Cyfoeth Naturiol Cymru
Natural Resources Wales

Good Practice Guide

Forest Resilience Guide 3
Managing the genetic diversity of Welsh woodlands

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Crynodeb gweithredol

Mae'r Canllaw Arferion Da hwn ar gyfer pob rheolwr coedwigoedd a choetiroedd yng Nghymru. Mae'n un o dri chanllaw sy'n rhoi gwybodaeth a chyngor i gefnogi'r broses o wneud penderfyniadau ar gyfer rheoli'r amrywiaeth o goetiroedd Cymru, ac felly eu gwydnwch.

Mae'r canllaw hwn yn ystyried amrywiaeth genetig, a dylid edrych arno ochr yn ochr â'r ddau ganllaw arall yn ymwneud ag amrywiaeth strwythurol a rhywogaethol. Mae'r argymhellion a nodir yn y canllaw hwn yn cefnogi cydymffurfio â Safon Coedwigaeth y Deyrnas Unedig, sef y meincnod ar gyfer rheoli coedwigoedd yn gynaliadwy ar draws y DU.

Oherwydd natur dechnegol y canllaw hwn, darperir crynodeb gweithredol yn Gymraeg ac yn Saesneg, ond dim ond yn Saesneg mae'r brif ddogfen ar gael, yn unol â'n Safonau Cymraeg.

Mae coetiroedd yn tueddu i fod ag amrywiaeth genetig nodweddiadol, sy'n amrywio cryn lawer rhwng safle a safle. Caiff amrywiaeth genetig ei dylanwadu gan gytrefiad naturiol hanesyddol a phrosesau dethol naturiol, y safle lleol a'i amodau hinsoddol, yn ogystal ag arferion rheoli yn y gorffennol a phenderfyniadau ynglŷn â ffynonellau hadau (h.y. amrywiaeth a tharddleoedd y rhywogaethau a blannwyd). Mae amrywiaeth genetig yn ystyriaeth bwysig gan y bydd yn effeithio ar y graddau y gall rhywogaethau coed addasu i effeithiau tebygol newid yn yr hinsawdd yng Nghymru.

Mae amrywiaeth genetig yn bwysig ar gyfer gwydnwch coetiroedd, ond nid yw bob amser yn briodol i geisio'i "wella" mewn modd gweithredol. Mae amrywiaeth eang o fathau o goetiroedd, ac yn achos coetiroedd lled-naturiol (yn enwedig coetiroedd lled-naturiol hynafol), sydd eisoes yn amrywiol yn enetig yn aml, dylai'r pwyslais fod ar reoli'r amrywiaeth genetig er mwyn *cynnal* yr amrywiaeth naturiol bresennol. Mae hyn yn berthnasol i safleoedd coetiroedd eraill sydd â photensial ecolegol uchel, megis y rhai a ystyrir yn Safleoedd o Ddiddordeb Gwyddonol Arbennig (SoDdGA) ac Ardaloedd Cadwraeth Arbennig (ACA). Ar y llaw arall, mewn coetiroedd a blannwyd ac a reolir yn fasnachol, mae amrywiaeth genetig yn debygol o fod yn isel a gellir cymryd camau cadarnhaol i'w *chynyddu* a'i *gwella*.

Mae'r canllaw hwn yn esbonio amrywiaeth o ddulliau gwahanol o gael deunyddiau atgynhyrchu coedwigoedd (FRM). Deunyddiau atgynhyrchu coedwigoedd yw'r enw cyffredinol ar gyfer yr hadau, moch coed, toriadau a'r stoc plannu a ddefnyddir wrth sefydlu coedwigoedd. Caiff y dewisiadau ar gyfer rheoli amrywiaeth genetig eu trafod wedyn, gan wahaniaethu rhwng y dewisiadau ar gyfer rhywogaethau coed brodorol ac anfrodorol, ond cydnabyddir bod y rhan fwyaf o goetiroedd, os nad pob un, yn cynnwys elfennau o rywogaethau brodorol ac anfrodorol. Mae'r dewisiadau'n dechrau gyda'r mwyaf "naturiol" (e.e. adfywio naturiol) i'r rhai sydd wedi'u "cynorthwyo/addasu yn artiffisial" fwyaf (e.e. stoc sydd wedi cael ei wella). Trafodir perthnasedd y gwahanol ddewisiadau o ran rheoli gwahanol senarios plannu hefyd (ar sail gwahanol amcanion rheoli coetiroedd cychwynnol).

Mae pennod olaf y canllaw'n nodi argymhellion ynghylch sut y gallwn fynd ati i reoli amrywiaeth genetig yng nghoetiroedd Cymru, i'w gwneud yn fwy gwydn i'r effeithiau a ragwelir o ran newid yn yr hinsawdd, wrth barhau i ddarparu amrywiaeth o wasanaethau ecosystem a manteision lles.

Mae'r wyddoniaeth sy'n sail i eneteg coedwigoedd yn dal i ddatblygu ac mae llawer o drafod ynghylch y strategaethau gorau ar gyfer y dyfodol. Fodd bynnag, mae gwerth o hyd mewn bod yn rhagweithiol wrth reoli amrywiaeth genetig oherwydd gallai gymryd degawdau i sicrhau canlyniadau dymunol. Bydd y canllaw hwn yn cael ei adolygu o bryd i'w gilydd er mwyn sicrhau ei fod yn parhau i gynrychioli'r syniadau a'r ddealltwriaeth bresennol yn y gymuned wyddonol.

Executive summary

This Good Practice Guide is intended for all forest and woodland managers in Wales. It is one of three guides that provide information and advice to support decision-making to manage the diversity and hence resilience of Welsh woodlands.

This guide looks at genetic diversity and should be considered alongside the other two guides on structural and species diversity. The recommendations in this guide support compliance with the UK Forestry Standard (UKFS), the benchmark for sustainable forest management across the UK.

Due to the technical nature of this guide, an executive summary is provided in both Welsh and English but the main document is available in English only, in accordance with our Welsh Language Standards.

Woodlands tend to have characteristic genetic diversity, which varies considerably from site to site. Genetic diversity is influenced by historical natural colonisation and natural selection processes, local site and climatic conditions, and also past management practices and seed sourcing decisions (i.e. the diversity and provenance of the species planted). Genetic diversity is an important consideration as it will affect the extent to which tree species can adapt to the predicted effects of climate change in Wales.

Genetic diversity matters for woodland resilience but it is not always appropriate to seek to actively "improve" it. There are a broad range of woodland types and in the case of semi-natural woodlands (especially ancient semi-natural woodlands), which are often already genetically diverse, the emphasis should be on managing genetic diversity to *maintain* the existing, natural diversity. This applies to other woodland sites of high ecological potential such as those classed as Sites of Special Scientific Interest (SSSIs) and Special Areas of Conservation (SACs). In contrast, in planted and commercially managed woodlands, genetic diversity is likely to be low and positive actions can be taken to *increase* and *improve* it.

This guide explains a range of different approaches to sourcing forest reproductive material (FRM). FRM is the generic name for the seeds, cones, cuttings and planting stock used in forest establishment. Options for managing genetic diversity are then discussed, with a distinction made between options for native and non-native tree species although it is recognised that most, if not all, woodlands contain elements of both native and non-native species. The options start with the most "natural" (e.g. natural regeneration) to the most "assisted/artificially modified" (e.g. improved stock). The relevance of different management options to different planting scenarios (based on different primary woodland management objectives) is also discussed.

The final chapter of the guide makes recommendations about how we can approach the management of genetic diversity in Welsh woodlands, to make them more resilient to the predicted effects of climate change whilst continuing to deliver a range of ecosystem services and well-being benefits.

The science of forest genetics is still developing and there is much debate about the best strategies for the future. However, there is still value in being proactive in managing genetic diversity as desired outcomes may take decades to achieve. This guide will be periodically reviewed to ensure it continues to represent current thinking and understanding in the scientific community.

1 Overview

This Good Practice Guide is intended for all forest and woodland managers in Wales. It is one of three guides that provide information and advice to support decision-making to manage the diversity and hence resilience of Welsh woodlands.

This guide looks at genetic diversity and should be considered alongside the other two guides on structural and species diversity.

The recommendations in this guide support compliance with the UK Forestry Standard (UKFS), the benchmark for sustainable forest management across the UK and the standard against which compliance is evaluated for felling licences and forestry Environmental Impact Assessments (EIAs).

UKFS Requirements are split into two levels: **Legal** and **Good forestry practice**. Legal requirements are minimum statutory obligations, contravention of which could lead to prosecution. Good forestry practice requirements are non-statutory, but must be adopted to meet the UKFS. The information and advice in this guide will help forest and woodland managers meet the Good forestry practice requirements of the UKFS.

Recent legislation in Wales has recognised the need to embrace sustainability and emphasised the importance of resilience in achieving this. *The Well-being of Future Generations (Wales) Act 2015* aims to embed the principle of sustainable development and introduces seven Well-being Goals for Wales. The Act makes it clear that is about achieving all of the goals as an integrated set, not just a selected one or two in isolation, if multiple benefits are to be realised.

One of the well-being goals is "**a *resilient Wales***":

"*A nation which maintains and enhances a biodiverse natural environment with healthy functioning ecosystems that support social, economic and ecological resilience and the capacity to adapt to change (for example climate change)"*

One of the ways woodlands can be made more resilient is by improving their structural and species diversity and managing their genetic diversity. The need to accelerate woodland diversification is a key recommendation in Welsh Government's *Woodlands for Wales* strategy and supporting Policy Positions.

Positive actions to manage diversity can be taken at different scales: some measures can be taken at a stand level, whereas for others diversity at a whole woodland level can to be tackled. Both approaches, when combined strategically and at a landscape level, can make a significant contribution to healthier and more resilient woodland ecosystems.

The science of forest genetics is still developing and there is much debate about the best strategies for the future. The ability of trees to genetically adapt is not fully understood and the science behind this process needs further exploration, particularly in light of predicted climatic change. For this reason, the information presented in this guide will be periodically reviewed to ensure it continues to represent current thinking and understanding in the scientific community.

2 Introduction

2.1 Characteristics of genetic diversity

Woodlands tend to have characteristic genetic diversity, which varies considerably from site to site. Genetic diversity is influenced by historical natural colonisation and natural selection processes, local site and climatic conditions, and also past management practices and seed sourcing decisions (i.e. the diversity and provenance of the species planted).

2.2 The importance of managing genetic diversity

Genetic diversity matters for woodland resilience but it is not always appropriate to seek to actively "improve" it. There are a broad range of woodland types and in the case of semi-natural woodlands (especially ancient semi-natural woodlands), which are often already genetically diverse, the emphasis should be on managing genetic diversity to *maintain* the existing, natural diversity. This applies to other woodland sites of high ecological potential such as those classed as Sites of Special Scientific Interest (SSSIs) and Special Areas of Conservation (SACs). In contrast, in planted and commercially managed woodlands genetic diversity is likely to be low and positive actions can be taken to *increase* and *improve* it.

Genetic diversity in native tree populations is generally considered to be very high. Trees differ from other plant species in that they are long-lived, and they reach sexual maturity at a relatively late age which means they exist in populations where the generations overlap. They are also mostly wind-pollinated, or seed is dispersed by birds, which means that their sexually reproducing populations may extend over large geographic areas. These characteristics tend to maintain high levels of adaptive diversity.[1]

An example of how adaptive diversity is now helping to protect the long term future of one of our native species relates to Ash, which is threatened by Chalara Ash dieback:

> *"UK scientists have identified the country's first ash tree that shows tolerance to ash dieback, raising the possibility of using selective breeding to develop strains of trees that are tolerant to the disease[2]. The research team compared the genetics of trees with different levels of tolerance to ash dieback disease. From there, they developed three genetic markers which enabled them to predict whether or not a tree is likely to be tolerant to the disease – even whether it is likely to be 'mildly' or 'strongly' tolerant. One particular tree (nicknamed "Betty" in a woodland in Norfolk), they discovered, was predicted to show strong tolerance"*

However, this natural diversity may not be sufficient to ensure resilience and adaptability in the face of predicted climate change. It may well be that the species prevalent in Welsh woodlands *survive* due to their naturally wide genetic diversity, but that they are *compromised* in terms of their suitability for timber production, and their ability to deliver wider ecosystem services such as flood mitigation, carbon sequestration and landscape

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[1] Hubert J, Cottrell J (2007). *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note No. 86. Forestry Commission, Edinburgh.
[2] The findings, which could help ensure ash trees will thrive in UK woodlands, have been published in a report co-funded by Defra and the Biotechnology and Biological Sciences Research Council (BBSRC). https://www.gov.uk/government/news/a-new-breakthrough-on-ash-dieback

enhancement. This is why we must ensure that we manage the genetic diversity of our woodlands so they are more resilient in the future.

Most commercial forestry in Wales and in the UK relies on a small number of non-native conifers, many of which were originally sourced from places such as the north west of America but also from central and northern Europe and the Far East. It is known from this history of importing seed that forest genetic resources have the capacity to adapt to conditions that are very different from those experienced in their native area. For example, key productive species in Wales include Sitka spruce and Douglas fir, both of which are native to North America.

In the case of native tree species, not all are of local origin and there is a history of sourcing seed and or plant material from more southerly provenances to improve growth. When done carefully, in many cases this has provided to be highly successful. However, due to predicted climatic change, what has worked in the past may not necessarily work in the future:

> *"for long-lived species like trees, populations have experienced natural selection, possibly over multiple generations, on a given site. However, the original population on which natural selection acted consisted only of those seedlings present at the start of selection. They may not have the genetic diversity or phenotypic plasticity to guarantee good performance under changed conditions. A different population from further away, which may have experienced selection under conditions more like those forecast for the site to be reforested, might represent a more suitable seed source."*[3]

The issue therefore is that our current sourcing practices are not necessarily "future-proof". Consequently, there is need to re-appraise our approach to the selection of forest reproductive material (FRM), to understand the current risks and how these can be minimised in the future through careful sourcing decisions. In practice, this means we need to question several key assumptions that have held true in the past:

- That local is best in most situations
- That local populations have enough genetic variation to cope with the effects of predicted climatic changes
- That even if sufficient genetic variation exists, the populations of tree species we have can respond fast enough to adapt to the predicted changes
- That increasingly refined tree breeding programmes for some key commercial species, with narrowing genetic diversity of parent material, will be an appropriate strategy.

2.2.1 The genetic conservation of native species

Table 1 can be used to help determine the relative importance of maintaining the existing genetic conservation of native species on a site. In practice, it may be difficult to identify the value of some stands against the criteria in Table 1, so "reasonable judgement" is the best that can be expected.

[3] Konnert M, Fady B *et al*. (2015). *Use and transfer of forest reproductive material in Europe in the context of climate change*. European Forest Genetic Resources Programme (EUFOGEN). Published by Biodiversity International Ltd.

Table 1[4]: Factors affecting an assessment of genetic conservation value

Factors to consider in selecting seed sources of native tree species	**Value levels** (in order of high to low importance for genetic conservation)
Factor 1: Value of the site for conservation	1. SSSI/SAC woodland 2. Ancient Semi Natural Woodland (ASNW) 3. Plantation on ancient woodland sites (PAWs) 4. Other semi-natural woodland 5. Other woodland 6. New afforestation – linked to semi-natural woodland 7. New afforestation – not linked to semi-natural woodland
Factor 2: Evidence for past planting/selection of main tree species on site	1. No indication of past planting and little selection for the species 2. No indication of past planting, but strong selection for a species 3. Past planting of local/unknown provenance 4. Past crop planted of non-local provenance
Factor 3: Proportion of the site affected by planting proposal, taking account also of past and likely future plantings	1. More than 80% 2. 61 – 80% 3. 41 - 60% 4. 21 – 40% 5. 1 – 20%
Factor 4: Current resilience	1. Species well-suited to site, mixed age, mixed species stands 2. Moderate suitability to the site, with some species and structural diversity 3. Uniform age and species composition, poorly suited to the site
Factor 5: Vulnerability of crop	1. Tree species not currently (or likely in the near future) to be susceptible to significant damage from pest or disease 2. Trees vulnerable but pest or disease not currently in the area (look to risk registers) 3. Pest or disease in the area but tree species not predicted to be especially vulnerable 4. Pest or disease in the area and the trees are known to be vulnerable

2.2.2 Increasing resilience to climate change

It is predicted that climatic change in Wales will result in an increasing risk to trees from pests and disease, there will be changes in the seasonal distribution of rainfall that will cause more frequent summer drought and winter flooding, and although the climate will become warmer, exposure will remain a limiting factor. Extreme weather events such as high rainfall, storms and high winds are also expected to become more frequent. These changes are a particularly significant issue in relation to both genetic and tree species

[4] Kirby K. *Trees species and provenance choice in high-value conservation sites*. The Royal Forestry Society, Quarterly Journal of Forestry.

diversity, as the genetic diversity of tree species will influence the extent to which they can adapt (i.e. how resilient they are) to predicted climatic impacts[5,6]:

3 Understanding approaches to the selection of FRM

FRM is the generic name for the seeds, cones, cuttings and planting stock used in forest establishment. In Wales, FRM for native tree species tends to be selected from local seed zones. For non-native trees, the trend is for increasingly refined genetic stock. These approaches, and others, are explained in more detail in this section.

3.1 Regions of provenance and seed zones

The current system for identifying "local" seed sources required under many grant systems and encouraged under the current UK Woodland Assurance Scheme (vs 3.1) is as set out in a Forestry Commission Good Practice Note[7]. In this document, Great Britain is divided into four regions of *provenance* (see Figure 1). These are defined areas within which similar ecological and climatic characteristics are found. They provide an administrative tool for specifying the sources of FRM rather than anything grounded in genetic science[8]. For native species, these regions of provenance are further split into a total of 24 non-statutory *seed zones*. These are in turn divided, where appropriate, into two altitude zones: below 300m and above 300m[9]. In Wales, there are two seed zones, East Wales (304) and West Wales (303).

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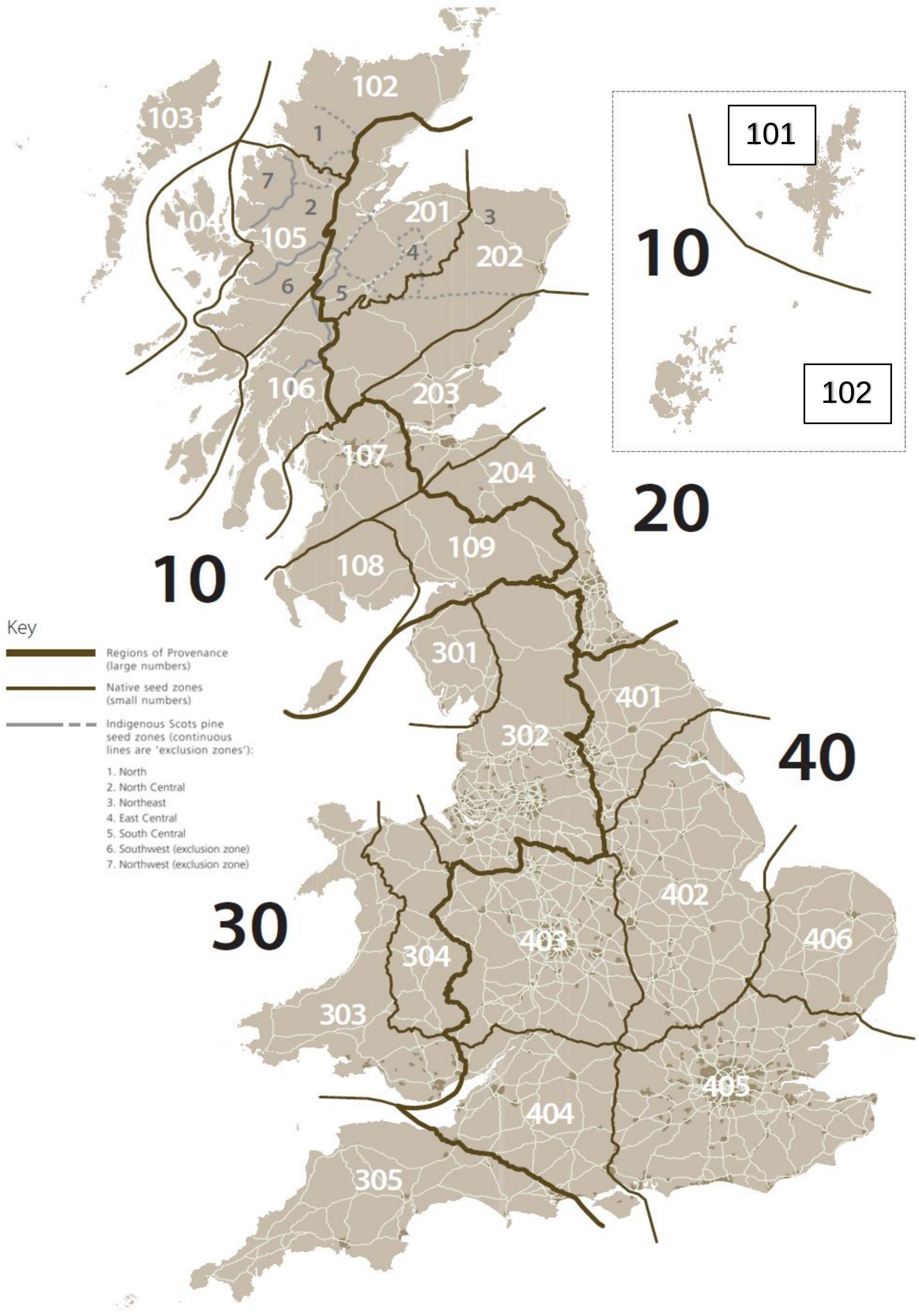
[5] Ray D (2008). *Impacts of Climate Change on forests in Wales*. Forestry Commission Information Note 301. Forestry Commission Wales.
[6] Read H J *et al* (2009). *Combating climate change - a role for UK forests*. The Stationary Office, Edinburgh.
[7] Herbert R, Samuel S, Patterson G (1999). *Using Local Stock for Planting Native Trees and Shrubs*. Forestry Commission Practice Note No.8. Forestry Commission, Edinburgh.
[8] Hubert J, Cottrell J (2007). *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note No. 86. Forestry Commission, Edinburgh.
[9] Forestry Commission (2007). *Forest Reproductive Material: Regulations controlling seed, cuttings and planting stock for forestry in Great Britain.* Forestry Commission, Edinburgh.

Figure 1: Regions of provenance and seed zones in Great Britain [10]

Regions of provenance and seed zones in Great Britain (including zones for indigenous Scots pine.)



10 Herbert R, Samuel S, Patterson G (1999). *Using Local Stock for Planting Native Trees and Shrubs*. Forestry Commission Practice Note No.8. Forestry Commission, Edinburgh.

However, the current approach using seed zones to identify what is “local” is not as robust as it could be. No other ecological factors are taken into account and all tree species utilise the same zones, whereas most continental systems have different seed zones for different species. For example, in Wales seed zone 303 stretches from Anglesey, down the Western side of Wales and as far as the Wye valley. This area is subject to a considerable variation of both site type and climate and native trees will have adapted to these variations. For this reason, making a decision on FRM purely on the basis of seed zones has limitations in terms of identifying appropriate material for any site.

3.2 Ecological Site Matching (ESM)

An alternative approach[11] which overcomes some of the shortcomings of the provenance and seed zone system, involves matching seeds to a site taking into account climatic characteristics such as warmth (likely frost occurrence), as well as soil moisture and exposure (aspect and altitude). This is known as Ecological Site Matching (ESM).

By way of an illustrative example, if the aim was to choose an appropriate Birch seed for a high elevation exposed site on the western side of Wales, the ESM approach could be used to identify a seed source that is as closely matched as possible using the criteria listed below:

1) Same or adjoining seed zone (see Figure 1 and Table 4)
2) Similar elevation/exposure (best match possible): > or < 300m elevation is the minimum requirement here
3) Predicted climatic zones due to climate change[12] (see also section 3.3)
4) Rainfall (summer and winter) : check soil moisture deficits from Forestry Commission’s online Ecological Site Classification (ESC) tool
5) Similar soil type: identify broad soils groups and match with ESC data for tree species suitability
6) Similar likelihood of late/early frosts
7) Similar distance from the coast (continentality).

The intention should be to make the best seed match possible, but compromises may be necessary as ESM has its own limitations, including:

- the resource required to do the comparison
- a close match may be difficult to find and some factors may be difficult to determine
- long term planning is required, e.g. many less well used species may have very limited seed sources available so ensuring availability and the practicality of managing the seed within nurseries may prove to be prohibitive.

3.3 Predictive or composite provenancing[13]

Another alternative approach is predictive or composite provenancing, both of which require “climate matching” either a proportion or all of the FRM used to plant on a site. If only a proportion of FRM is matched, it is known as composite provenancing. If all FRM is matched, it is known as predictive provenancing. Both approaches will bolster existing

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[11] Hubert J, Cottrell J (2007). *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note No. 86. Forestry Commission, Edinburgh.
[12] Ray D (2008). *Impacts of Climate Change on forests in Wales*. Forestry Commission Information Note 301. Forestry Commission Wales.
[13] Hubert J, Cottrell J (2007). *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note No. 86. Forestry Commission, Edinburgh.

genetic resources as the plants are sourced from areas currently experiencing a climate similar to that predicted at the planting site in the future. Whilst the climate may be broadly similar, there are risks associated with this approach, for example a lack of frost hardiness in occasional cold winters.

Seeds are usually sourced from a more southerly provenance. Historically it has been considered safe to do this for two degrees of latitude south and to remain in a similar longitude. Sourcing seed of native species from more easterly continental climates has always been considered inadvisable, as the climate of inland continental Europe is quite different. In Wales, it is also important to identify crops with similar continentality (closeness to the coastal influences of climate). Two degrees latitude south of mid Wales is Cornwall and Devon.

As explained in Section 3.1, seed zones 303 and 304 cover Wales. However, as shown in Table 2, other UK seed zones may be suitable for consideration as the source of seed for native species planting in Wales based on predicated climatic changes. However, It is recognised that most, if not all, woodlands contain elements of both native and non-native species so the information in Table 2 will need to be balanced with overall management objectives and woodland types. Furthermore, for sites such as SSSIs and SACs, the information in Table 2 is likely to be too coarse, and the need to source seed as locally as possible is likely to be the overriding factor.

Table 2: Selection of seed sources for native species based on current and future climate scenarios

Seed Zone	Area covered	Current climate - suitability for ESM	Future climate - suitability for climate change matching
302	Lancashire/Pennines	**Medium** - Potentially could climate match (ESM) with NE Wales	**Medium –** Possibly suitable to use seed from this area in NE Wales, not likely to be first choice.
303	West and South Wales	**High** - Seed from this area could likely be matched to most of East Wales with the exception of seed from the most exposed coastal areas	**High** - this seed will likely remain suitable for use in this zone
304	East Wales	**High** - Seed from this area could likely be matched to most of West and South Wales with the exception of the most exposed coastal areas	**High** – this seed will likely remain suitable for use in Wales including West and South Wales excluding the most extreme elevations and coastal areas
305	Cornwall and Devon	**High** - This area will likely have sites that could be ecologically matched to West or South Wales and seed should be considered from this area.	**High** - Currently a close climate match with much of Western and upland Wales. Both areas are likely to become more seasonally drier (Summer droughts) and winters wetter but the warmer climate of Cornwall and Devon, plus the similar coastal influences mean seed from this area should be considered for predictive climate matching
403	English Midlands	**High** - This area will likely have sites that could be ecologically	**High –** The drier climate of the English midlands could be

		be matched to East Wales and seed should be considered from this area.	suitable for particularly the lower Eastern elevations of Wales in the future
404	Bristol Channel, Somerset, Wiltshire, Dorset to the Isle of Wight	**High** - This area will likely have sites that could be ecologically be matched to East or South Wales and seed should be considered from this area.	**High** - Potentially the current climate of this area could be matched with future predicted climate for southern and Eastern Wales

If native tree species are being grown where timber production is of primary concern, planting stock from maritime areas of NW Europe could be considered. It has been successfully done in the past and could continue to be part of the suite of seed sources used. Climate change predictions have suggested that the climate in Wales may resemble that of a far lower latitude. For example, the climate in Brechfa (Camarthenshire) in 2080 is predicted to be similar to Quimper in Brittany which is 3.5 degrees south of Cardiff. At the extreme end of predictions for 2080, the climate could be similar to that in Santander, in northern Spain, which is 8 degrees south of Cardiff. However, the greater the distance from Wales, the greater the risk in terms of seed sourcing. It is best to seek advice from Forest Research regarding which specific continental seed sources may be suitable for any specific site and consider composite provenancing as the preferred option.

3.4 Commercial approaches for non-native species

For commercial timber growers, yield, form and achieving specific mechanical properties for their respective timber markets are the basis of breeding programmes where they exist Breeding programmes will be based on the selection of superior trees as parent material. These trees can be used to produce FRM either by sexual reproduction through seed (seed orchards, parents or families), or by asexual reproduction through vegetative propagation (clones, clonal mixtures)[14].

Breeding programmes are highly refined for Sitka spruce, less so for Douglas fir and non-existent for many species[15]. Most Sitka spruce planting stock now comes from this "improved" stock. This is favoured by the processing sector as they value uniformity and opportunities for economies of scale. However to achieve this, tree breeding is potentially utilising more and more refined processes, fewer parents and reduced genetic variance[16] [17] [18], and there is a risk that such practices may increase the likelihood of damage by pests and diseases in the future as the trees are less resilient and able to adapt.

All original non-native stock of species were imported from specified provenances. In the case of Douglas fir and Sitka spruce, these came from the west coast of America. However, as these species have now being growing on some sites in Great Britain for several generations and through their own self-selection combined with thinning to favour the "best" features, a "locally adapted stock" could be considered to be developing in some

[14] Forestry Commission (2007). *Forest Reproductive Material: Regulations controlling seed, cuttings and planting stock for forestry in Great Britain.* Forestry Commission, Edinburgh.
[15] Lee S (2016). *New Breeding Plans.* Forest Research.
[16] Forestry Commission, *Operational Guidance Booklet 31 Seed Sources,* 2012
[17] Hubert J, Cottrell J (2007). *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note No. 86. Forestry Commission, Edinburgh.
[18] Forestry Commission (2007). *Forest Reproductive Material: Regulations controlling seed, cuttings and planting stock for forestry in Great Britain.* Forestry Commission, Edinburgh.

locations. This stock is adapted to the specific site conditions and has improved yield and form compared that of the original stock.

3.5 Imported stock of non-native tree species

Traditionally much of the seed for non-native species was sourced from abroad from their native ranges. Today, seed for most of the commonly used tree species is sourced from stands of that species that are now grown in the UK or Europe. However for some of the less commonly found trees that are being considered for use in Wales and the UK, it may still be appropriate/necessary to source seed from its native range outside the UK.

There is a potential plant health risk associated with importing stock and this should be taken into account in sourcing decisions. There are many pests and diseases that can seriously damage crops and plants in the UK. The risks involved in importing plants are much higher than those involved in importing seeds if properly treated

To protect plant health, the Department for Environment, Food and Rural Affairs (Defra) sets policy and enforces controls and restrictions on the import, movement and keeping of certain plant and other materials such as soil. The Plant Health and Seeds Inspectorate (PHSI) is part of the Animal and Plant Health Agency (APHA) and implements and enforces plant health policy in England, and in Wales on behalf of the Welsh Government.

Plant health legislation controls the import and movement of certain plants, plant products, seeds and organic matter (such as soil). Controls differ according to the species (and whether or not they are classified as quarantine organisms), and whether they are being imported from within or outside the EU) but could include the need for classification, a phytosanitary certificate, a plant passport and/or inspection requirements. Some plants and plant produce are prohibited from entering this country from outside the EU while others must meet certain requirements and be accompanied by a phytosanitary certificate. Comprehensive guidance is available on the UK Government website.

3.6 Seed stands

These are good quality stands registered as potential seed sources on account of a number of superior characteristics e.g. growth, form, tree health. Normally they are registered relatively late in their life when it is possible to judge, after thinning, that the likely quality of the final crop will be good.

4 Options for managing genetic diversity

4.1 Assessment of management options

Table 3 presents a range of options for managing genetic diversity, and considers the advantages, disadvantages and suitability of each. A distinction is made between options for native and non-native tree species but it is recognised that most, if not all, woodlands contain elements of both native and non-native species. Within Table 3, the options start with the most “natural” to the most “assisted/artificially modified”.

Table 3: Options for manage genetic diversity

No	Option	Advantages	Risks/limitations	General comments
Maintaining genetic diversity				
1	Natural regeneration **Relevant to: native and non-native**	• Providing the trees have been on the site for a long period and natural selection and thinning of preferred trees has been completed, the remaining trees should be considered the most optimal for the site [19]. • If a process of continual regeneration is being followed this allows for genetic adaptation to occur as a result of climatic change. • The local genetic makeup is preserved with only natural processes of gene flow occurring. • Can be cheaper and encourages rapid reinstatement of woodland conditions with site adapted materials. • Maintains local genotypes	• Limited to working with the genetic variability of the crop that exists on the site with no opportunity to widen the genetic diversity. • No accounting for any significant changes to the climate of the site. • Regeneration may not take place or can be unreliable depending on site conditions, type of species.	• This is the default option for use on SACs, SSSIs, and ASNWs of high ecological value. There is a presumption against planting in these areas, unless there are exceptional factors that rule out successful natural regeneration within an acceptable timescale, or for operational reasons where tree woodland canopy needs to be reliably re-established following illegal felling. • Can be used on any site where there is confidence in the parent crop (species/genetic traits). • Wider adoption of LISS to improve structural diversity will support more use of natural regeneration.
2	Coppicing (including coppicing with standards) **Relevant to: native and non-native**	• Rapid, cheap establishment with no/limited restocking or establishment costs. • Rapid new establishment of woodland condition. • Genetic conservation – can maintain and preserve current site genotypes in some situations • Historic/cultural continuity of management • Mimics natural processes.	• Low risk option, mainly because of the short rotations involved (i.e. less risk of climatic changes within rotation period of < 20 years) • No changes in genetic stock or species possible unless enrichment of failed coppice occurs. • If there is a need to change the genetic stock then this is not an option. • Only available to those species which coppice well.	• Specifically aimed at short rotations (unless coppice with standards). • Has ecological niche providing a succession of habitats but also a strong cultural history in native woodlands. •

[19] Hubert J, Cottrell J (2007). *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note No. 86. Forestry Commission, Edinburgh.

Improving or increasing genetic diversity				
3	Local provenancing and seed zones (see Figure 1) **Relevant to: native**	• This is the current method of matching seed to sites. • Some matching of source and destination is occurring to ensure suitability of planting material but elevation must be taken into account. • Is a second best option where a good ESM cannot be found.	• Where climatic conditions are not uniform within a seed zone (e.g. in Wales), small but locally significant climatic variations may be overlooked which could cause problems. • Seed is not always available from the local provenance for some species. • Doesn't take into account climatic changes to the destination site that may occur. • Approach does not take into account that different species have different adaptive capacity within differing topographical and climatic factors.[20]	• Can be considered in exceptional circumstances for SACs, SSSIs, ASNWs of high ecological value, where natural regeneration is unlikely to occur (NB: natural regeneration is the default option) • Make best match with target site to be planted.
4	Ecological site matching (ESM) **Relevant to: native and non-native**	• Close match of planting site to a well suited seed source. • Trees planted should be well adapted to the destination sites conditions, soils and current climate.	• Sourcing appropriate seed that is from a matched site may be difficult and systems will need putting in place to ensure this works. • Doesn't take into account predicted climatic changes to the destination site that may occur. • Needs continuity and guarantees from nursery sector in sale of ESM trees. • Requires continuity in the private sector, for example in relation to grant provision • Requires good quality planning in the public sector with long term commitments.	• Can be considered in exceptional circumstances for SACs, SSSIs, ASNWs of high ecological value, where natural regeneration is unlikely to occur (NB: natural regeneration is the default option) • Use as part of portfolio or composite provenancing as outlined in Option 6.

[20] Hubert J, Cottrell J (2007). *The Role of Forest Genetic Resources in Helping British Forests Respond to Climate Change*. Forestry Commission Information Note No. 86. Forestry Commission, Edinburgh.

5	Selected stands - seed selected from seed stands. **Relevant to: non-native**	• These will have been specially selected stands for their characteristics but also they will be proven to be adapted to the site (local climate, conditions etc.) • Requires a less vigorous process of inspection.	• Doesn't take into account climatic changes to the site that may occur. • Not as good quality as seed stands selected from plus trees / orchards, clonal material.	• Use where improved growth/form is required but there are limited orchards and limited or no breeding programmes, e.g. for some of the emerging new species • Identification of theses stands will be important and may prove to be the best source of locally adapted trees.
6	Composite provenancing (sometimes known as a "portfolio approach") **Relevant to: native and non-native**	• In theory, there are the advantages of using local material (planted and or natural regeneration) and preserving local genetics plus the benefits of building in added security by introducing seed from climate matched sites that could increase the resilience of the crop to predicted climate change. • The introduced stock should, if well matched, help boost yield/quality of the site.	• High risk, particularly on upland sites where it is difficult to predict the effects of climate change where topographical changes and climate can vary considerably and there is a risk of the introduced stock failing due to poor site matching • Sourcing of additional material needs to be done carefully from appropriate sources that are free from disease. • Risk of "swamping" of local stock if the proportions of non-locally sourced stock are not correct and they grow at a faster rate than local stock in the early phases	• Appropriate for native broadleaved woodland establishment including ancient woodland with medium or low ecological value. • Source must be carefully chosen (see Table 2). • Consider a portfolio approach to non-native tree species at a strategic scale especially where a limited range of tree species is being used. • Consider source of existing local material in decision making process.

7	Predictive provenancing (also known as "assisted migration") **Relevant to: native**	• If climate changes as predicted this could be a good option as local stock increasingly becomes unsuitable. • If climate changes quickly as predicted this could be the best option. • Increased yields may occur from more southerly provenances if sites are well matched.	• High risk – assumes confidence in predicted climatic change but the risks can be reduced depending on where the source material is from i.e. keeping it within 2° latitude, within GB, will be less of a risk than parent material sourced from further afield. • Any local genetic / adaptation advantages could be lost. • Requires careful balance as planting must be suitable for current <u>and</u> future climate. Of concern are factors such as frost occurrence in the spring or autumn that may damage or kill stock sourced from seed from a more southerly latitude.	• Not appropriate for genetic conservation. • See Table 2 for range of suitable seed sources.
8	Imported stock of non-native tree species **Relevant to: non-native**	• This is a well refined process with good information on appropriate provenance for some of key species in Wales, less so for some of the new "minor" tree species. • Maybe the only source of seed for some minor species	• Plant health risks (and controls) associated with importation of plant or seed stock. Less information exists on suitable provenance for some of the more minor species. • Stock, although suited to sites, is not necessarily improved in yield and form	• Requires ongoing improvement in our knowledge of some minor species. • Recommendation is to use locally adapted stock/seed stands where available.
9	Improved stock Including: • seedling seed orchards • seed plantations • clonal **Relevant to: native and non-native**	• Potentially the biggest gains to be made in yield from this option, but it requires careful selection of parent material. • Trees will also have been tested for a range of qualities such as straightness of timber	• Risk of reduced genetic diversity, depending on parent material • Not adapted to predicted climatic changes	• Use where primary objective is maximise yield to minimise risk. • Shorter rotations might also reduce risk associated with long term climate change. • Seek advice from Forest Research for minor tree species.

4.2 The link between management options and planting scenarios

This section builds on the options presented in Table 3 and discusses these in relation to four key planting scenarios:

Planting scenario	Description
1	Planting in exceptional cases and where the primary objective of woodland management is biodiversity, e.g. SSSIs, SACs, ASNWs, sites with high ecological potential
2	Not ASNWs, SACs or SSSIs, but planting where the primary objective woodland management is still biodiversity but other objectives are also desired such as the production of timber
3	Planting where the objective is primarily timber production but there is a commitment to improve the ecological condition of the forest to improve resilience to climatic change
4	Achieving higher yields, shorter rotations or better timber quality (or a combination of all three) is the primary objective.

On the basis of these four planting scenarios, Table 4 identifies the preferred and secondary options from Table 3 for each scenario.

Table 4: Preferred and secondary options for managing genetic diversity based on different planting scenarios.

Scenario	Preferred options	Secondary option/s	Comments/suitable combinations
Planting in exceptional cases and where the primary objective of woodland management is biodiversity, e.g. SSSIs, SACs, ASNWs, sites with high ecological potential	1, 2	3, 4	• Natural regeneration is the default option as genetic conservation is of primary concern (see Table 1). • New planting will only be in exception circumstances. Seed should be sourced on the basis of local provenancing and seed zones and ecological site matching.
Not SSSIs, SACs or ASNWs, but planting where the primary objective woodland management is still biodiversity but other objectives are also desired such as the production of timber	1, 2, 4, 5 and 7	3	• Utilise a range of approaches but ensure a proportion of stock is either obtained from natural processes and / or best possible use of ESM • Genetic conservation likely to be an important consideration.
Planting where the objective is primarily timber production but there is a commitment to improve the ecological condition of the forest to improve resilience to climatic change	1, 4, 5, 6, 8 or 9	3, 6	• This applies to most productive forests in Wales • A Portfolio approach is likely to be best. It can be applied at stand, forest management unit or larger scale.

Scenario	Preferred options	Secondary option/s	Comments/suitable combinations
			• Greater emphasis here on improving growth and yield on the selection of choices.
Achieving higher yields, shorter rotations or better timber quality (or a combination of all three) is the primary objective...	2, 8, 9	7	• Rotations maybe less than 20 years so less risk of a mismatch between suitability and climate change • Single objective here is to maximise volume and returns from crops

4.3 Seed availability

Seed supply and availability are relevant to all the options and discussion in this chapter, and can be a significant limiting factor which hampers selection of the "preferred" option and results in selection of the "best match possible given the circumstances". Seed availability is already an issue within the forestry sector. The supply chain for seed and forest nursery tree supply requires long term planning, investment in identifying appropriate seed sources, maintenance of seed sources, investment in new or existing seed orchards or seed stands, and continuity of market demand to encourage forest nurseries to commit to both new tree species and the local provenancing. Some of the key issues are identified and explained in current research[21].

5 How to manage genetic diversity

This final chapter makes recommendations about how we can approach the management of genetic diversity in Welsh woodlands. The science of forest genetics is still developing and there is much debate about the best strategies for the future. However, there is still value in being proactive in managing genetic diversity as desired outcomes may take decades to achieve so forward planning is essential.

5.1 Recommendations for all woodland types

Recommendation 1: Review your current approach to managing genetic diversity and identify opportunities and future priorities (NB: this could be to maintain, increase or improve genetic diversity, depending on woodland type and management objectives etc.).

Recommendation 2:Determine the appropriate scale of possible action - stand, forest management unit, larger strategic scale.

Recommendation 3: Consider the range of options for managing genetic diversity and adopt a risk-based approach to inform your decision-making, based on woodland type and overall management objectives.

Recommendation 4: Plan your sourcing decisions well in in advance to support the forest nursery sector in suppling future needs.

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[21] Whitteta R, Cottrrell J, Cavers S, Pecurul M, Ennos R (2016). *Supplying trees in an era of environmental uncertainty: Identifying challenges faced by the forest nursery sector in Great Britain*. Land Use Policy 58 (2016) 415–426.

Recommendation 5: Be flexible in your approach as new evidence and research on genetic diversity becomes available, or unexpected events occur (e.g. faster than predicted climatic change). Flexibility includes acceptance of the constraints in the availability of suitable forest reproductive material which may require consideration of the "second or third best option" in some cases.

Recommendation 6: Establish and maintain a record of the source of forest reproductive material you use. This will enable long term evaluation of planted or established trees, how they have developed and enable better decision-making in the future. Use the information provided under the FRM Regulations to establish the origin or provenance of available planting material. Include a justification where non-local sources are used: this may include reasons such as tree vigour, timber quality, and long term forest resilience.

6 Summary

This guide explains the importance of managing genetic diversity, discusses the different approaches that can be taken, provides a range of useful tools to aid decision-making (Tables 1-4) and makes recommendations for future action.

By better managing the genetic diversity of Welsh woodlands, alongside improving their species and structural diversity, we will make them more resilient in the future to withstand and adapt to the predicted effects of climatic change, as well as ensuring that they continue to deliver a range of ecosystem services and well-being benefits.

Appendix 1: Sources of further information

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http://www.silvifuture.org.uk/

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Tree species: http://www.forestry.gov.uk/website/forestresearch.nsf/searchtreespecies
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http://www.futuretrees.org/