useful indication of how urns can be expected to perform.

Figure 26: Performance of urns in reducing sap volume in 22 trial runs

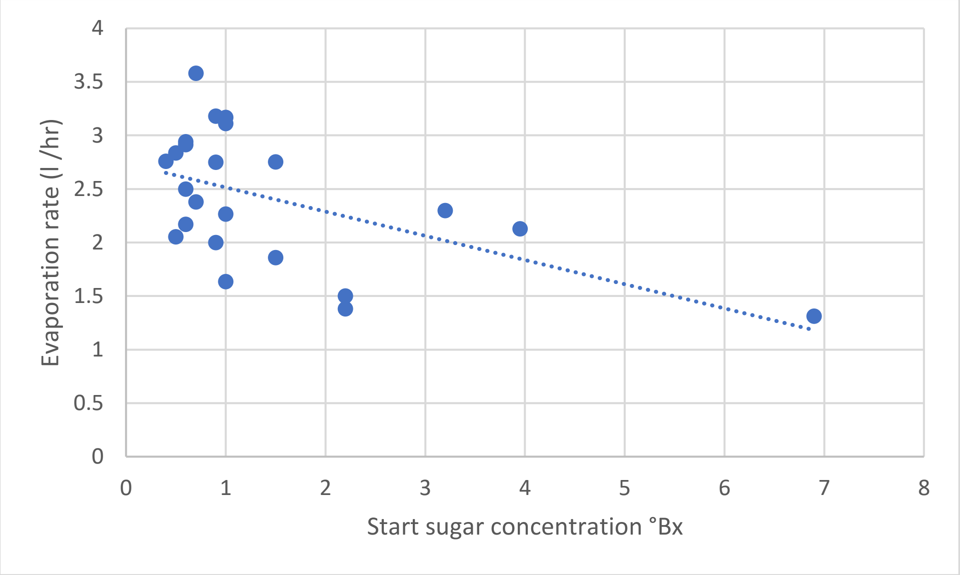


On average, the OGs processed a starting volume of 27 litres of sap at a time and this took approximately 8 hours to reduce the initial sap volume down to 6 litres (a reduction of more than 75%).

The evaporation rate is related to sugar content (decreasing at higher concentrations as shown in Figure 27) and also more generally depending on the thermostat settings used and the ambient temperature – if the urn was run outdoors, especially in cold/windy conditions. The evaporation rate is also constrained as the sap level falls by the deep urn preventing rapid escape of steam.

The average evaporation rate across all trials was 2.6 litres per hour and this is useful rule of thumb for practical back-of-the-envelope planning.

Figure 27: Relationship between sugar concentration and evaporation rate for both catering urns



The side-by-side comparison of the two urns gave the Adexa urn a distinct advantage with an average evaporation rate over a five-hour run that was at least 50% faster than that for the Buffalo. This is because the Adexa had both a higher power rating (3 kW) and a higher maximum temperature (110°C) than the Buffalo (2.6 kW and maximum of 100°C) so could more easily keep the full urn at a rapid boil.

The automatic pot stirrer was considered beneficial, by reducing processing times, possibly by 10%. Unfortunately, the only model available was battery-operated and could only run for about 150 minutes before it needed re-charging. If a fully mains-operated model was available this would be more useful.

Setting up the urns was very quick and easy, and at the end of processing each day, the urn only needed a quick rinse with clean water. At the end of the sap collection season, the urn needed a more thorough clean to remove any burnt sugars on the inside surfaces, especially near the heating element.

The main drawback with the urn was the deep container which gave rise to very long run times, but the thermostat meant that supervision during runs was minimal and in a secure location the urn can be left to boil down all day.

6.3.2 Energy costs

The two urns tested had nominal power ratings of 3.0 kW (Adexa) and 2.6 kW (Buffalo) when running on the maximum temperature setting, but in trials the average consumption was approximately 1.8 kwH. Initially, to ensure the sap did not burn, lower thermostat settings were used, but as the OGs gained experience of using the urns, they were safely run at the highest temperature setting for more of the processing time without burning the sap.

Energy consumption was directly related to the length of time that the urn was on. There was some variation in energy consumption depending on the thermostat setting used and the ambient temperature (some trials took place outdoors where low air temperatures and wind may have had a cooling effect).

The higher rated Adexa unit was able to support higher evaporation rates than the Buffalo. However, this didn't easily translate into a clear cost advantage. The purchase cost of the Adexa unit was 20% cheaper but power costs were 16% higher though with higher evaporation rates the run time is also expected to be shorter. In the end the processing cost per litre of fresh sap in the urns was 15p for the Buffalo and 16p for the Adexa. Cost differences are relatively small and it is the time saving with the Adexa that is likely the most important component of a preference for a higher rated urn.

In the trials, at £0.17 per unit (unit cost at the time of the trials) an average run (approx. 8 hours) cost approximately £2.72 in electricity. To reduce a full urn containing 36 litres of sap down to 8.5 litres (70% reduction) would be expected to take 650 minutes (just under 11 hours), which is probably the limit of what is practical. The cost of processing this volume would be approximately £3.33 (2021 prices).

6.3.3 Observations

Processing a moderate volume (~30 litres) of sap took a long time (~10 hours) and energy costs are high. Using urns for processing larger quantities of fresh sap with a low sugar content might be impractical due to the cost of electricity through they have the advantage of requiring little supervision. This type of urn may prove more useful for processing sap with a higher sugar content – e.g. sap that has been reduced by reverse osmosis.

In this trial, OGs only tapped between 10 and 13 trees, so the volume of fresh sap to be processed each day was generally only 15 to 21 litres. This may be feasible to process each day using a catering urn, or sap could be frozen and combined for processing. However, if tapping was scaled up to more than 25 trees a single catering urn system for primary concentration would not seem practical.

6.4 Wood-fired stove

Wood-fired stoves are often used by Maple syrup tappers in USA and Canada, often in cabins popularly known as 'Sugar Shacks' It was hoped that a similar system could be set up and the birch sap processed by volunteers in the woodland. Unfortunately, due to Covid restrictions communal outdoor boil-downs using volunteers could not proceed, so testing of an outdoor wood-fire to 'boil-down' sap was somewhat limited. More tests (which were open to the general public) were carried out in the 2022 tapping season.

A design for an outdoor stove developed from those used in north America (e.g. Garbers 2000) was adapted for trials at Candleston and Newborough (Figure 28). The stove was constructed in a safe site in the woodland not far from the tapped trees, and comprised a fire-box made from 30 standard sized solid breeze-blocks, a metal grill to provide an air space beneath the fuel, and another to support the evaporation pans. As a safety precaution, the blocks were supported by 1.2 m metal stakes driven into the ground. The smoke from the fire was directed away using a 2.5 m length of flexible 125 mm flue-liner supported by metal stakes. The fire was controlled using moveable breeze blocks at the entrance to control air-flow, and by adding judicious quantities of firewood.

Figure 28: Wood-fired outdoor stove in use at Candleston

Wood stove system showing firebox | + two 45l Gastronorm pans

The fire was lit approximately 30 minutes before sap processing began to allow the fire to become established along the length of the firebox. The trays were then placed in position and fresh or partially de-frosted sap placed in them. As far as possible, the trays of sap were heated evenly to prevent the base of the trays scorching. Small amounts of fuel were added at regular intervals and if the fire became too vigorous, the entrance was partly blocked to restrict the air flow using spare blocks. Once the pans were boiling evenly, the fire could be stoked and then the system left for up to 60 to 90 minutes at a time. To prevent the sap getting too low in the trays and burning at the edges, additional sap was added when the levels got low. When there was insufficient sap to run two trays, the fire was pushed to the rear, and the remaining sap was combined and heated in a single evaporating pan.

Energy consumption was measured by estimating the weight of wood used by counting the numbers of pre-weighed bags or weighed barrow-loads of kiln-dried firewood.

6.4.1 Evaporation rates

Some time was needed at the beginning to get the fire burning steadily, but once this was done the stove could be run with just occasional supervision. The main issues were ensuring the fire kept burning evenly and along the length of the trays and the sap levels did not drop too low Any smoke from the fire was ducted away from the sap via the flue and the process did not appear to add any ‘smokiness’ flavour to the final syrup.

Ten trials were carried out, processing a range of initial volumes of sap from 15 to 171 litres as shown in Figure 29. The starting conditions for the sap for each trial where a little different in that some commenced with defrosting frozen sap and some with concentrate at different sugar concentration that had already passed through RO. In common with the other systems, evaporation rates were lower at higher sugar concentrations though this is less useful as an indicator of run times as it was because it was found to be most efficient to keep the stove running for longer periods of time and to top up the pans with fresh, defrosted and even frozen sap until the final few hours of the run, so sugar concentration varied throughout the run. As shown in Figure 30 the longer the stove was lit the more efficient it became with high average evaporation rates once the stove is hot and pans boiling hard making up for the time taken to get the fires burning and the sap defrosted.

Figure 29: Processing times for wood-fired stove

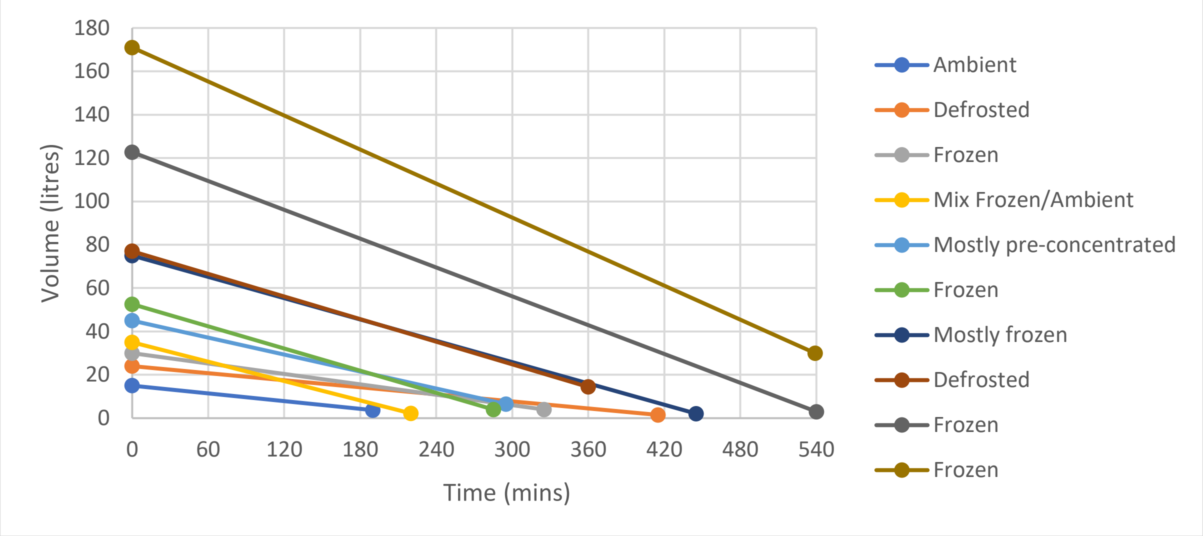
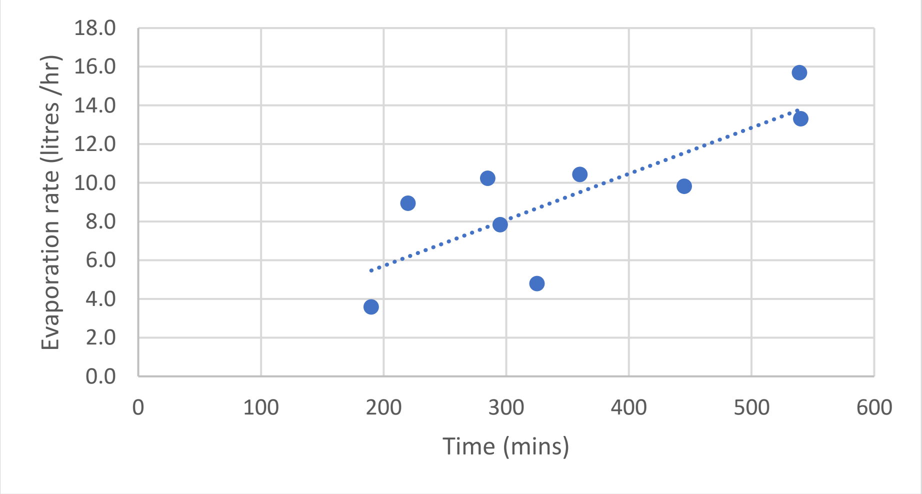


Figure 30: Evaporation rate vs burn time for wood stove



On average, each trial processed a starting volume of 65 litres of liquid sap. Processing took approximately 360 minutes (6 hours) to reduce the initial sap volume down to 7.1 litres (a reduction of 89%). The average evaporation rate from the pans was 8 litres per hour.

For comparison with other processing systems, in one trial 35 litres of fresh sap was reduced to 2.2 litres (i.e. 94% reduction in volume) in approximately 220 minutes (3 hours 40 minutes). The average evaporation rate was 9 minutes per litre.

A final sugar concentration of over 31% was achieved with careful supervision, and this took about 285 minutes (4 hours 45 mins) processing sap that had already been processed using RO. The maximum volume processed during these trials in a single day, using two evaporation pans was 171 litres, and this took just under 9 hours.

Additional time (approx. 20-30 minutes) was sometimes needed at the start of the process to get the fire burning steadily depending on weather conditions (amount of wind). Some time is also required at the end to clean off any residues from the inside of the Gastronorm trays. This is important, as burnt-on sugars from the sap can encourage the production of unwanted 'sugar sand' and encourages further scorching next time the trays are used.

6.4.2 Fuel costs

Fuel costs for running the stove can be extremely variable depending on whether bought-in kiln-dried firewood is used, or thinnings / scrap wood which might be much cheaper or even free. For the trials, kiln-dried high quality birch wood was used as the fuel (£140 per 525kg) and it is anticipated that most birch tappers might have access to dry firewood much cheaper than this.

In the ten trials carried out it appears that costs (using bought-in, kiln-dried firewood) were in the region of £25 to £35 (2021 fuel prices) to process two full trays (80 l) of sap. Fuel consumption was approximately 12kg of firewood per hour, equivalent to £3 per hour.

6.4.3 Observations

The design of the 'version 2' stove with a lower firebox seemed to work well and was very easy to construct (and dismantle if need be). The breeze blocks appeared to withstand the heat fairly well. Fire-bricks will likely last much longer, but are much more expensive.

It is envisaged that processing the sap using an outdoor stove could be run as an all-day social event, possibly run by volunteers when carrying out other work in the woodland. This was not possible during trials, but appears feasible. Two outdoor boil-downs were carried out as public events and there is additional potential when using this processing method for generating interest in birch syrup production.

Evaporating the sap using the large Gastronorm trays appears quite efficient due to their large surface area, and little supervision is required until fluid levels begin to get low and the risk of burning the sap increases. This system would appear to work best when large quantities of sap need to be processed as more sap can then be added throughout the day to ensure fluid levels are kept high. With careful supervision it is possible to achieve high final sugar concentrations though care must be taken to ensure sap does not get burned, which can affect the syrup flavour.

6.5 Cost benefit analysis

By far the quickest and cheapest, was the reverse osmosis system. However, this has only been tested with relatively small quantities of sap and the final sugar concentrations have been low. Nevertheless, with the small numbers of trees tapped by each of the groups, processing using RO was considered extremely useful in reducing the volume of sap needing to be frozen each day. Although only a limited number of tests of the wood-fired stove could be carried out, this also seems to have significant potential in processing raw sap to high sugar concentrations before leaving the farm gate. The catering urn system would appear to have the least potential for processing large quantities of dilute sap due its slowness and high energy consumption. However, initial purchase and on-going maintenance costs are relatively low and may still suit groups tapping only a small number of trees. There are clear pros and cons between the processing systems, as shown in Table 9.

Table 9: Comparison of results from the different sap processing systems

Aspect of processing	Reverse Osmosis	Catering Urn	Wood-fired stove
Initial purchase cost of kit	£388 - £500	£119 - £161	£380 including new bricks, flue and evaporating pans
Ongoing running costs	Replacement membranes: £114 x 2 (Pentair) £45 x1 (RB5) + £1.20 each for pre-filters x 3 per season	Low? No recurring costs to maintain, and should last 5-10 years?	Periodic replacement of heat-damaged components (blocks and grills)
Reduction in volume over average trial run	To 29% of start (average)	To 75% of start	To 89% of start
Approx. time to reduce volume by 1 litre	7 minutes	23 minutes	6.5 minutes
Approx. time to reduce 30 litre sap volume by 50%	95 – 100 minutes depending on RO system	~600 minutes depending on temperature setting. Plus 15-30 mins if sap processed from frozen	~180 minutes once fire running well
Average energy cost per hour	£0.01 - £0.03 Negligible	£0.45 (at £0.17 per unit) To £1.02 (at £0.34 per unit)	0 (if free fuelwood available) - £3.08 (2022 prices ~2x this)
Maximum sugar concentration achieved	5%	28%	30%
Supervision required during processing	Some, mainly towards end	Some at beginning & towards end	Regular checks every 30 mins throughout
Most efficient sap volumes for processing	50 to 100 litres	~30 litres per urn	150 to 200 litres

7 Prospects for birch tapping in Wales

The EIP project and the Dewis Gwyllt project have between them amply demonstrated that birch sap yields from trees in Wales are comparable to birches in north America and northern Europe. A model adapted from one developed in North America for sugar maple indicates that tapping is likely to be sustainable over several years for fast growing, healthy trees. Good practice and practical advice on responsible tapping is given in the accompanying *Manual*.

The barrier to small scale collection posed by the perishable nature of sap can be overcome by immediate processing to reduce volume and increase sugar content prior to preservation by freezing. This can be achieved by evaporation or reverse osmosis with the latter being the most practical and cheapest. Further concentration using evaporation on a wood stove or in an urn can be done on-site before transport to a commercial kitchen for finishing. The costs and benefits of the wood-stove and urn are quite distinct and enable processing in a variety of contexts which means processing is available to a wider group of potential producers. A description of all three methods is given in the accompanying *Manual*.

Birch tapping and processing is very seasonal and requires daily attention for a few hours for about four weeks in March. It is estimated that around 30 trees would provide about 6 litres, of high value syrup.

Market trials suggests there is interest in Welsh birch syrup though further work on pricing and sales strategy would be beneficial. Creative marketing and value addition is possible for a single producer. However, for those with less time to invest in marketing there maybe the potential for a number of producers to co-operate to gain economies of scale in finishing (often just a few litres of syrup each), promotion, branding and marketing. An outline of a marketing and business plan is given in the accompanying *Birch sap start up support*.

There is a plentiful birch resource in Wales much of it in small woodlands which offers the opportunity for many small producers. Entrants may require some mentoring in the first year but tapping and on-site preservation is straightforward.

Income from birch may provide an incentive for retention and pro-active management of birch scrub. It may also provide a future income stream from new woodlands which should have negligible impact on carbon sequestration or stores. Increasing productivity of sap requires thinning which would generally increase growth rates which should be entirely in keeping with management of woodlands for which carbon credits have been sold. A section on woodland management and creation is included in the accompanying *Manual*.

The proposal to include sap as a forest product in UKWAS 5.0 opens up the possibility of larger scale birch tapping in the large, commercial and certified forests. Development of tapping in larger forests under permit would allow larger scale production which could help launch birch sap products. However, it seems likely that this would only be done under permit by third party tappers. Taking advantage of this opportunity would require a different type of entrepreneur and likely a larger investment in a more technocratic approach to harvesting and processing. Options for this scale of development were not addressed in the EIP project but there is a large body of experience on this for maple and birch to draw on.

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Appendix 1 Methods for site and tree descriptions

Tree data	EIP 2021-22
Tag number	Sequentially numbered aluminium tree tag
GPS location	Waypoint on Garmin 78s
Betula species	Scoring of characters in field and examination of leaf and twig samples in summer following tapping
Number of stems per tree	Restricted to single stemmed trees
Diameter	Diameter tape to nearest mm at 1.3 m
Tree height (m)	Measured using a wedge prism relascope from 15-20 m from the tree
Live crown height (m)	Tree height – height of lowest green leaves
Height of lowest green leaves (m)	Measured using telescopic pole or with relascope
Canopy extent (m^2)	Distance (m) to furthest green leaves to N, S, E & W of trunk
Canopy volume (m^3)	Calculated as volume of ellipsoid volume
Stand density immediately around tree (m^2ha)	Angle gauge sweep around tree
Understorey	Notes
Ground flora	Notes

Appendix 2 Protocols for sap collection

The intention for the project is to a) trial different on-site sap processing systems to reduce the volume of the pure sap collected prior to freezer storage for boil-down to syrup at a later date. And b) to look at potential detrimental effects on the trees tapped by observing growth parameters including tree health, time of bud break, leaf growth and damage from tapping hole wounds.

Three different processes are to be tested:

a) Reverse Osmosis (RO) micro-filtration
b) Large electric catering urn
c) Wood-fired outdoor hearth

For each system tested, at least 2 batches of approximately 40-50 litres of pure sap should be processed to reduce the water content of the sap and to increase its sugar concentration. Depending on the processes tested, this will require approximately 100 - 280 litres of sap to be collected. Previous tapping of Birch has shown that 200 litres might be achieved by tapping 10-15 trees. Ideally, for the tree health measurements, at least 10 of these should be trees that have not been tapped previously. In year 2, five new trees will be tapped for the first time (replacing 5 trees previously tapped in year 1). So ideally, a minimum of 15 healthy, previously untapped trees >20cm diameter are needed altogether. In addition, for comparison, 15 healthy trees of similar size should be identified to act as 'controls'. These will not be tapped during the project period and should be in the same general location as the tapped trees.

If possible, to look at potential staining damage / rot caused by the tap-hole wounds, a small number (2- 5) of the tapped trees will be felled and cross-sectioned in Autumn 2021.

Data collection

1) **TREE INFORMATION**: All the trees (tapped & controls) need to be tagged with a unique number and mapped using a GPS. Measurements such as crown scoring, dbh etc. will be carried out by the technical consultants (Bryan/Jenny) to ensure consistency between sites.

2) **TAP RECORDS**: Once trees have been selected, tagged, a record of the date and precise location & description of the tapping should be recorded (see attached sheet)

3) **SAP PRODUCTION**: Once the sap is flowing, the amount of sap (volume or weight) from each tree should be recorded on the recording sheets provided. The sugar % from each tree should also be measured if possible. A record of any changes in colour of the sap and length of the flow season is also needed.

4) **PROCESSING SYSTEMS**: what is needed for each system is a record of:

- Preservation time to produce concentrate from sap
- Logistics
- Operating costs – in particular fuel costs
- Product quality e.g. total sugar content, colour and taste

See attached record sheets to assist in this. Any experience acquired whilst using the different systems that could help improve their efficiency will be really useful.

After processing, the concentrate or "semi-syrup" should be cooled and then stored frozen until arrangements can be made to complete the processing into Birch syrup.

TREE information	
Site	Tree TAG #
Tree species (*Betula pubescens/B. pendula*?):	OS Grid Ref (GPS Waypoint)
Tree Location notes:	
Form, Canopy & Health notes	
DBH (cm)	m to nearest tree >10cm dbh
Understorey vegetation (up to 1.5m high)	Ground vegetation (<30cm high)
Other notes	

<table>
<tr><td colspan="4">TAP information</td></tr>
<tr><td>Date of first tap</td><td></td><td>Time of first tap</td><td></td></tr>
<tr><td>Aspect of tap</td><td></td><td>Tap depth (cm)</td><td></td></tr>
<tr><td>Height of tap (cm)</td><td></td><td>Photos?</td><td></td></tr>
<tr><td colspan="4">Tap positioning (N,S,E,W, below branch etc.)</td></tr>
<tr><td colspan="4">Tap system</td></tr>
<tr><td colspan="4">Notes</td></tr>
</table>

<table>
<tr><th colspan="4">Tapping notes</th></tr>
<tr><td colspan="3">Site</td><td>Date</td></tr>
<tr><td colspan="3">Weather on day</td><td>Weather Previous 24hrs</td></tr>
<tr><td>Temp MIN</td><td>Temp NOW</td><td>Temp MAX</td><td>Precipitation previous 24hrs</td></tr>
</table>

Sap collection notes

Tree TAG #	Time	Litres / kg	Sugar%	Sap appearance / Notes

Processing System notes: Catering Urn

System name & reference #			
Site name			
Date			
Sap: Fresh / Frozen / Mix		Initial sap temp ^{O}C:	
Start time		End time	
Initial sap volume		Final sap volume	
Initial sap % Sugar		Final sap % sugar	
Time to reach 50% volume		Photos?	

Time	Activity / Notes	Level (cm)	Setting	Temp	Sugar%

NOTES:

Processing System notes: Wood fired Hearth

System name & reference #			
Site name			
Date of use			
Start time		End time	
Initial sap volume		Final sap volume	
Initial sap % Sugar		Final sap % sugar	
Initial sap temperature ^{O}C		Photos?	
Fuel description			
Time	Fuel used (standardised volume or weight e.g # of measure wheelbarrow loads)		
TOTAL amount of fuel used:			
Time	Activity / Notes		
NOTES:			

Processing System notes : Reverse Osmosis

Date:				
Model:				
Sap:				
Weight / Volume	Bucket	Liquid+Bucket	Liquid	
Start Weight Sap (S):				
End weight Concentrate (C):				
End weight Permeate (P):				

Time	**Sample S/C/P**	**% Sugar**	**TDS PPM**	**EC**	**Temp °C**	**Weight Kg**	**Pressure gauge**	**Notes**

Additional notes: