Herbicide-free and plastic-free woodland creation: investigating the ecological, economic and efficacious benefits

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Executive summary

Woodland establishment in the UK still relies largely on using plastic tree guards and controlling grass weeds around newly planted trees with a herbicide for the first two to three years after planting. As part of a larger Glastir Woodland Creation project, we trialled different methods of plastic-free and herbicide-free tree protection, including biodegradable tree guards to protect trees and clover-rich cover crops and grass mulch to supress grass weeds. It was clear that clover-rich cover crops can be easily established for less than £200/acre and can be a helpful tool in reducing grass weeds in at least the first year after their establishment. Assessing the ecological, economic and efficacious benefits or disbenefits of the different measures of tree protection is part of a long term, landscape-level project. However, all tree guards were intact at the time of writing this report – almost one year after planting.

Introduction

Reducing synthetic chemical and plastic pollution in our woodland soils is vital to conserve productivity (Jones *et al.*, 2020) and promote valuable ecosystem services (Beynon *et al.*, 2015). Woodlands are of key importance in our landscapes, providing corridors for dispersal of many taxa (Diekotter *et al.*, 2008). The effects of synthetic chemical and plastic pollution may be prominent in woodland soils, as soil microbiomes are highly diverse, complex and sensitive to microplastic pollution (Shi *et al.*, 2022).

While research has demonstrated that some biodegradable mulches and cover crops can effectively suppress weed growth around trees (McCarthy and McCarthy, 2005 and references therein), no comprehensive study exists demonstrating the effectiveness, ecological impacts and economic viability of biodegradable tree guards, mulches and cover crop options for replacing plastic tree guards and herbicides during woodland establishment (search completed on Conservation Evidence, 2022).

At a time when Non-Governmental Organisations (NGO's) and governments of the UK are pledging to increase woodland planting through initiatives like the Wales National Forest, England Trees Action Plan and the Woodland Trust's commitment to plant 60,000 hectares (ha) of native woodland, we must ensure environmental health is promoted throughout the whole creation process. Generating a model for plastic- and herbicide-free woodland creation, that is successful, cost-effective and can maximise soil health, will have landscape scale benefits applicable across the UK and for many governmental and non-government bodies. Whether the purpose of the woodland is carbon storage or biodiversity, soil health and faunal diversity is paramount to the long-term ecosystem health.

We present qualitative and quantitative information learned from our experiences during woodland establishment. This report comprises of information from the larger-scale woodland creation and also from specific replicated trial plots. The longer-term research project aims to compare different tree protection options currently on the market, and investigate how these methods of tree protection and ground cover crops can be used to replace plastics and herbicides, how they affect soil biota and what impact will this have on the ecosystem services within the woodland. We will aim to conclude which of these methods is most successful, cost-effective, and provides the most wide-ranging ecosystem health benefits.

Woodland establishment methods

Woodland planting site

The woodland spanned five fields on two farms: Lower Harglodd Farm and Penweathers Farm, both in St Davids, Pembrokeshire. An area of 4.3 hectares (ha) of woodland was planted at Lower Harglodd, while 0.95 ha was planted at Penweathers (Table 1). The fields have all been used over the last decade for non-intensive arable crops or as semi-improved, grazed grassland (Appendix A). The fields were botanically surveyed and mapped in 2022 using Phase 2 National Vegetation Classification (NVC) methods (Wolstenholme, 2023a,b).

Table 1: Woodland planting areas.

Farm	Field name	Field number	Woodland area (hectares)
Lower Harglodd	Cartwys	SM7726 4630	0.81
Lower Harglodd	Parc Newi	SM7725 4994	1.49
Lower Harglodd	Parc y Bont	SM7726 0710	1.00
Lower Harglodd	Parc Yet Coch	SM7725 8567	0.22
Lower Harglodd	Parc Yet Wen	SM7726 3530	0.22
Lower Harglodd	The Roft	SM7725 6498	0.39
Lower Harglodd	The Hagard	SM7726 5424	0.17
Penweathers	Parc Ifan	SM7526 4817	0.95
Total			**5.25**

The woodland at Lower Harglodd formed a corridor around the boundary of the farm, where it is adjacent to neighbouring intensive farmland, to improve biosecurity and act as a wildlife corridor. Woodland planting at Penweathers was in one discrete block in the southern half of Parc Ifan (Figure 1).

The weather in this area is historically warmer on average than the rest of Wales and the UK, with fewer frost days and a greater number of sunshine hours. The area has higher annual rainfall averages than the UK as a whole, but experiences less rainfall on average than the rest of Wales, and the same goes for the number of days where rainfall is equal to or more than 1 mm. While the area feels quite exposed, it experiences the same monthly mean wind speed as the UK average which is lower than the average for Wales. As such, the weather affecting the tree guards in this location can be considered a mid-point, they are likely to fare better in many parts of England, but worse in other parts of Wales (Table 2).

Table 2: Average weather data from climate period 1991-2020 (Met Office, 2022), Brawdy weather station data is approximately 6 miles from the woodland planting site.

	Maximum temperature (°C)	Minimum temperature (°C)	Days of air frost (days)	Sunshine (hours)	Rainfall (mm)	Days of rainfall ≥1 mm (days)	Monthly mean wind speed at 10 m (knots)
Brawdy	13.67	6.49	37.13	1530.91	1277.3	160.38	9.27
Wales	12.93	5.94	44.91	1407.15	1464.63	173.12	9.74
UK	12.79	5.53	53.36	1402.73	1162.93	159.08	9.27

Cover crops

To reduce the need for herbicide use during woodland establishment, replicated areas of three clover-rich cover crops and a control (the 'experimental areas'), were planted across the woodland planting areas in the spring prior to tree planting. Another two cover crops were planted in one area each (Figure 1; Table 3). All seed was purchased from Cotswold Seeds Ltd in spring 2022 after a literature synthesis and discussions with their Technical Manager, Sam Lane. U1 was a low-growing variety of white clover (AberAce), sown at 4kg/acre; U2 consisted of AberAce plus Ekola yellow trefoil, sown at 4kg/acre and U3 consisted of 50% Kardinal organic crimson clover, 30% Winner berseem/Egyptian clover and 20% Passat organic Persian clover, sown at 5kg/acre.

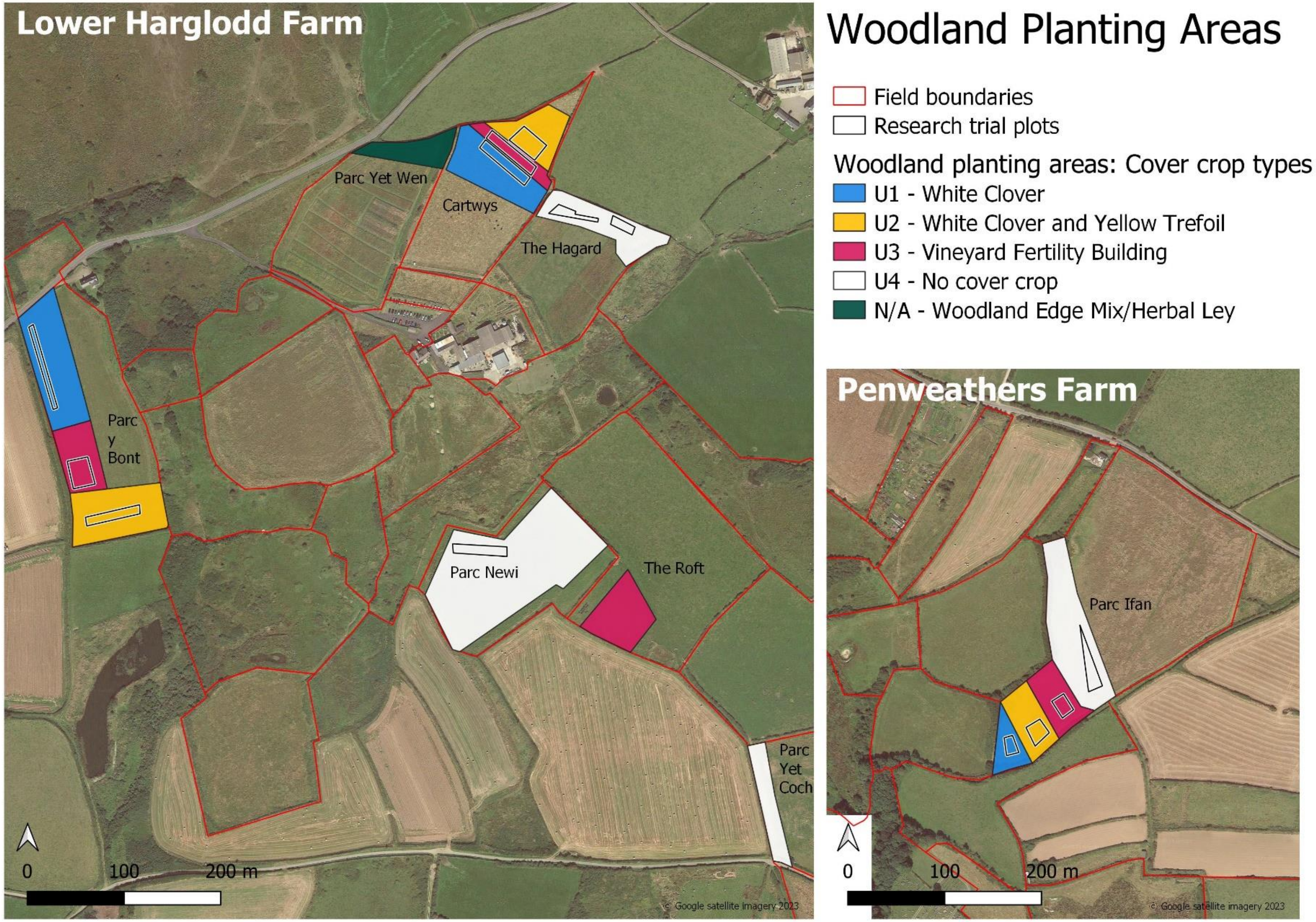

Figure 1: Cover crop and research trial plot locations across the woodland planting sites.

Table 3: Cover crop types sown in the year prior to woodland planting.

Treatment	Type	Number of kg/acre
U1	White clover	4
U2	White clover and yellow trefoil	4
U3	Vinyard fertility building mix	5
U4	No cover crop	0
N/A	*Woodland edge and shady area mix*	*10*
N/A	*Herbal ley*	*13*

The control plots with no cover crops were heterogenous in vegetation type and cover. In the Hagard, the plot spanned a locally-sourced wildflower seed mix from St Davids Airfield SSSI, sown in 2018, a mixed agricultural grass ley sown before 2014 (into which the wildflowers were spreading) and a commercial wildflower seed mix ley (Cotswold Wild Flora - Appendix C) sown in 2017. In Parc Newi, the field was in fallow regeneration after growing crops of winter wheat in 2018 and 2019. The regeneration included a high proportion of yarrow and common knapweed from an earlier sowing of herbal leys (in 2015), along with ground cover of creeping buttercup, couch grass and some creeping thistle and spear thistle. In Parc Ifan, the field was in fallow regeneration after growing a crop of winter wheat in 2021. Prior to 2021, the field had been in a grass ley, which had been grazed by sheep. Vegetation included a high proportion of creeping buttercup, couch grass, Yorkshire fog and rough-stalked meadow-grass, with some white clover already in the seed bank.

The Roft was sown with the vineyard fertility building mix, 0.5 acres of Parc Yet Wen was sown with Cotswold Seeds 'Woodland edge and shady area mix' and 0.5 acres of Parc Yet Wen was sown with a 70% organic, biodiverse herbal ley (Cotswold Seeds 'Herbal grazing ley – 4 year drought resistant ley' – henceforth 'herbal ley') (Appendix B).

All fields at Lower Harglodd were grazed by 23 Welsh Black cattle in the autumn and winter of 2021-2022. Cattle were fed with large bales of hay and haylage in ring feeders in Parc y Bont and Cartwys which led to significant poaching, nutrient enrichment and compaction. Five Welsh Black cattle also grazed Parc Ifan during the winter of 2021-2022, but with no supplementary feeding in the field.

All woodland plots (except for the controls) were ploughed, power-harrowed and sown in May 2022. Seeds were broadcast onto a well-prepared seed bed and rolled with a flat roller. No inputs were applied either before, during or after establishment of the cover crops or in the control areas. During the winter of 2022-2023 (up until the start of woodland planting in January 2023), all fields were grazed with cattle and managed as per winter 2021-2022.

Outside of the main experimental trial areas (Figure 1), additional groundwork was carried out to improve habitat heterogeneity. In the autumn of 2021, ~30 cm of topsoil from a heath creation project in a separate section of the Roft was added to the planting area of the Roft and 2 m-high earth banks, topped with native hedging whips, were created around the planting site. Additional topsoil was used to create east-west-facing ~80 cm-high earth banks in Parc Newi, to form the northern boundary to the woodland, with a new wildflower meadow area created on the northern boundary. In Parc Yet Wen, small humps (~0.5 m high by 1 m wide) and scrapes were created after seeding to create additional microhabitat conditions within the planting area.

Biodiversity net gain measures

From conception, the woodland was planned with biodiversity net gain at the forefront. At the landscape scale, the aim is to create a linked habitat mosaic of open rides and glades, closed-canopy woodland, hedgerows and standard trees alongside arable, grassland and marshy grassland/heath and freshwater habitats. A full woodland planting rationale document (available on demand) was created and distributed among local ecologists for comment prior to woodland planting. Care was taken as to not fragment marshy grassland habitat on the farm or to form a barrier between marshy grassland on the farm and the adjoining habitat on the North West Pembrokeshire Commons Special Area of Conservation (SAC) to the north and south for species that may struggle to cross woodland, such as the marsh fritillary butterfly (which we are hoping to reintroduce to the area in the future). Planting was also sensitive to conserving arable plant habitat within, and adjacent to, the woodland across the farm, as the farm is located in an Important Arable Plant Area, with rare arable plant records from both farms.

Within the woodland planting areas, it was also important to us to include as much heterogeneity and edge habitat as possible, with planting focused at creating habitat for species including the brown hairstreak butterfly (*Thecla betuleae*) (Butterfly Conservation, 2004). Following best practice suggestions, the woodland planting was designed to incorporate clumps of shrubs at the edges of rides and glades and clumps of shrubs within the woodland itself to give structural complexity (Herbert, S. *et al.*, 2022). We also incorporated small wildflower meadows and areas of tussocky grass adjacent to the new planting.

We wanted to have the option to regularly cultivate rides and glades to provide habitat for rare arable plants. However, due to Glastir Woodland Creation (GWC) conditions, there were limitations on the total area of un-planted space within each planting area, as un-planted ground could not exceed 15% of the total planted area and individual unplanted areas could not exceed 0.1 ha. We used a combination of mapping and on-the ground rotovating to plan our rides and glades, which enabled us to calculate the percentage cover and ensure it fell within GWC requirements (Figure 2).

Rides (approximately 3 m wide) and glades (variable in diameter, but most approximately 10-12 m) were rotovated prior to planting and again in spring 2023. The rides and glades were hand-sown with a mixture of native and annual wildflower seeds (Appendix C) before being rolled with a flat roller. In future years, we plan to rotate the rotovated rides and glades across the farm to create a mosaic of habitat, creating nesting sites for skylarks by rotovating some rides and glades in the winter to provide undisturbed nesting habitat from February to July each year. In years that the rides and glades are not rotovated, we will use a flail collector to maintain mown paths in some areas and other areas will be mown and collected in spring, left to flower through the summer, and mown (and collected) again in autumn along with the farms' hay meadows.

Figure 2: (Left) Rotovated rides in Parc Newi; (Right) Rotovating rides in Parc Ifan.

There was also a strong personal motivation for woodland creation: the woodland at Lower Harglodd was planted as a memorial woodland for Dr Sarah Beynon's late mother, Pauline Beynon, and the woodland at Penweathers was planted as a memorial woodland for Dr Sarah Beynon's late father, John Beynon.

Planting and protection

The woodland was planted from January-February 2023 under the 'Biodiversity' option of two GWC contracts, with 1,600 stems planted per hectare (Appendix D). The contract was managed, and woodland planted, by H W Forestry. Due to the random planting and our desire to not use blanket herbicide treatments, we were offered, and accepted, a planting only contract where we provided the tree protection, carried out the maintenance ourselves and replaced all failed plantings.

A mixture of tree and shrub species were chosen from the 'Native Trees and Shrubs in Pembrokeshire' list (Pembrokeshire Coast National Park Authority, 2000) (Tables 4 & 5; appendices F & G). Potentially invasive species of heathland (e.g. silver birch and downy birch) were excluded due to the sites' proximity to the SAC.

Table 4: Woodland composition at Lower Harglodd. See Appendix F for more information.

Tree species	Percentage of mix	Protection
Sessile oak	10	Spiral
Wild cherry	10	Spiral
Aspen	10	Spiral
Alder	10	Spiral
Rowan	10	Spiral
Crab apple	10	Spiral
Hawthorn	10	Spiral
Hazel	5	Spiral
Goat willow	5	Spiral
Elder	5	Shelter
Blackthorn	5	Spiral
Holly	5	Shelter
Dog rose	5	Spiral

Table 5: Woodland composition at Penweathers. See Appendix G for more information.

Tree species	Percentage of mix	Protection
Sessile oak	20	Spiral
Alder	20	Spiral
Aspen	~5	Spiral
Rowan	10	Spiral
Crab apple	10	Spiral
Hawthorn	10	Spiral
Hazel	10	Spiral
Grey willow	~7	Spiral
Goat willow	~8	Spiral

Outside of experimental plots, trees (generally 40-60 cm whips, although oak whips were 10-20 cm tall) were largely planted in single-species groups of 25-50 trees with variable spacing and protected with Treebio spirals, with the exception of holly and elder, which were protected with re-used Tubex shelters. This clumping of species was not always possible in small areas and so planting was random rather than clumped. Woody shrubs (largely hawthorn, blackthorn, elder, holly and dog rose) were planted along all margins to create as much edge habitat as possible and as clumps of 30-60 shrubs within the woodland itself where space allowed (appendices F and G). There was no planting within 3 m of hedgerows or 5 m of pond edges.

Due to the presence of willow blister fungus *Cryptomyces maximus* onsite (categorised as one of the World's 100 most threatened species), additional goat willow and grey willow were planted alongside the woodland planting area. Along the south edge of Parc Yet Wen and Cartwys, planting was dense, with two rows of willow, spaced approximately 1.5 m apart, planted at ~5 stems per metre to shelter the woodland and also to form a tunnel over time. A livestock fence was erected ~1 m from the southern-most row of willow in each field to enable livestock in the adjacent fields to browse the willow in the future and also for the willow to act as a shelter for the animals. Additional trees and shrubs (largely whips, but with some standard trees) from the Pembrokeshire native list were also planted in newly-fenced shelter belts within fields and to thicken existing hedges around the farm. All additional planting was carried out outside of the GWC contract areas.

Penweathers has been historically in arable production but, on many occasions, it has been impossible to harvest the crop from this section of the field due to the ground being too wet and the heavy clay soils leading to poor crop yields. The percentage of willow and alder planted were increased significantly to account for the wet conditions and so the breakdown in Table 5 is more of an estimate. Otherwise, planting followed that at Lower Harglodd.

Research methods

In each experimental cover crop block, 100 trees were planted 2.3 m apart with at least 2.3 m between the planting plot and any edge to avoid interaction with edge habitat. Five species of tree were planted within these plots: sessile oak, aspen, alder, rowan and crab apple, with 20 of each making up the 100 trees in each planting plot. In these experimental areas of the woodland planting, we tested the: (A) economic, (B) ecological and (C) efficacious benefits/disbenefits of 14 different treatment options: 4 cover crop weed suppression treatments (U) (Table 3) and 10 tree protection treatments (T) (Table 6) using a split-plot design with a two-way interaction between U and T. Conditions T1 and T9 act as positive controls with conditions U4 and T10 acting as negative controls. Within experimental areas, each tree protection treatment (n = 10 replicates per treatment) was tested across each cover crop block (n = 12 blocks) (Figure 1) to test for an interaction between tree protection treatment and cover crop treatment, giving 120 trees per treatment and 1,200 experimental trees.

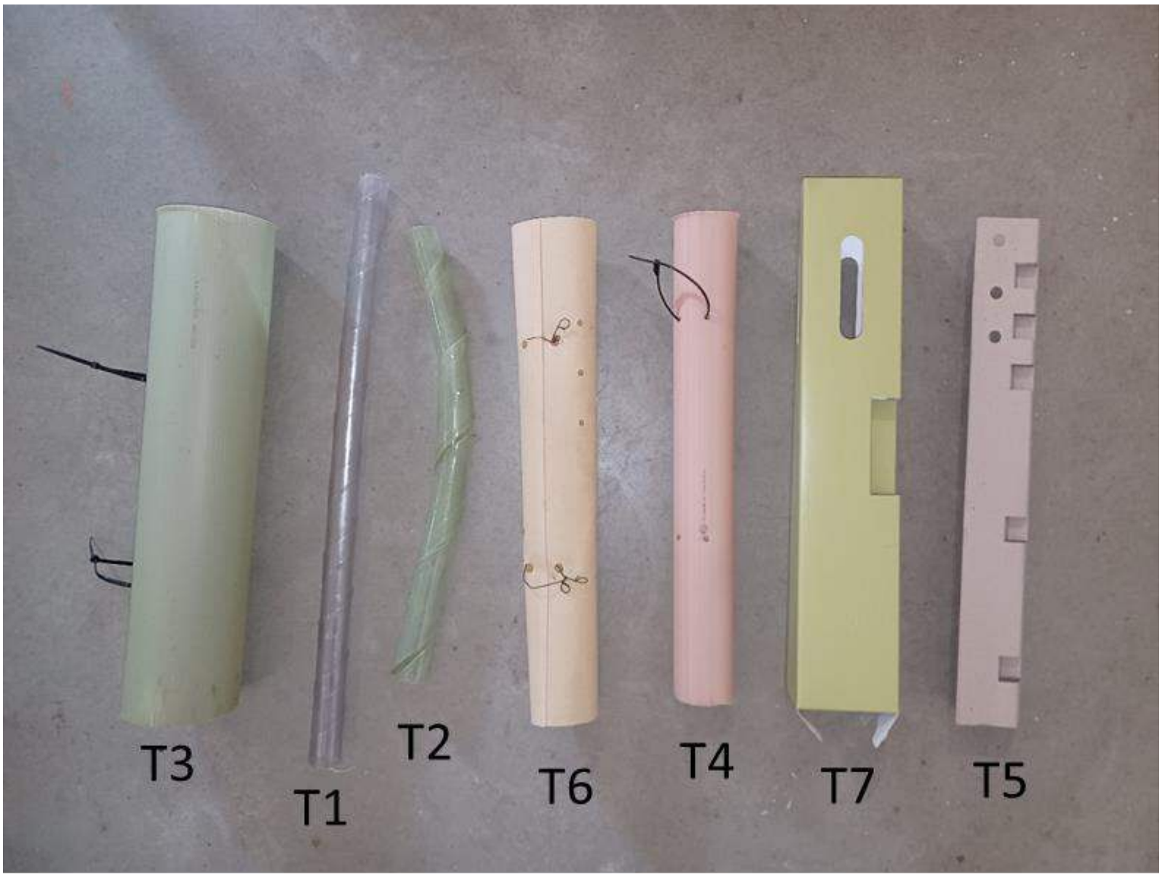

Figure 3: Plastic and plastic-free tree shelter and spiral options. From left to right, re-used plastic shelter (T3), recycled plastic spiral (T1), Treebio PLA spiral (T2), Treehugger cotton and pine rosin shelter (T6), Tubex Nature surgarcane, corn and starch shelter (T4), Bio-Earth coated cardboard shelter (T7) and WhiptecBio Moulded fibre shelter (T5).

Table 6: Tree protection treatments used. All tree protection treatments are pictured in Figure 3.

Treatment	**Protection**	**Brand**	**Material type**	**Stake/cane**	**Stake/cane length (cm)**
T1	Spiral	N/A	Recycled plastic	Cane	90
T2	Spiral	Treebio	PLA	Cane	90
T3	Shelter	Tubex	Re-used plastic	Stake	65
T4	Shelter	Tubex Nature	Sugarcane, corn and starch	Stake	90
T5	Shelter	WhiptecBio	Moulded fibre	Cane	90
T6	Shelter	Treehugger	Cotton and pine rosin	Stake	65
T7	Shelter	Bio-Earth	Coated Cardboard	Stake	90
T8	Mulch	N/A	Cut grass mulch	N/A	N/A

T9	Herbicide	Roundup ProVantage	Glyphosate*	N/A	N/A
T10	No protection	N/A	N/A	N/A	N/A

*30 ml/2 l water

In January-February 2023, trees were randomly allocated to a treatment (T) using a two-step random allocation process. To mark trees, colour-coded canes and stakes were used to indicate which treatment would be used. First, a coin was flipped to determine whether a cane or stake be allocated (heads for cane, tails for stake) and then the appropriate cane/stake was selected at random from a bag with 10 of each colour mixed up and facing down so the colour could not be seen, until all canes and stakes had been used.

The appropriate spiral/shelter was then applied. For T8 and T9 (herbicide and mulch), a standard guard (Treebio spiral) was applied and trees were left until July when the 1 m surrounding area was strimmed and then herbicide or mulch was applied. Mulching was carried out between August-December 2023. The mulch used was cut arisings from the rides and glades in the same field and ½ a wheelbarrow load was applied to each mulched tree in a ring doughnut shape around the base, ensuring that a gap of at least 20 cm was left between the tree and the mulch.

Data collection

Data were collected on the establishment costs, while cover crop establishment success was recorded quantitatively. In year 1, data collection began in September with tree height and health recorded. Health metrics determined as H = >50% leaves healthy, U = <50% leaves healthy (if a tree has leaves and all are dead it would fall into this category, not the dead category), D = Tree present but with no leaves (presumed dead), M = Tree missing. Dead and missing trees were not replaced until two consecutive years had identified them as such allowing a year to recover in case stress may have allowed them to appear dead or missing.

Standard 2 m × 2 m vegetation quadrats were established in all experimental cover crop areas, with data collected in 2023. Data collection is ongoing, so results are not presented here.

In year 2, we plan to measure metrics such as vegetation height, percentage cover, species composition and the number of nectar resources within a 1 m quadrat around each tree; along with tree height, leaf count, mortality and guard condition. In addition, for T8 and T9 (mulch), we plan to take soil cores and insert bait lamina into the ground adjacent to these experimental trees to measure soil faunal functioning (decomposition rates). We also foresee data collection to relate mammal activity to tree damage and investigate insect dispersal metrics across planting areas. However, the exact experimental design will be determined in the next stages of planning.

Results

The collection of results is in the preliminary stages and therefore we provide some initial observations as opposed to analysed results.

Ecological benefits

We are yet to collect data on the ecological benefits of the different treatments, as this is part of a longer-term project. However, in year 1, we have recorded wood mice in some shelters, harvest mice nests in Tubex shelters and a barn owl hunting in Parc Newi and Parc y Bont, regularly following the rides and glades.

Efficacious benefits

All cover crops established successfully, but establishment was heterogenous across different fields. Early observations indicate that tree species may have a greater impact on mortality than the guard type or cover crop, although data collected in future years will allow examination of the differences in tree health between the different guard types.

Economic benefits: Establishment costs

We allocated costs to the establishment of the different cover crops and tree protection (Table 7; Table 8). Clover-rich crop establishment costs were approximately £200/acre (£185.71-£249.01) while seeding with a wildflower-rich seed mixture was significantly more expensive (£939.04/acre). Protecting trees with guards ranged from approximately £1.00-£4.00 per tree

Table 7: Cover crop types sown in the year prior to woodland planting. Costs were correct at time of establishment.

Treatment	Type	Number of kg/acre	Cost per kg (£)	Seed cost/acre (£)	Contractor establishment cost per acre *(£)	Total cost per acre (£)
U1	White clover	4	11.50	46.00	145.14	191.14
U2	White clover and yellow trefoil	4	13.45	53.80	145.14	198.94
U3	Vinyard fertility building mix	5	8.13	40.65	145.14	185.79
U4	No cover crop	0	0.00	0.00	0.00	0.00
N/A	*Woodland edge and shady area mix*	*10*	*79.39*	*793.90*	145.14	939.04
N/A	*Herbal ley*	*13*	*7.99*	*103.87*	145.14	249.01

*Establishment costs were calculated at ploughing (£26.00/acre) plus power-harrowing (£45.00/hour = £22.50/acre) plus sowing (£26/acre) plus rolling (£26/acre) plus diesel (9 litres/acre at £1.24/litre = £11.16/acre/job).

Table 8: Tree protection costs. Costs were correct at time of planting.

Treatment	Protection	Brand	Cost of protection per tree (£)	Cost of cane/stake per tree (£)	Time cost of protecting per tree (£)	Total cost of establishment per tree (£)
T1	Spiral	N/A	0.60	0.15	0.20	0.95
T2	Spiral	Treebio	0.67	0.15	0.20	1.02
T3	Shelter	Tubex	1.50	0.38	0.40	2.28
T4	Shelter	Tubex Nature	2.30	0.65	0.60	3.55
T5	Shelter	WhiptecBio	0.78	0.15	0.20	1.13
T6	Shelter	Treehugger	2.00	0.38	0.40	2.78
T7	Shelter	Bio-Earth	2.30	0.65	0.60	3.55
T8	Mulch	N/A	N/A	N/A	2.40* + guard	2.40 + guard
T9	Herbicide	Roundup ProVantage	0.40	N/A	0.80**+ guard	0.80 + guard
T10	No protection	N/A	N/A	N/A	0.10	0.00

Costs (excluding VAT) do not include replanting costs associated with failure. Planting costs assume a rate of £12/hour (£0.20/minute) and are estimates from a non-expert planting team.

*£0.40 was allocated to professional strimming, £2.00 allocated to mulching, of which the greatest time was spent collecting mulch from a pile with a wheelbarrow and moving it to the tree. The cost of mulching does not include the costs associated with obtaining the mulch or moving it to a central position.

**£0.40 was allocated to professional herbicide application, £0.40 was allocated to professional strimming.

Discussion

With the exception of the costs associated with cover crop establishment and tree protection, we are yet to collect and analyse experimental data and so discuss anecdotal observations only.

Protection

We are not able to report on the relative benefits of the tree protection at this time, as this is part of a wider research project where data collection is only beginning. However, we did find that knocking the extra-long 90 cm stakes into stony ground was extremely difficult and time-consuming. We originally used a rubber mallet for hitting in stakes, but using a small post knocker was much more effective. During the first two months after planting, very strong winds blew over approximately 5-10% of spirals and shelters supported by canes. However, replacement was quick and simple but would have added an extra (un-accounted-for) cost. After vegetation had grown around and stabilised the tree protection, no more shelters or spirals blew off. At the time of writing this (October 2023), all the tree spirals and shelters were intact.

Cover crops

Clover cover crops were not prohibitively expensive or difficult to establish when working with a local agricultural contractor. Establishment costs ranged from £185.79 per acre to £198.94 per acre with the majority of the cost allocated to the contractor (£145.14 per acre). Outside of the main replicated experimental areas, the cost of seed for the woodland edge and shady area mix (£793.90 per acre) would probably be prohibitive for many unless planting just a small area.

In agreement with Ross *et al.*, (2001), both annual (vineyard fertility building mix) and perennial white clovers plus yellow trefoil appeared to reduce weed biomass in year 1, but with varied success in establishment across fields. Qualitative establishment assessment would suggest that the establishment was most successful in Parc y Bont > Parc Ifan > Cartwys (Appendix H). While all cover crops established well, there was limited establishment success for yellow trefoil in the yellow trefoil + white clover treatment. The yellow trefoil that did appear (largely in Parc y Bont) was soon outcompeted by the white clover in the mix. In Parc y Bont, mob-grazing the cover crops with 23 cattle in advance of flowering in the summer seemed to increase the rate of clover growth and tillering for all cover crops and establishment was better here for all cover crops than in other fields. This agrees with Ross *et al.*, (2001), where mowing the clovers early in the season, before flowering, increased the efficacy of clover cover crops in supressing weeds.

Late, overwinter grazing (and thus soil poaching and compaction) by cattle in the autumn/winter after sowing and before tree planting possibly reduced the year 2 efficacy of the cover crops in all fields, particularly the annual clovers in the vineyard fertility building mix treatment. We had hoped that grazing after these annual clovers had set seed, would enable the dropped annual clover seeds to germinate the following spring, but annual clover cover the following year in the vineyard fertility building plots was generally poor. Nevertheless, when growing in year 1, the annual clovers were tall and vigorous and, when they died, their leaves covered the ground a papery, brown ground mulch cover over the winter. In year 2, the papery ground cover was still apparent and the dominant successive vegetation in the vineyard fertility building plots was broad-leaved dock (Parc y Bont and Parc Ifan at Penweathers) and spear thistle (Cartwys and the Roft). Nevertheless, grass weeds in these plots, particularly the plot in Parc y Bont, were sparse. Grass weeds (particularly Yorkshire fog) were much more prevalent in all plots in Cartwys, possibly due to supplementary feeding of cattle on the field during the winter. The clover leys still established well in Cartwys, but under a thatched cover of grass. From our anecdotal observations, we would suggest lower levels of grazing in winter months could help clover establishment and reduce grass weed competition in 'grassy' fields.

Planting these clover cover crops in the autumn just before tree planting in the winter may have been more effective than planting in the previous spring as was done here. The cover crops were more effective at supressing weeds in year 1 than subsequent years and this did not correspond with tree protection, as the trees had not yet been planted.

In the very dry spring following tree planting, more tree leaves appeared to have died in Parc y Bont compared to in any other field. At the time, it looked like a significant proportion of the trees had died, particularly in the western-most yellow trefoil + white clover plot, which was situated on the east-facing slope of the field. This was in comparison to a lush clover understorey in this field. Despite being wet in winter, with heavy soils, this field dries out quickly in the late spring. There is some evidence that clovers may either compete with trees for soil nutrients (Ross *et al.*, 2001) and perhaps the competition may also be relevant for water in times of drought. However, after initially dropping their leaves, the majority of the trees in this area re-grew leaves later in the summer.

We observed a significant growth of mildew on the leaves of the vineyard fertility building mix clovers during the autumn after planting and it will be interesting to see if this has affected tree establishment over time and whether there is any interaction between this and the more porous biodegradable shelters.

Outside of the main trial areas, the woodland edge and shady area mix and the herbal ley both established well in Parc Yet Wen. Both crops grew tall (~1 m), but were either comprised of fine grasses and herbs (woodland edge and shady area mix) or bulky, stalky forage, such as chicory and red clover (herbal ley) which did not smother the trees in the first year.

During a follow-up inspection from H W Forestry in May 2023, we were advised to carry out mechanical or herbicide control of grass weeds in Cartwys, the thistles in the Roft and grass weeds in Parc Yet Coch and it was suggested that an autumn herbicide (propyzamide) treatment was required around all trees. The contractor visited the site to strim around the trees in Cartwys in July 2023 and he was concerned about the weedy growth across the whole planting site, particularly the tall and abundant spear thistles in the Roft which was, by that point, inaccessible. He was also concerned as to the time it would take to strim or spray around trees across the whole site due to the random planting and the fact that the grass had already thatched and was stalky and difficult to strim. He therefore suggested that this was not a viable option. It appears that contractors do not have much experience of *not* spraying/strimming around trees due to the fact that most planting contracts include maintenance and re-planting any failed plantings and therefore they cannot afford to take the risk.

As some trees in Cartwys (including the majority of the experimental trees) had not been strimmed, we were able to qualitatively compare grass re-growth. By October 2023, re-growth around strimmed trees did not appear to be very different to un-strimmed trees and simply trampling around these trees, and all the other non-experimental trees in the autumn, flattened all grass weeds. This was possible as trees could be located because of their shelters/spirals. Un-guarded trees would not have been visible. No additional weed control was carried out anywhere other than pulling grass weeds from inside the shelters. Trees looked generally healthy and, at the time of writing this report, the average number of dead trees in each planting area is <10 and does not appear to correlate with the tree being smothered by weeds.

The herd of 23 Welsh Black cattle escaped into Parc Newi (but not into the fenced experimental plot) during the summer of 2023 and spent approximately 24 hours in the field. The cows grazed around the trees and, even if they walked over a spiral, it sprang back into place. When the cows had broken the canes, and the spirals were laying horizontally, the trees inside were undamaged. The only damage was from the young steers scratching their undersides or heads on the shelters and snapping the canes – individual animals developed a liking for this behaviour. Mature cows and a horse caused no damage and walked and grazed carefully between the trees. Due to the success here, we purposefully let our cows graze a series of earth banks that we had planted with hedging whips and the cows successfully flattened all the grass that was smothering the whips without damaging many whips. We have since used the cows to help manage grass weeds around newly planted trees elsewhere. The cows were also extremely successful in trampling down the high (~2 m) and dense spear thistles to give us access to the trees in the Roft and again, damage to the trees was minimal. It was encouraging to see that the trees growing under the spear thistle canopy had survived well during their first year.

Conclusion

While we are not yet able to make any conclusions regarding the ecological or efficacious benefits of different methods of plastic-free and herbicide-free tree protection, it is clear that clover-rich cover crops can be a helpful tool in reducing grass weeds in the first year after establishment. Cover crops were relatively straightforward to establish but perhaps should have been established in the autumn before tree planting rather than in the spring, to make use of the weed suppression in the first summer after planting. All tree guards were intact at the time of writing this report. Now that we have established a baseline, measuring the effect of these tree protection measures on tree survival and woodland biodiversity and functioning will enable us to assess whether they are a cost-effective option in the longer term and the experimental design enables the site to act as a landscape-level research experiment for students in the future.

Acknowledgements

The woodlands were planted by H W Forestry as part of two Glastir Woodland Creation contracts. This project was funded by the Nature Networks Programme. It is being delivered by the Heritage Fund, on behalf of the Welsh Government. We would like to thank H W Forestry for advice on planting and maintenance, Andy Holcroft for carting the trees and tree protection to each site and for rotovating and mowing the rides and glades. We would like to thank Angela Samuel, Caroline Sidonio, Gerald and Kim Dewsbury, Paul Williams, Grace Leach, Louise Carey, Dean Cain, Kyle Lewis and Hannah Kerr for assistance with mulching and measuring trees.

A section of the woodland planting and the research experiments can be seen at The Bug Farm visitor attraction on the Bug Farm Trail.

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Wolstenholme, L. 2023b. National Vegetation Classification Mapping at Penweathers, St David's, Pembrokeshire. Unpublished report.

Appendix A – Land use 2014-2021

Table 9: All over-winter stubble and fallow land/arable regeneration was grazed by cattle. Wildflower meadows were cut for hay, with aftermath and spring grazing by cattle, goats and ponies.

Field name	Field number	2014	2015	2016	2017	2018	2019	2020	2021
Cartwys	SM7726 4630	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass
Parc Newi	SM7725 4994	Spring barley	Herbal ley*	Herbal ley	Herbal ley	Grass	Winter wheat	Fallow	Fallow/arable regeneration
Parc y Bont	SM7726 0710	Potatoes	Spring barley	Spring barley	Spring barley under-sown with clover + trefoil	Fallow/arable regeneration	Winter wheat	Fallow/arable regeneration	Fallow/arable regeneration
Parc Yet Coch	SM7725 8567	Spring barley	Spring barley	Spring barley	Spring barley	Grass/winter wheat	Winter wheat	Fallow/arable regeneration	Fallow/arable regeneration
Parc Yet Wen	SM7726 3530	Spring barley	Spring barley	Potatoes	Spring barley	White clover	Mixed arable	Mixed arable	Mixed arable
The Hagard	SM7726 5424	Grass	Grass	Grass	**Wildflower meadow/grass	Wildflower meadow/grass	Wildflower meadow/grass	Wildflower meadow/grass	Wildflower meadow/grass
The Roft	SM7725 6498	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Relocated topsoil
Parc Ifan	SM7526 4817	Grass	Grass	Grass	Grass	Grass	Grass	Grass/winter wheat	Winter wheat /arable regeneration

*The field was split into 4 equal sections from east to west. Seed mixes planted, from east to west, were: (1) Pochon persistent high clover grazing ley, (2) legume and herb-rich sward EK21, (3) Maximum D-value 4-5 year ryegrass ley (ref: Mix C) and (4) Herbal grazing ley four year drought resistant ley. Full seed mixes are available on request. The experimental area spanned mixes 1 and 2.

** The field was split into 3 equal sections from east to west. The northern third was sown with seed collected from St Davids Airfield SSSI, the central third remained as grass and the southern third was sown with MIXFLO Cotswold Wild Flora, an annual and perennial wildflower mix from Cotswold Seeds (Appendix C) and are available on request.

Appendix B – Additional cover crop seed mixes

The 'Woodland edge and shady area mix' is a biodiverse mix of native and commercial grasses and herbs: 1% quaking grass (*Briza media*); 1% commercial Barxera tufted hairgrass; 2% commercial sweet vernal grass; 8% certified Highland common bentgrass; 10% certified Southland crested dogstail; 14% certified Enhary wood meadow grass; 24% certified Archibal slender creeping red fescue; 25% certified Highnote chewings/red fescue; 2.5% red campion (*Silene dioica*); 2.25% white campion (*Silene latifolia*); 2% self heal (*Prunella vulgaris*); 1.45% garlic mustard (*Alliaria petiolate*); 1% Hedge Bedstraw (*Galium mollugo*); 1% Tufted Vetch (*Vicia cracca*); 1% yarrow (*Achillea millefolium*); 1% meadowsweet (*Filipendula ulmaria*); 0.75% wood avens (*Geum urbanum*); 0.5% teasel (D*ipsacus fullonum*); 0.5% bluebell (*Hyacinthoides non-scripta*); 0.25% betony (*Stachys officinalis*); 0.25% perforate St John's wort (*Hypericum perforatum*); 0.25% upright hedge parsley (*Torilis japonica*); 0.15% autumn hawkbit (*Leontondon autumnalis*); 0.15% rough hawkbit (*Leontodon hispidus*).

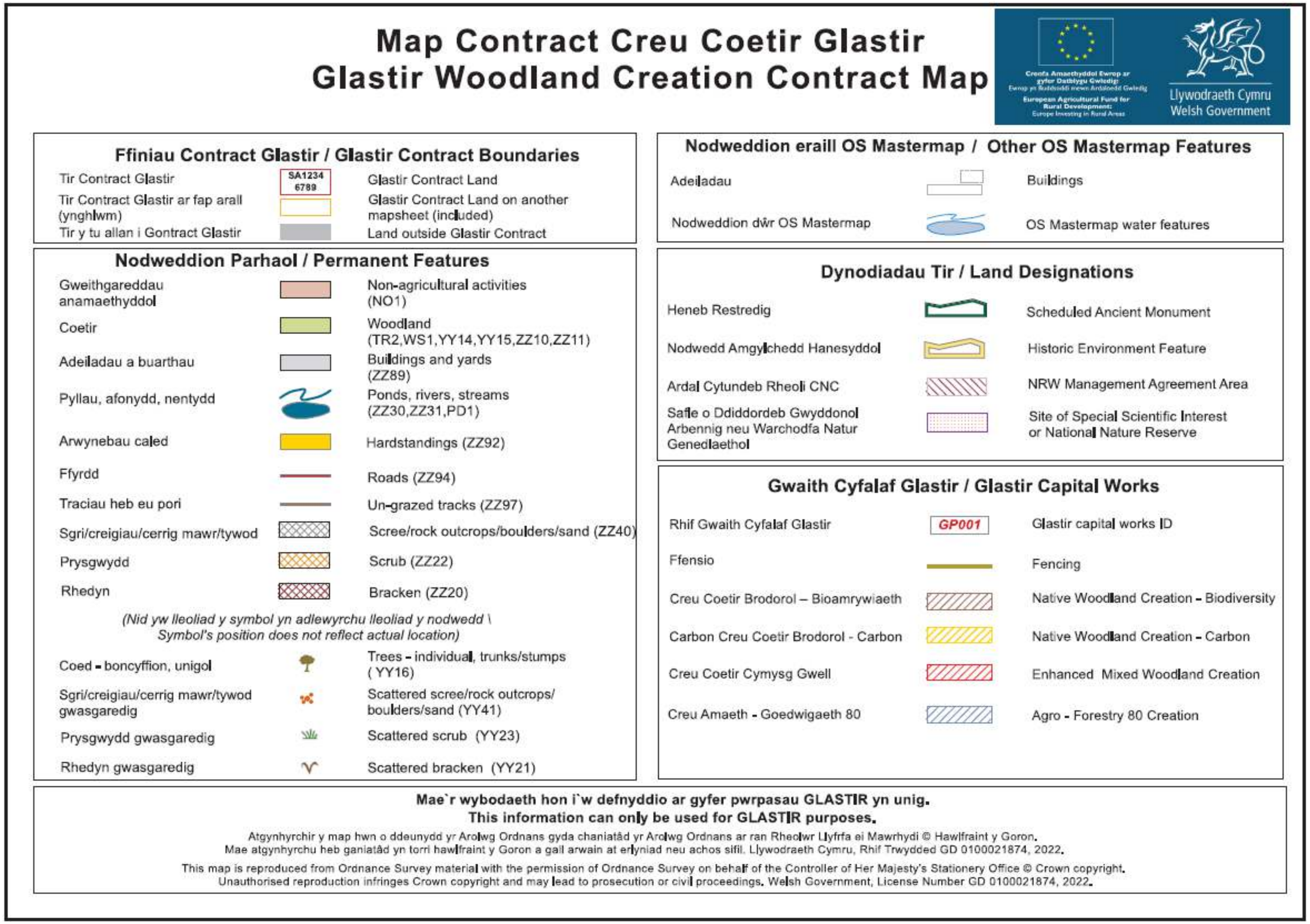
The herbal ley consisted of: 11.5% certified Donata organic cocksfoot; 10% certified Solid organic tetraploid hybrid ryegrass; 10% certified Toddington organic perennial ryegrass; 9.2% certified Comer organic timothy; 7.7% certified Tored organic meadow fescue; 7.7% certified Lofa festulolium; 15.4 commercial organic sainfoin; 4.5% certified Bonus organic red clover; 2.3% certified Buddy white clover; 1.5% certified Rivendel organic white clover; 1.5% commercial sweet clover; 2.3% certified Plato lucerne; 1.9% certified alsike clover; 2.3% certified Baco birdsfoot trefoil; 3.9% certified Puna / Endurance chicory blend; 1.9% certified Diversity ribgrass; 5% burnet forage herb; 0.8% sheep's parsley forage herb; 0.4% yarrow forage herb.

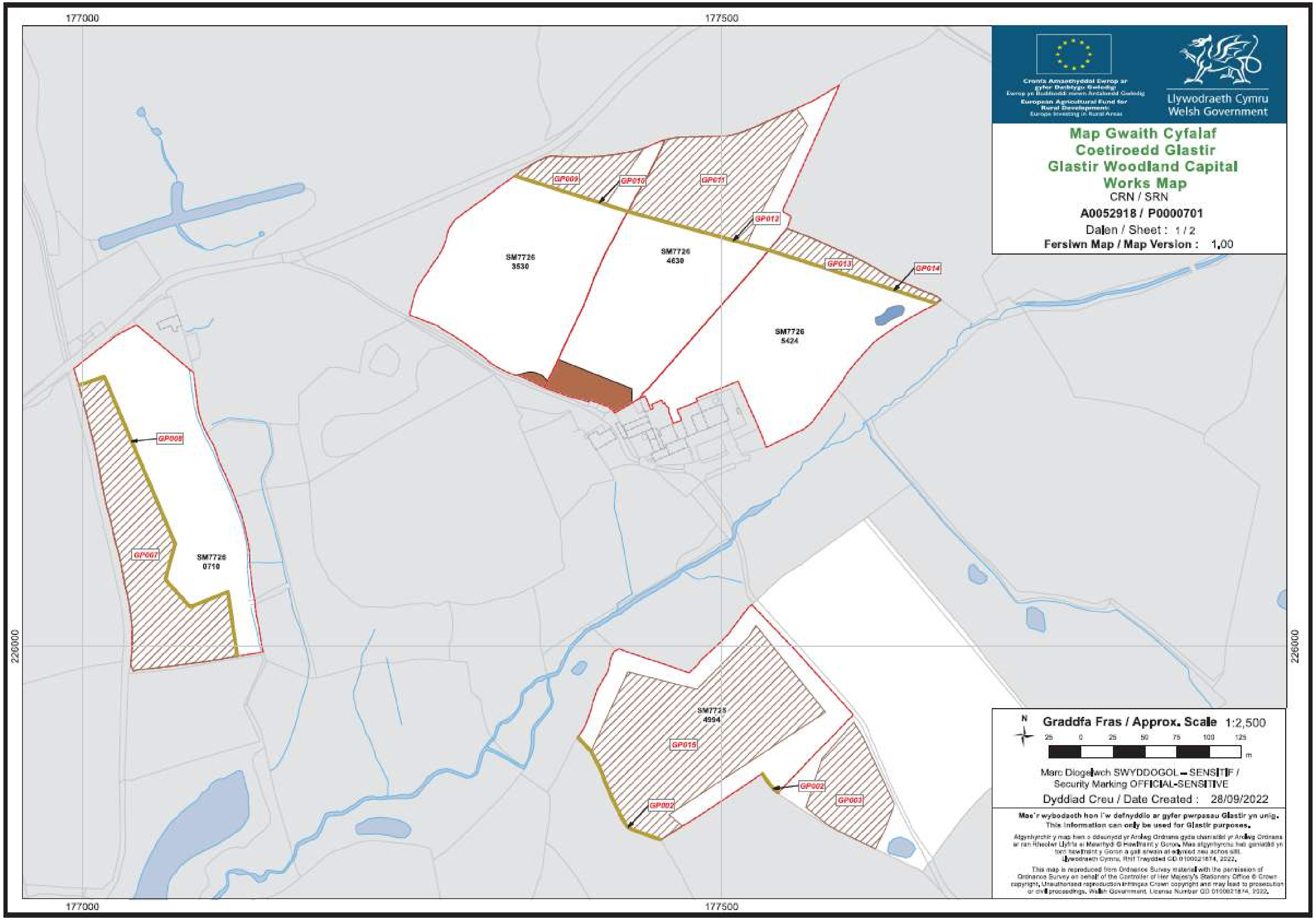
Appendix C – Seed mixtures used in rides and glades

The annual and perennial wildflower mix consisted of: 5 % certified common bentgrass; 0.5 % commercial yellow oatgrass; 13.5 % certified crested dogstail; 11 % certified smaller catstail; 15 % certified sheep's fescue; 15 % certified smooth stalked meadow grass; 20 % certifed Caracter red/chewings fescue; 2 % salad burnet (*Sanguisorba minor*); 1.5 % native sainfoin (*Onobrychis viicifolia*); 1.2 % lesser knapweed (*Centaurea nigra*); 1 % self heal (*Prunella vulgaris*); 1 % ox-eye daisy (*Leucanthemum vulgare*); 1 % ribwort plantain (*Plantago lanceolata*); 1 % red campion (*Silene dioica*); 1 % wild carrot (*Daucus carota*); 1 % field scabious (*Knautia arvensis*); 0.8 % musk mallow (*Malva moschata*); 0.5 % meadow buttercup (*Ranunculus acris*); 0.5% yarrow (*Achillea millefolium*); 0.5 % betony (*Stachys officinalis*); 0.5 % white campion (*Silene latifolia*); 0.1 % cowslip (*Primula veris*); 1.5 % corn cockle (*Agrostemma githago*); 1 % corn marigold (*Chrysanthemum seg*); 1 % cornflower (*Centaurea cya*); 1 % field poppy (*Papaver rhoeas*); 1 % yellow rattle (*Rhinanthus minor*).

The cornfield annuals consisted of: 40 % corn cockle (*Agrostemma githago*) annual wildflower; 14 % field poppy (*Papaver rhoeas*) annual wildflower; 13 % cornflower (*Centaurea cya*) annual wildflower; 13 % corn marigold (*Chrysanthemum seg*) annual wildflower; 7 % certified Leo birdsfoot trefoil; 6.5 % certified Heusers Ostsaat crimson clover; 6.5 % certified Maral Persian clover.

Appendix D – Glastir Woodland Creation Maps, Lower Harglodd

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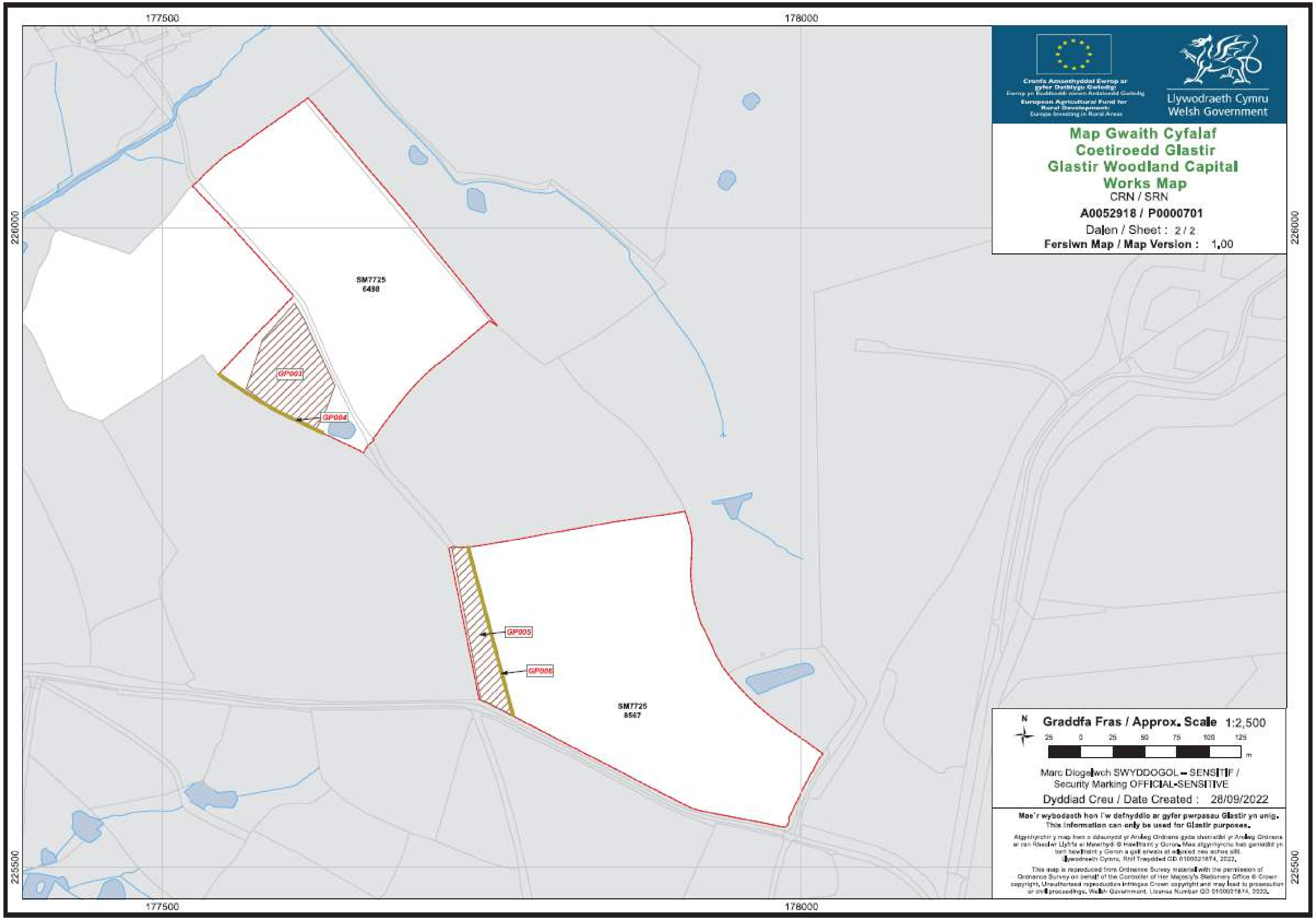

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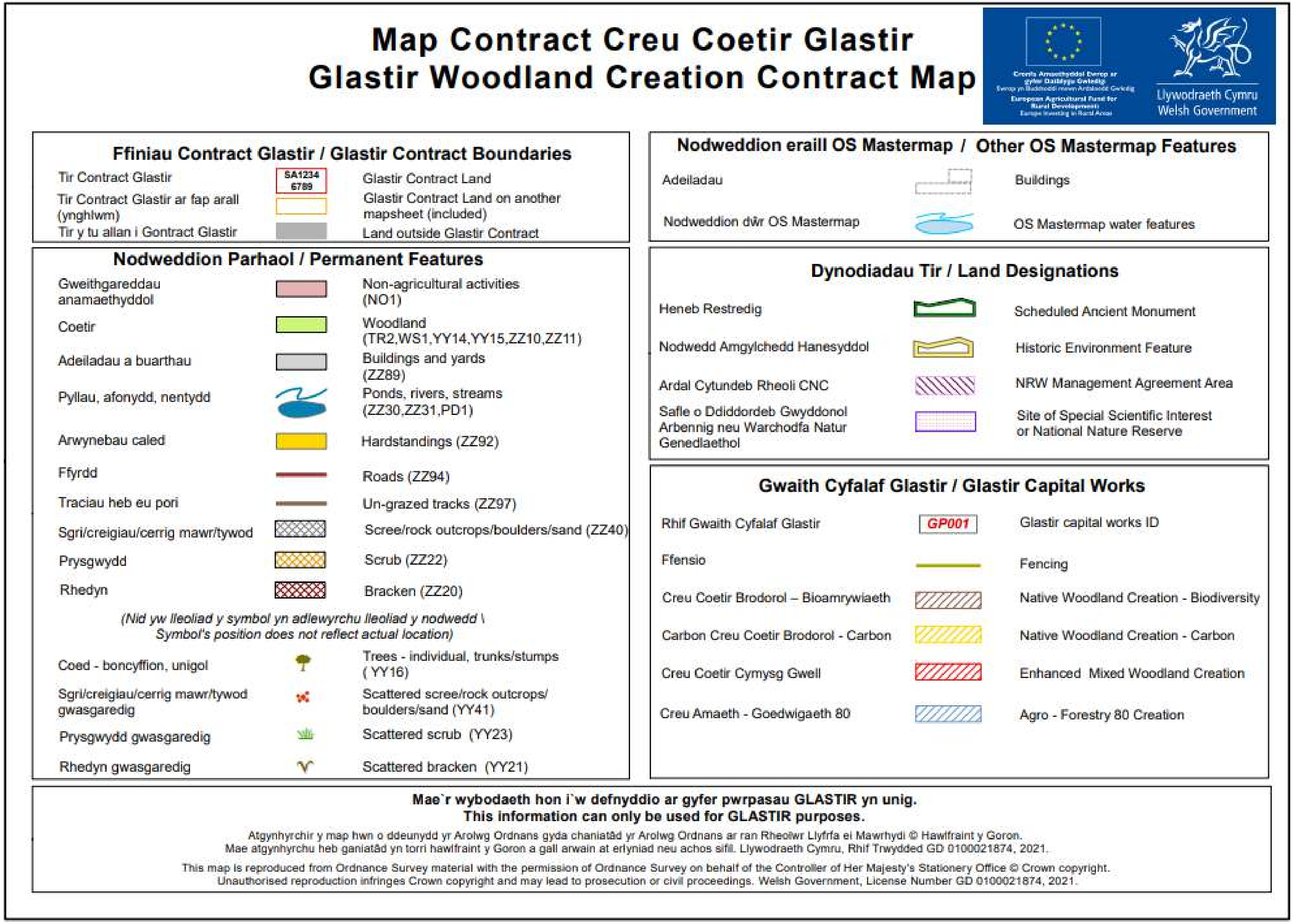
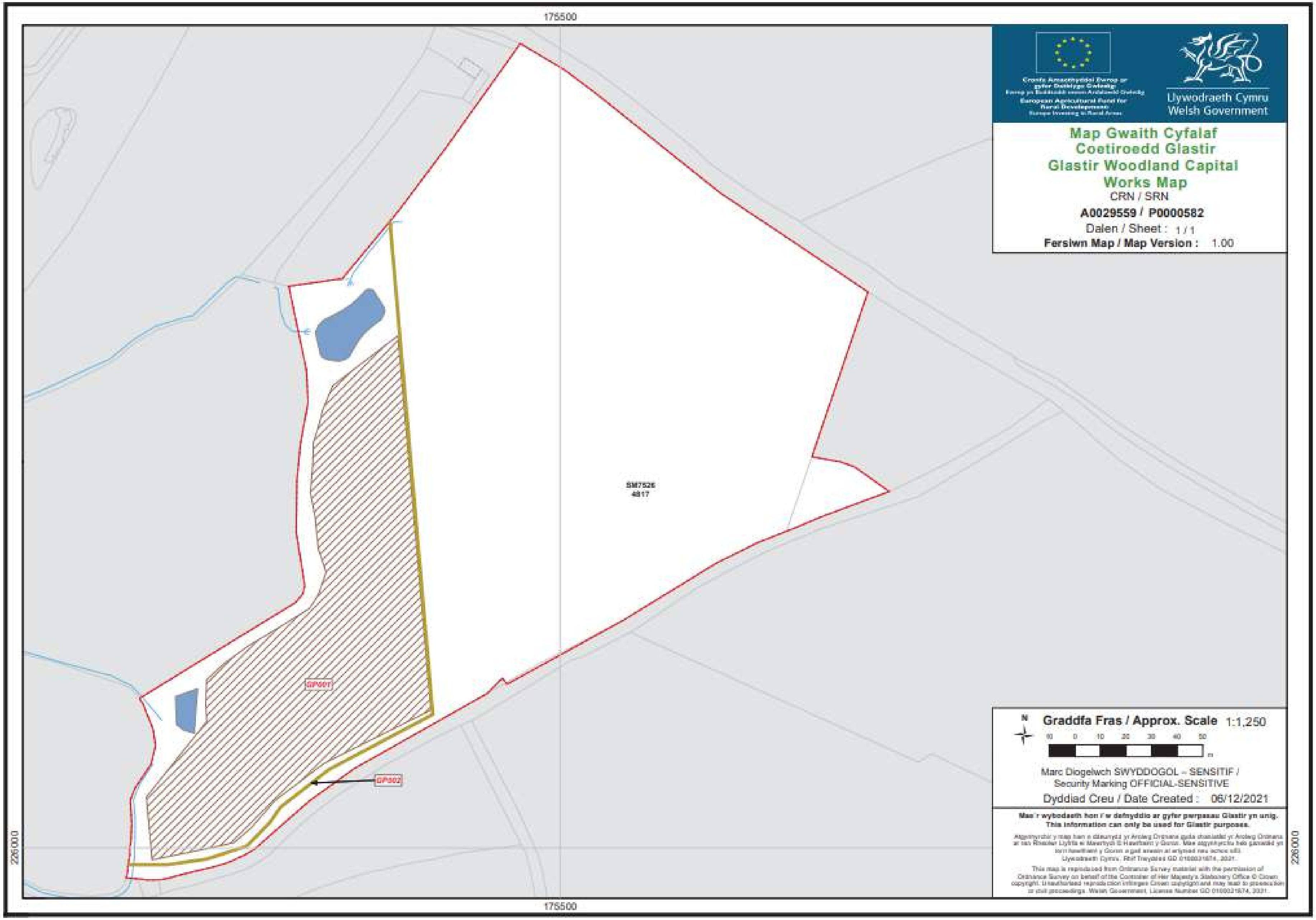
Appendix E – Glastir Woodland Creation Maps, Penweathers

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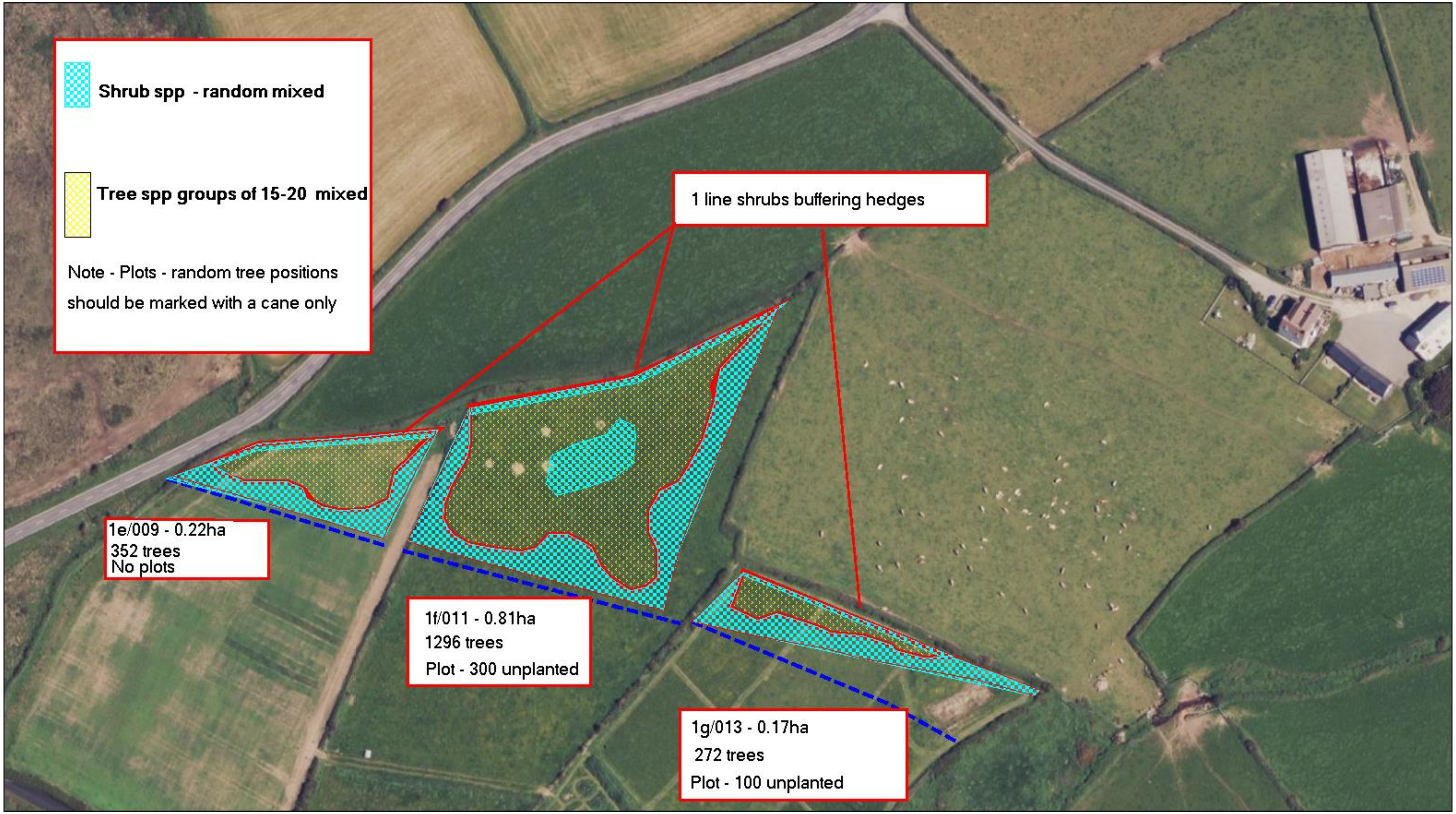
Appendix F – Planting Plans, Lower Harglodd

H W Forestry planting plans for Lower Harglodd. Treat blue as shrubs, green as trees and shrubs, red as trees. All numbers are approximate due to tree availability at the time of planting.

SPP	*%*	*1a/4994 GWC015 1.49ha 2384 trees*	*1b/6498 GWC003 0.39ha 624 trees*	*1c/8567 GWC005 0.22ha 352 trees*	*1d/0710 GWC07 1.0ha 1600 trees*	*1e/3530 GWC009 0.22ha 352 trees*	*1f/4630 GWC011 0.81ha 1296trees*	*1g/5424 GWC013 0.17ha 272 trees*	*TOTAL TREES 6880*
Sessile oak	**10**	238	62	35	160	35	129	27	686
Cherry	**10**	238	62	35	160	35	129	27	686
Aspen	**10 (+slack)**	242	66	40	160	40	138	32	718
Alder	**10**	238	62	35	160	35	129	27	686
Rowan	**10**	238	62	35	160	35	129	27	686
Crab	**10**	238	62	35	160	35	129	27	686
Hawthorn	**10**	238	62	35	160	35	129	27	686
Hazel	**5**	119	31	17	80	17	64	13	341
Goat willow	**5**	119	31	17	80	17	64	13	341
Elder	**5**	152	31	17	80	17	97	13	407
Blackthorn	**5**	119	31	17	80	17	64	13	341
Holly	**5**	119	31	17	80	17	64	13	341
Dog rose	**5**	86	31	17	80	17	31	13	275
PLOTS+		100	0	0	100	0	300	100	600



318 - LOWER HARGLODD FARM (4.3HA 1600/HA – TOTAL 6880 TREES)


Leave unplanted
Small groups of 32 shrub species only
1D / 0710 - 1ha
1600 trees
Plot - 100 trees unplanted

1a/015 - 1.49ha
2384 trees
Plots - 100 unplanted
Note - there will be trails marked on ground thru here
- plant clusters of shrubs along these
30 shrubs only in each
60 shrubs only in each
1b/6498 - 0.39ha
624 trees
No plots


PROW
1c / 005 - 0.22ha
352 trees
No plots

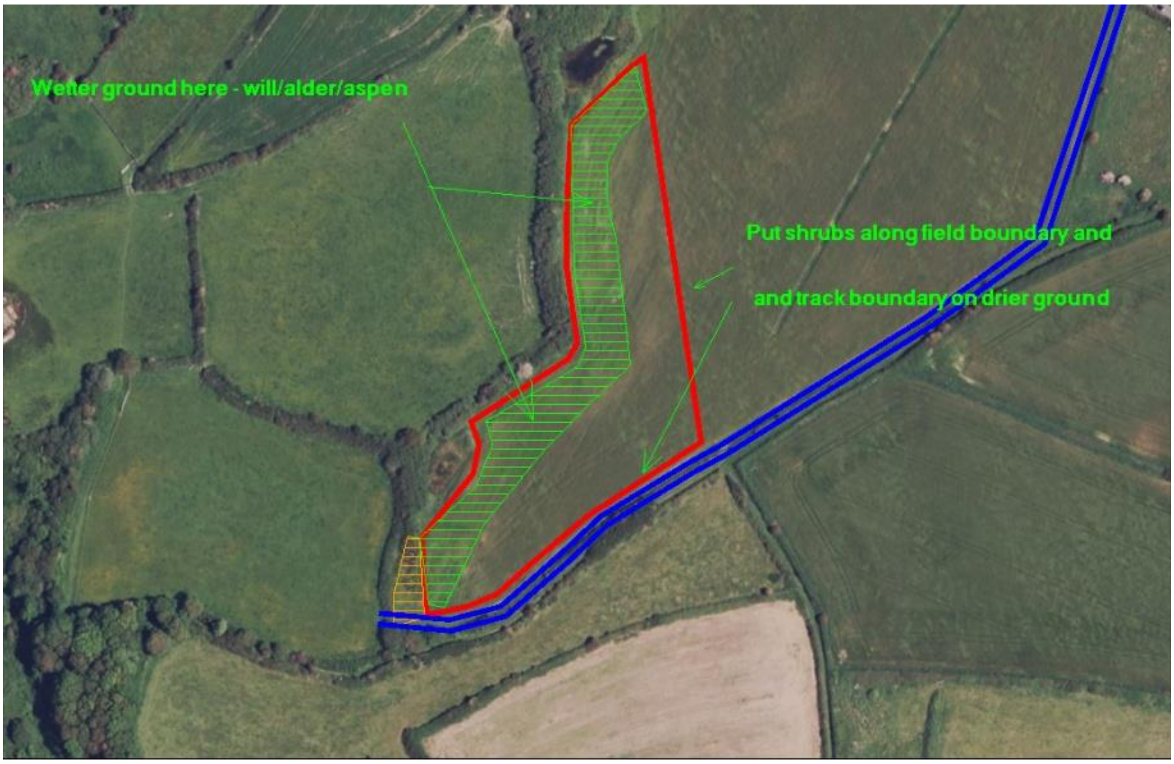
Appendix G – Planting plans, Penweathers

H W Forestry planting plans for Penweathers. Treat blue as shrubs, green as trees and shrubs, red as trees. All numbers are approximate due to tree availability at the time of planting.

SPP	*%*	*TOTAL TREES*
Sessile oak	**20**	**304**
Alder	**20**	**304**
*Aspen**	*~5*	*80*
Rowan	**10**	**152**
Crab apple	**10**	**152**
Hawthorn	**10**	**152**
Hazel	**10**	**152**
Grey willow	**~7**	**100**
Goat willow	**~8**	**124**
Total	**100**	**1520**

Downy birch was mistakenly included in the planting plan (30%, 456 trees). The number of other species was increased to account for this at the time of planting and downy birch was not planted. During planting, the contractor was also concerned how wet the ground was (see below) and so also included grey willow and goat willow and increased the number of alder. We have attempted to estimate the changes in the Table above, but the number of trees of each species planted was not recorded and so all numbers are approximate.

*Although aspen was not included in the planting plan, it was included in experimental areas only.



Appendix H

Parc y Bont

Cover crop establishment

Left and right: The planting area – May 2022.

Left: Sowing Parc y Bont; Right: The seedlings germinating – looking largely like just grass.

White clover

Left: White clover starting to come through – August 2022; Right: White clover starting to establish – August 2022.

Left and right: White clover - September 2022.

Left: White clover – January 2023; Right: Experimental plot in white clover – March 2023.

Left: Ride through the white clover area – May 2023.

White clover + yellow trefoil


Left: White clover + yellow trefoil – August 2022; Right: Cattle grazing white clover + yellow trefoil – September 2022.


Left and right: White clover + yellow trefoil – December 2022.


Left: Rotovating rides through white clover + yellow trefoil – January 2023; Right: White clover + yellow trefoil – January 2023.


Left and right: Experimental plot in the white clover + yellow trefoil – January 2023 (left) and March 2023 (right).


Left and right: White clover + yellow trefoil experimental plot – May 2023.

Vineyard fertility building mix


Left: Vineyard fertility building mix well-established – August 2022; Vineyard fertility building mix – September 2022.

Left and right: Vineyard fertility building mix dying off – December 2022.

Left: Rotovating rides through vineyard fertility building mix; Right: Dead ground cover of vineyard fertility building mix – January 2023.

Left and right: The experimental plot in the vineyard fertility building mix in January (left) and March (right) 2023.

Left: Vineyard fertility building mix to the far side of the ride – May 2023.

Parc Newi

Control


Left and right: Control area – January 2022.

Left: The field in May 2022.


Left and right: Spreading wildflower-rich green hay in the control area – January 2023.


Left and right: Tree planting in the control area – January 2023.


Left: The cows having escaped into the non-experimental areas – April 2023; Right: Ragwort patch in the control area – July 2023.


Left: Yarrow flush in one of the rides of the control area – July 2023; Right: An abundance of common knapweed in the experimental control area – July 2023.

Cartwys

Left: The planting area – May 2022; Right: leftover hay from over-winter feeding on the planting area – May 2022.

White clover + yellow trefoil

Left and right: White clover + yellow trefoil – September 2022.

Left: White clover + yellow trefoil – September 2022; Right: White clover + yellow trefoil mid-woodland planting – January 2023.

Left: White clover + yellow trefoil experimental plot – March 2023.

White clover

Left: White clover, with arable (annual wildflower) re-growth in the background – September 2022; Right: White clover – September 2022.

Left: White clover – December 2022 – before grazing by cattle; Right: White clover smothered by Yorkshire fog before grazing with cattle - December 2022.

Left and right: White clover after grazing with cattle, showing overwinter poaching – January 2023.

Left: White clover experimental plot – March 2023.

Left: Strimmed trees in the white clover area – May 2023.

Vineyard fertility building mix


Left and right: Vineyard fertility building mix well-established – August-September 2022.


Left: Vineyard fertility building mix – January 2023; Right: Vineyard fertility building mix mid woodland planting – January 2023.


Left and right: Strimmed trees in the vineyard fertility building mix – May 2023; Right: The willow tunnel and two standard rowan trees next to the vineyard fertility building mixture plot – May 2023.


Left and right: Strimmed trees in the vineyard fertility building mix – June 2023.


Left: Vineyard fertility building mix with a flush of corn marigold and Yorkshire fog – July 2023; The willow tunnel and two standard rowan trees next to the vineyard fertility building mixture plot – July 2023.

The Hagard

Control


Left: Rotovating paths in the control area – January 2023; Right: Measuring out experimental plots in the control area - January 2023.


Left: Mulched trees in the control area – May 2023; The control experimental area – May 2023.

Right: Mown rides through the control area – July 2023.

Parc Ifan


Left: Cattle grazing control area – January 2022; Right: The planting area – May 2022.

White clover


Left and right: White clover experimental plot – March 2023.

White clover + yellow trefoil


Left: White clover + yellow trefoil experimental plot to the right of the picture, with vineyard fertility building mix plot to the left of the picture – March 2023; Right: White clover + yellow clover experimental plot to the left of the picture, with control plot to the right of the picture – March 2023.

Left and right: White clover + yellow trefoil experimental plot – March 2023.

Vineyard fertility building mix

Left: Vineyard fertility building mix in the foreground, control in the background – September 2022;
Right: Vineyard fertility building mix – September 2022.

Left: Vineyard fertility building mic experimental plot – March 2023.

Control

Left: Marking out the new fence line above control area – February 2023.

Non-experimental areas

The Roft


Left: Cattle grazing the planting area before ploughing – May 2022; Right: The field after ploughing.


Left and right: Early flush of creeping thistle in the Roft prior to planting – June 2022.


Left: The impenetrable spear thistle 'forest' – June 2023; Right: The site after cattle trampling – September 2023.

Left and right: Healthy trees among the thistles and docks - September 2023.

Left: Tubex shelters after cattle trampling and grazing – September 2023.

Parc Yet Wen


Left and right: The field before ploughing – May 2023.


Left: Rotovating paths showing humps to create microhabitats - January 2023; Right: Planting in Parc Yet Wen – January 2023.


Left: Planting in Parc Yet Wen – January 2023; Right: Interface between herbal ley and woodland edge and shady area mix – July 2023.

Left and right: Woodland edge and shady area mix – June-July 2023.

Left: Trees in the herbal ley – October 2023.

Left: Trees amongst the herbal ley before trampling of vegetation – October 2023. Most trees were not swamped with vegetation like this one; Right: Trees amongst the herbal ley after trampling of vegetation and mulching – October 2023.

Left: Trees amongst the herbal ley before trampling of vegetation – October 2023. Most trees had this level of vegetation around them; Right: Trees in a damp area of the woodland edge and shady area mix – October 2023.

Parc Yet Coch


Left: Ploughing the field – April 2023; Right: the woodland planting area – May 2022.


Left and right: Parc Yet Coch – October 2023.



Left: A tree smothered with grass – October 2023; Middle: The same tree after trampling down the grass - October 2023; Right: A healthy tree among the thistles – October 2023.

Additional photographs


Left: All the trees plus tree protection – still quite a bit of single-use plastic; Right: The trailer loaded with all the trees and protection for one field.


Left: Harvest mouse nest from inside a Tubex shelter in the Roft – September 2023; The same Tubex shelter with a holly tree inside - September 2023.