Cyfoeth Naturiol Cymru
Natural Resources Wales

Good Practice Guide

Forest Resilience Guide 2
Improving the tree species 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 rhywogaethau coed, a dylid edrych arno ochr yn ochr â'r ddau ganllaw arall yn ymwneud ag amrywiaeth strwythurol a genetig. 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 mathau arbennig o goetiroedd yn tueddu i gynnwys rhywogaethau coed nodweddiadol. Mae'r rhain yn rhannol naturiol, wedi'u dylanwadu gan dirwedd, y math o bridd, goddefiant uchder a chysgod, ac o ganlyniad i arferion rheoli yn y gorffennol yn rhannol. Yng Nghymru, mae ein coedwigoedd a'n coetiroedd yn cael eu dominyddu i raddau helaeth gan ystod gyfyngedig iawn o rywogaethau coed, ac mae llawer ohonynt yn cael eu plannu fel ungnydau un rhywogaeth. O ystyried y newid hinsoddol a ragwelir, a chynnydd tebygol yn nifer yr achosion o blâu a chlefydau, mae angen i ni wella'r amrywiaeth o rywogaethau coed er mwyn cynyddu gwydnwch coetiroedd Cymru.

Mae'r canllaw hwn yn trafod y ffactorau a'r newidynnau sy'n dylanwadu ar ddewis rhywogaethau coed, gan gynnwys parthau hinsoddol, math o goedwig, math o bridd a'i amlygiad, a phwysigrwydd graddfeydd (h.y. llannerch, clwstwr, bloc coedwig) ar gyfer gwneud penderfyniadau. Bydd gwahanol raddfeydd o amrywiaeth yn bodloni ystod wahanol o amcanion rheoli.

Mewn cyfres o "Dablau Rhywogaethau", caiff y rhywogaethau coed neu'r amrywiaeth o rywogaethau sydd fwyaf tebygol o fod yn addas i amrywiaeth o senarios gwahanol (ar sail parth hinsoddol, math o goedwig, math o bridd ac amlygiad) eu nodi. Mae'r Tablau Rhywogaethau yn grynodeb wedi'i symleiddio o wybodaeth hanfodol ac yn ganllaw: ond nid ydynt yn cymryd lle'r wybodaeth goedamaeth fanwl sydd ei hangen wrth wneud dewisiadau ar sail safle.

Mae pennod olaf y canllaw yn gwneud argymhellion ynghylch sut y gallwn ehangu a chynyddu'r amrywiaeth o rywogaethau coed yng nghoetiroedd Cymru. Bydd cynyddu'r amrywiaeth o rywogaethau coed yn gwneud ein coetiroedd yn fwy gwydn i newid yn yr hinsawdd, yn ogystal â gwella canlyniadau a chreu cyfleoedd am fioamrywiaeth,cynaeafu a marchnata cynnych pren a di-bren, a hamdden.

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 tree species diversity and should be considered alongside the other two guides on structural and genetic 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.

Particular woodland types tend to have characteristic tree species. These are partly natural, influenced by terrain, soil type, elevation and shade tolerance, and partly the result of past management practices. In Wales, our forests and woodlands are largely dominated by a very limited range of tree species and many are planted as single species monocultures. Given predicted climatic change, and a likely increase in the incidence of pests and diseases, we need to improve tree species diversity to increase the resilience of Welsh woodlands.

This guide discusses the factors and variables that influence tree species selection, including climatic zones, forest type, soil type and exposure, and the importance of scale (i.e. coupe, stand, forest block) in relation to decision-making. Different scales of diversity will meet a different range of management objectives.

In a series of “Species Tables”, the tree species or range of species that are most likely to be suited to a range of different scenarios (based on climatic zone, forest type, soil type and exposure) are then identified. The Species Tables are a simplified summary of essential information and a guide only: they do not replace the detailed silvicultural knowledge that is necessary when making site-based choices.

The final chapter of the guide makes recommendations about how we can broaden and increase the tree species diversity of Welsh woodlands. Improved tree species diversity will make our woodlands more resilient to climate change, and also improve outcomes and create opportunities for biodiversity, the harvesting and marketing of timber and non-timber products, and recreation.

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 species diversity and should be considered alongside the other two guides on structural and genetic 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.

2 Introduction

2.1 Characteristics of species diversity

Achieving good species diversity involves all, or some, of the following:

- making better use of the tree species commonly planted in Wales
- considering tree species not historically widespread in Wales that may become more suitable due to predicted climatic change
- adopting a silvicultural system that supports the use of range of species and mixtures

- identifying opportunities to create stands of mixed conifer and broadleaf
- making sure that any intimate, line or group mixtures are of compatible species
- using existing or expected natural regeneration to diversify stands where possible
- identifying opportunities for under-planting of other species to supplement natural regeneration
- taking opportunities to retain minor species when thinning or re-spacing.

Each woodland has its own character and will vary according to the nature of the woodland, its features, and the management objectives being followed. These characteristics may be evident at different scales: within a single forest, between woods locally, or across connected landscapes. Particular woodland types tend to have characteristic tree species. These are partly natural, influenced by terrain, soil type and elevation and to the degree of shade tolerance of the major tree species, and partly the result of past management practices.

Figure 1: Current status of Welsh woodlands[1]

The vast majority of our managed woodland is…	***Very little of our woodland is…***
planted single species, single aged (over half is coniferous) predominantly manged on clearfell & restock regime	***managed as a forest ecosystem using natural processes as a basis for management with tree species diversity at a variety of scales***
We need a wider spectrum of forest management systems in use and a reduction in the reliance of single species crops at a range of scales – stand, forest and landscape.	

The challenge is to manage the species (and structural and genetic) diversity of Welsh woodlands so they are more resilient in the future.

2.2 The importance of improving species diversity

In Wales, our forests and woodlands are largely dominated by a very limited range of tree species and many are planted as single species monocultures (particularly spruce when the forest is being managed for timber production). This is a risky strategy in light of future predicted climatic change, and a likely increase in the incidence of pests and diseases.

Improving tree species diversity can be expected to:
- increase the resilience of Welsh woodlands to the impacts of climate change
- increase the range and connectivity of woodland habitats and biodiversity
- increase the range of timber and non-wood products that can be harvested and marketed
- improve the visual impacts of forests at the landscape and macro scale
- improves recreational opportunities and potential new income streams.

[1] Adapted from "Policy Position in support of *Woodlands for Wales*, the Welsh Assembly Government's strategy for woodland and trees. Welsh Assembly Government (September 2010) - http://gov.wales/docs/drah/publications/130424-welsh-woodland-en.pdf

2.2.1 Increasing resilience to climate change

The climate in Wales is predicted to change in a number of ways. Changes in the seasonal distribution of rainfall may cause more frequent summer droughts 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[2]. This is a particularly significant issue in relation to tree species diversity with the following likely impacts[3, 4]:

- There will be an increased risk from pests and diseases but it is not known which individual species will be most affected. Species of concern include oak processionary moth (*Thaumetopoea processionea*), gypsy moth (*Lymantria dispar*) and the European spruce bark beetle (*Ips typographus*).
- Soil moisture and the increased occurrence of droughts will increasingly become a limiting factor. This will affect a number of species, including Sitka spruce in some areas.
- There could be increased growth rates of some species, particularly in west Wales where the climate becomes warmer and soil moisture does not become limiting[3].
- The growing season will lengthen. Some species of tree will have earlier bud-burst and later dormancy, giving more frequent and prolonged lammas (late season) growth which may reduce timber quality.
- Mammal numbers including deer and grey squirrel are likely to increase. Milder winters with fewer frost days will reduce winter mortality, increase the survival of young, and increase damage to trees through browsing and bark stripping.
- There will be changing seasonal patterns of flushing and leaf-shed / dormancy.
- The epidemiology of tree diseases will change. For example, wetter and milder winters followed by droughty summers may predispose oak and other broadleaved species to root pathogens such as *Phytophthora cinnamomi*.
- There will be more waterlogged soil conditions (due to wetter winters), which will impact on the rooting depth of many tree species and therefore their stability. Some tree species are particularly unsuited to sites with seasonally fluctuating water tables from very wet to dry conditions, especially Beech and Douglas-fir.

As a result of these predicted changes, there is a need to use a wider range of species, at a range of scales and ensure that the species are well-suited to the site both now and in the future.

2.2.2 Pests and diseases

The increased risk of pests and diseases is not just in an issue in relation to predicted climate changes: pests and diseases are also an issue because of the increasingly global nature of trade which has led to a larger number of new pests and diseases being introduced to Britain. Recent examples of this include Chalara Ash Dieback and *Phytophthora ramorum*, which are already present, but there are also other concerns such as European spruce bark beetle (*Ips typographus)*.

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[2] Broadmeadow M, Ray D. (2005). Climate Change and British Woodlands. Forestry Commission.

[3] Ray D.(2008*). Impacts of Climate Change on forests in Wales*. Forestry Commission Information Note 301.

[4] Read HJ. et al (2009) Combating climate change - a role for UK forests. The Stationary Office, Edinburgh.

2.2.3 Improving woodland habitats and biodiversity

Many species are dependent on or closely associated with woodlands. These include European Protected Species, species identified by Welsh Government under Section 7 of the Environment (Wales) Act 2016, and those listed in the UKBAP and the Wildlife and Countryside Act 1981. Management for these protected and priority woodland species will usually require some intervention to create or maintain conditions for them to thrive.

Diversifying the tree species we currently use has the potential to increasethe range of woodland habitats, with positive impacts on biodiversity. For example, we currently have large areas of single species: introducing new tree species, even non-native ones, will change the nature of the woodland as they will grow at different rates, seed at different times of the year, have different rotation lengths, and may support different species of flora and fauna. Also, introducing new new species in appropriate places may help to buffer and link existing habitats, improving overall habitat connectivity and networks which will improve woodland resilence to future climate change.

2.2.4 Improving timber and wood fibre production

A woodland that is managed to promote increased tree species diversity will provide a wider range of timber and non-timber products and will allow more marketing opportunities with a range of species and products on offer. It may help ensure continuity of supply, as different species will be ready to harvest at different times, and more emphasis can be placed on the increasing the quality and value of products that are produced. However, these benefits can only be maximised if combined with improved forest management e.g. thinning of crops to maximise future log supply.

2.2.5 Improving woodlands for people

Increasing the range of tree species we use and planting them at a smaller scale will inevitable improve the landscape value of our woodlands. Traditional monocultures will gradually be broken-up into a more varied mosaic of tree species, which will of particular benefit in woodlands located close to communities and recreational areas.

2.3 The link to silvicultural systems

The choice of silvicultural system dictates how crops are maintained, harvested, and replaced and is one of the main factors influencing the species diversity of a forest. A silvicultural system has three main features[5]:

- the method of regeneration of the individual crops constituting the forest
- the form of the crop produced; and
- the orderly arrangement of the crops over the whole forest, with special reference to silviculture and protective considerations and efficient harvesting of produce.

Silvicultural systems include clearfell and a range of Low Impact Silvicultural System (LISS). It is the not the purpose of this guide to explain silvicultural systems *per se*, beyond their link and relevance to species diversity, but references and additional sources of information are provided at Appendix 2. Reference should also be made to Forest Resilience Guide 1 on Improving the Structural Diversity of Welsh Woodlands.

[5] Matthews JD. (1989). *Silvicultural systems.* Oxford University Press.

Typically, forests managed by a clearfell silvicultural system are characterised by poor species (and structural) diversity, i.e. uniform crops of a limited number of species. In contrast, forests managed using LISS tend to exhibit more species diversity as a wider range of species are needed to manage the forest in these scenarios. Some species have particular value in an intimate mixture or for under-planting only within LISS crops.

3 Factors that influence species selection

Tree species selection needs to take account of a range of factors and variables. In this chapter, we explain what these are and how they can aid decision-making to improve species diversity.

3.1 Climatic zones and forest type

Identifying the climatic zone that a woodland is located in is essential for both forest and site level planning. It can be done as a desk-based exercise. Climatic zones form part of the basis of the Forestry Commission's Ecological Site Classification (ESC) tool, which is a site-based approach to tree selection.

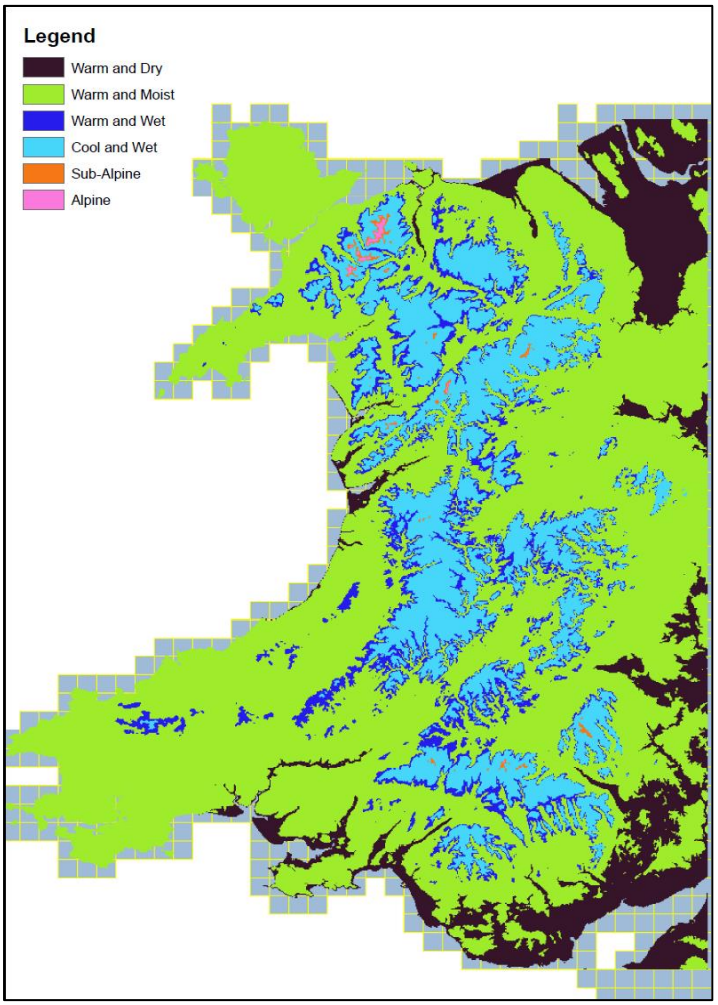
The ESC tool uses a combination of four climatic factors to identify climatic zones that relevant to choosing tree species:

- warmth
- wetness
- continentality (seasonal variability)
- windiness.

There are seven recognised climatic zones in Great Britain, but only six of these occur in Wales. Two of these, "Sub Alpine" and "Alpine" only exist at the tops of the highest peaks in Wales, above the tree line, so can be discounted. Another zone, "Warm and Wet" is an important transition zone between 300 -400 metres but is currently limited in extent in Wales (although it is predicted to increase due to predicated climatic change). Of the remaining three, two are widespread and one is limited to the south and east of Wales.

Figure 2: Distribution of climatic zones in Wales[6].

[6] Pyatt G, Ray D, Fletcher J. FC Bulletin 124 - *An Ecological Site Classification for Forestry in Britain.* Forestry Commission.



The largest zones are those of "Warm Moist" (below 400 metres) and "Cool Wet" (over 400 metres). At lower elevations, especially in the east and south, there are areas of "Warm Dry", and it is this climatic zone that is predicted to expand most in Wales under most climate change predictions[7].

These zones relate to elevation and geographical location. In Wales, the hills are steep and so climatic zones can change quickly over short distances. Analysis has shown a strong correlation between species choice and elevation within Welsh woodlands, diversification decreasing considerably over 400 metres.

Predicted changes to the climate zones in Wales (see Table 1) are important for both strategic and site planning and affect species choice.

Table 1: Main predicted changes to climate zones in Wales[7]

Climatic zone	Geographical / spatial extent	Implications of predicted climate change
Cool Wet	Close correlation with elevation > 400 metres.	Largely disappears under all scenarios and replaced with Warm Wet under lower scenarios and Warm Moist under higher scenarios.
Warm Moist	Most of the lower elevations in Wales (below 400 metres)	Will largely become restricted to higher elevations in the west
Warm Dry	Mainly below 50 metres in SE corner of Wales	Will increase significantly in extent from the east and could dominate Wales under high emission scenarios.

[7] Ray D.(2008*). Impacts of Climate Change on forests in Wales*. Forestry Commission Information Note 301.

The link between the three main climatic zones in Wales and forest types is shown in Table 2. The relevance of forest types to species selection is explained further in Appendix 1.

Table 2: Climatic zones and forest types in Wales

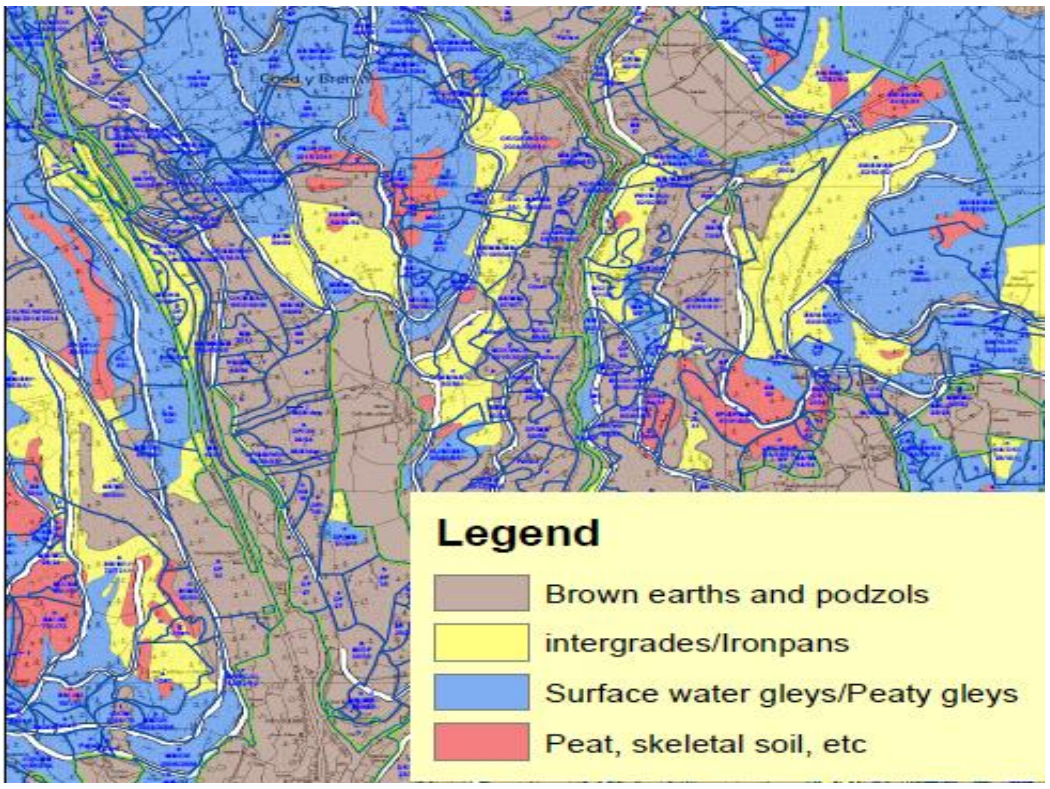
Dominant climatic zone	Forest type
Cool wet	Upland
Warm moist	Mixed woodland
Warm dry	Mixed forest / pine

3.2 Soil type

Identifying soil type, and making best use of variations in soils on site, is critical to achieving increased species diversity as certain species favour certain soils. It is important to note that soils vary considerably and it is often not easy to define them. For example, a brown earth can range from a very deep, fertile, completely free-draining soil on the best lower elevations, to either a very shallow upland brown earth or verging on a peaty-gley or intergrade at higher elevations. It is important to take these variations into account when selecting species. Soils and soil variations must be verified by site surveys.

Figure 3 is a simplified soil map as used on the WGWE GIS system to inform tree species selection. The soils have been grouped into broad categories and these categories are discussed in relation to species selection in chapter 5 and in Appendix 1.

Figure 3: Illustrative map showing soil variability (NRW)



3.3 Exposure

Evaluating the level of exposure is critical when choosing suitable tree species. The Forestry Commission's decision support tool ForestGALES can be used to help indicate the level of exposure at a strategic or forest scale and it has informed the list of tree species contained with the tables provided in Appendix 1. Detailed site assessments are still essential to determine actual exposure. To assess exposure it is necessary to consider the following factors:

- elevation
- aspect
- shelter (e.g. from nearby hills, or adjacent trees)
- topography and variations in the site (e.g. frost hollows).

The approach used in this document suggests categorising a site as follows:

- Exposed (DAMS[8] score >18): many species will be restricted by exposure and species choice will be limited
- Moderately exposed (DAMS 16-17): some limitation for those species most at risk to exposure.
- Moderate or sheltered (DAMS <15): most if not all species should be suitable to this area.

Plate 1: Photograph illustrating damage due to wind and exposure

Climate change predictions are unclear about changes to the 'windiness' of Wales. However there is a prediction of an increased occurrence of extreme weather including storms. Until further research is undertaken, it is recommended that current exposure conditions are used when deciding species choice. This, combined with use of a wider range of silvicultural systems, will help increase resilience to the risk of wind damage.

3.4 Delivering multiple benefits from woodlands

Woodlands provide a wide range of physical and non-physical benefits (or ecosystem services). These include the regulation of climate, purification of air and water, flood protection, soil formation and nutrient-cycling. They also provide timber and wood products, opportunities for recreation and an appreciation of nature.

The range of benefits that a woodland delivers is linked to the setting of management objectives for that woodland. For example, if the production of timber is the primary

[8] DAMS (Detailed Aspect Method of Scoring) from *ForestGALES - Calculating wind risk* (Forestry Commission). ForestGALES calculates the probability of wind damage to a stand in two stages by looking at information from the trees and the site.

objective, and the enhancement of biodiversity is secondary, then this will have an impact on the range of ecosystem services that the woodland provides.

Widening the range of tree species, if done in the right way will increase the value of trees and woodland in terms of delivering a wider range of ecosystem services compared to the benefits that any individual or group of species can offer. For example, an increase in the use of Birch in uplands areas on acidic soils, particularly in riparian areas, can improve soil quality by increasing the pH and therefore improving soil condition[9].

3.5 Economic considerations

Diversifying woodlands successfully means working towards a range of objectives, and securing a valuable forest resource in the long-term. This requires a recognition of the economic costs of change which should be factored into decision making. The following factors should be considered:

- establishment costs.
- intensity of management, particularly in managing intimate mixtures
- operational – harvesting costs.
- marketing – a wider range of products can have positive and negative implications.

These factors should not stop the process of species diversification but will need to be carefully considered in the planning stages.

4 The importance of scale

Increasing the range of species we use in Wales is critical to creating resilient forests, but the scale or scales at which this is achieved is also important. There are a range of options and each presents different opportunities and limitations. Scale is also linked to the choice of silvicultural system.

4.1 Defining scale

The following terminology is used:

- **Stand** (sub- compartment) – areas of forest comprising a more-or-less homogeneous crop in terms of age-class distribution, species composition and condition.
- **Coupe** – an individual management unit within a forest plan or forest design / resource plan, not necessarily fixed to clearly defined stand boundaries and of varying scale.
- **Forest block** – individual block of forest or woodland used as a management unit, can be any size.
- **Catchment** – as designated by the Centre Ecology & Hydrology (CEH) / Environment Agency Wales (EAW) water catchment maps for the Water Framework Directive (WFD) planning process at 1:50000.

4.2 Diversity options at different scales

In looking to increase diversity, the term “tree species mixtures” is often used but this can mean different things and can be set at different scales. Different scales of diversity will meet a different range of objectives. Table 3 identifies the range of planting scale options available, as well as issues related to their use and the opportunities (benefits) of using them. It should be noted that no single scale will achieve the full range of benefits, and it is essential in larger forest plans that a range of options are used to help create greater

[9] Evans J. (1984). *FC Bulletin 62 - Silviculture of Broadleaved Woodland*

diversity. It is important to ensure that the scale used is appropriate to the site conditions, the silvicultural management system, the tree species selected and management objectives for the site.

Table 3: Explanation of scale in relation to diversity options[10]

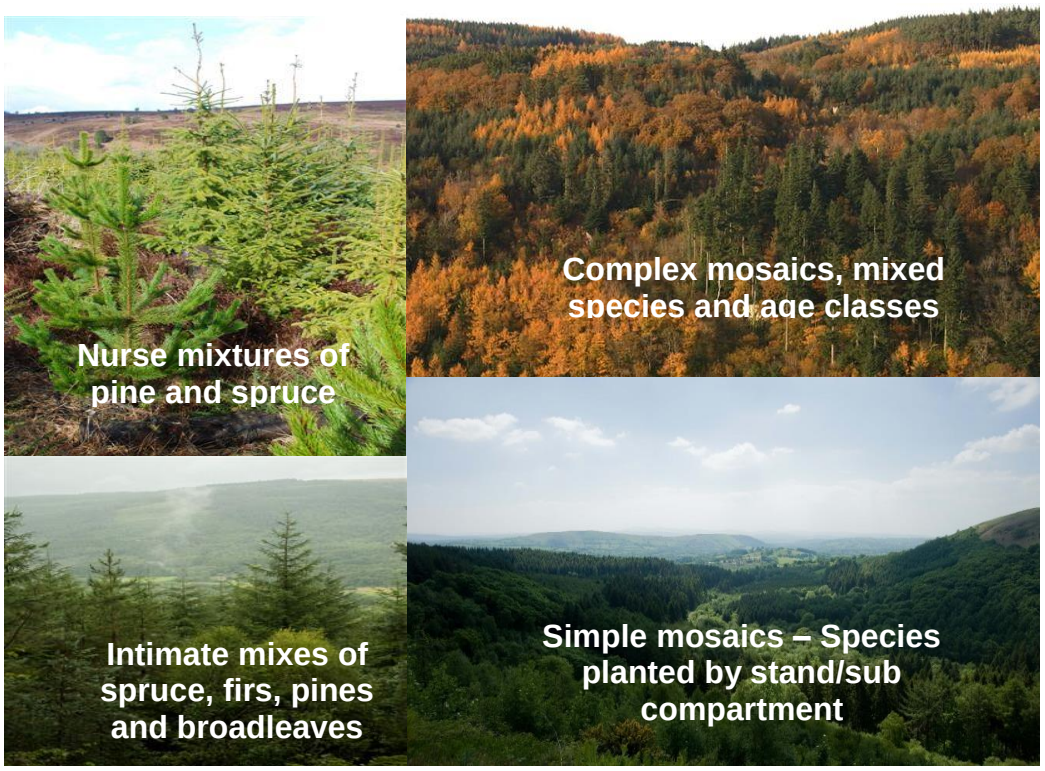
Scale of mixture	Definition	Limitations / Issues	Opportunities
Intimate or random mixtures within a stand*	Randomly planted trees with groups of individual species no larger than nine. Minimum standard: two or more species in an intimate or random mixture throughout a stand with each component permanently composing more than 25% of the canopy	• Operational limitations of working with multiple species. • Species should be well suited to growing together and / or shade tolerant. • Long-term intimate mixtures need compatible species and skilled management to maintain diversity. • It is more expensive to establish and harvest intimately mixed crops. • Management costs will be higher in more complex mixtures. • These types of crop are currently most commonly associated with Continuous Cover Forestry (CCF) management.	**Short-term** • Provide shelter from frost & exposure • Assist growth of species with poor apical dominance • Prevent check induced through N deficiency • Reduce epicormic growth • Provide early financial returns with long term crops **Long term** • Increase biodiversity • Increased protection e.g. against pathogens • Better defence against climate change • Increase range of site conditions e.g. light • More efficient use of site • Increased flexibility of management, manipulating crops over time to more diverse stands or to specific timber markets or other objectives • Increased range of products
Systematic line or group mixtures within a stand, groups up to 0.25ha*	Line mixtures can be easy to plant and establish but can develop in different ways. They can be managed to develop into intimate mixes or can be used as nurse crops where one of the species will eventually remain.	• Requires compatible species and, or, interventions on time to ensure species diversity is maintained. • Line mixtures should be avoided where landscape (including historic landscapes) is an important factor.	As above

[10] Generated by NRW in discussion with Forest Research

Scale of mixture	Definition	Limitations / Issues	Opportunities
	Groups: greater than 10 trees and up to a maximum of 0.25ha. Note for some species combinations it may be necessary to plant in groups of no less than 25 trees e.g. Oak in Norway spruce. Line: any combination of line mixtures designed to meet set objectives.	• Timely interventions will be needed in some circumstances to ensure one species doesn't dominate – This depends on the desired outcomes and species used. • Line mixtures can be easier to manage than groups. • The systematic nature of these can limit use of specific site features	
Mosaic - diversity measured at a Sub-compartment / stand scale - groups usually over 0.25ha but make take into account smaller site features	Two or more species at a coupe or compartment or sub compartment scale. Maximising diversity using discrete blocks of species usually greater than 0.25 ha within a compartment or coupe. No less than 0.1ha.	• Likely to be the option most often chosen by foresters for economic and simplicity of management reasons but the range of opportunities as set out above within a stand can be lost or compromised	• Planting a variety of species in mosaics which best fit species to site conditions will optimise the growth potential of species. • Can be relatively easy to manage and considered the best economic option usually
Strategic - Forest Block or catchment or larger	This can be defined at a range of scales but is intended for strategic planning and analysis	• Strategic scale is only intended for the purpose of analysis and informing more local decisions on tree species choice. • Use for development of future plans (Forest Resource Plans, other "forest" plans).	• Spatial analysis will inform a bigger picture of future opportunities for tree species diversity and analysis of the impacts of change. • Analysis and prioritization of specific species at this scale can inform future production forecasting of timber supplies • Inform plant and seed supply • To inform future long-term timber production.

*Note: When using intimate or line mixtures it is essential that tree compatibility is taken into account i.e. where permanent mixtures are proposed, that the species selected are compatible in growth rates, demand for light and regeneration.

Plate 2: Examples of tree species diversity at a range of planting scales.



The implications of scale and diversity / mixtures to the achievement of different management objectives is summarised in Table 4.

Table 4: Relevance of scale of diversity to the achievement of management objectives.

Management objective	Diversity/mixture Type (See also Table 3) (Note: Stars denote value of mixture type, 5 stars being the highest possible value)				Comment
	Intimate or Random mixtures	**Line / group mixtures**	**Mosaic Stand scale**	**Mosaic Catchment scale**	
Increasing biodiversity – stand scale	★★★★★	★★★★	★★★		Diversity is achieved by creating as wide a variety of habitats as possible within a given area ensuring that the diversity is at the right scale to be beneficial. Hence, although intimate mixes are considered beneficial in maximising diversity, consider using a range of structures and scales to maximise biodiversity opportunities.
Increasing biodiversity – forest or catchment scale.			★★★	★★★★★	
Increased protection against pests and diseases	★★★★★	★★★★★	★★★★	★★	Improving ecological health (and hence resilience) is better achieved with more intimate mixtures. Increasing the range of species at a strategic scale will improve overall resilience to attacks from individual pests or diseases.
Better resilience in the face of climate change	★★★★★	★★★★★	★★★★	★★★	It is important to consider diversity at all levels to increase resilience against the impacts of predicted climate change. As climate patterns shift, the suitability of species will change, but the predictions vary and are unclear, so it is important to utilise a range of species that are well suited to the site now and in most future climate change predictions.

Ecological or site improvement	★★★★★	★★★★★	★		The European Water Framework Directive and European Soil Framework Directive will put increasing pressure on all land managers to protect water and soils. Focus on improving the condition of the site by using a greater range of species including those that are known to improve site conditions.
Maximising yield based on species selection	★★★★	★★★★★	★★★★★		Often for simplicity of management, compromises are made to planting regimes. Planting more species suited to specific site conditions could increase yield and compensate for lost potential yield from establishing greater areas of native species.
Risk management	★★★★★	★★★★★	★★★		Improved species (and structural) diversity will achieve a wider range of objectives, and reduce overall risks.
Social outcomes (e.g. recreation, access, community engagement)	★★★★	★★★	★★★★★	★★	Improved species diversity, at a variety of scales, will improve the experience of all people using the forest, and potentially open up new opportunities.
Landscape enhancement, i.e. making sure the landscape value of trees and woodlands is considered in the planning and management of woodlands.	★★★	★★	★★★	★★★	Intimate mixtures or varied canopy structure may look better close-up, but have minimal benefit at a larger landscape scale. Varieties of species and structures at a mosaic or stand level may well create most benefit at this scale or combinations of scale.
Maximising economic output. Note: the economic output is not always timber.	★	★★★	★★★★	★★★★	There are economic implications of using more complex species mixtures. Delivering a wider range of objectives needs to be balanced with the costs of achieving these outcomes.

5 Species selection

Building on the information contained within Chapters 1-4, this chapter identifies the tree species or range of species that are most likely to be suited to a range of different scenarios. However, it is important to remember that whilst this information can be used as a good guide, only site inspections will give the detailed information required to make the correct silvicultural decisions and optimise the use of tree species available.

5.1 The "Species Tables"

Taking all factors into account, "Species Tables" have been created (see Appendix 1) to aid decision making about the range of species that may be suitable for any site, based on climatic zone, forest type, soil type and exposure.

It should be noted that the lists of species contained with the Species Tables are not exhaustive. If a species is not mentioned it does not mean it cannot be used if it is both suitable to the site and meets management objectives. It will also be necessary to extrapolate from the tables in order to fully accommodate site variability and the potential range of options – they are a guide only and do not replace the detailed silvicultural knowledge that is necessary when making site-based choices.

The Species Tables are a simplified summary of essential information and therefore have the following limitations:

- Only the primary soil groups in Wales have been identified and some interpretation is therefore required. Information on minor soil groups has not been included which may necessitate further research. It has been assumed that deep peats will not be planted with trees.
- Soil moisture and nutrient regimes have not been identified so it is important to independently identify sites and species where these are significant factors in species choice.
- The tables show climatic zones and species suitability in present conditions and do not take account of predicted climatic changes. Species used now must be re-evaluated to check whether they will remain suitable in the future based on the impact of predicted climate change. More detailed information is available via the Forest Research website.
- Information on some species is limited in terms of the potential impacts of planting and whether there is a risk it could be invasive. For many sites and many species, this risk will be low and measures can easily be taken to buffer their effect. Where new tree species are being introduced to a new forest area they should be carefully monitored and effective mitigation measures should be implemented to control any negative impacts of these species beyond the area where they have been planted.
- The Species Tables should be used in conjunction with additional specific tree species information on the NRW website that is continually updated with latest information (see Appendix 2).

Table 5 explains how the Species Tables in Appendix 1 have been sub-divided into four parts based on climatic zone, forest type and exposure.

Table 5: Sub division of species tables in Appendix 1

Climatic zone	Forest type	Exposure	Species table (Appendix 1)
Predominantly cool & wet	Upland Wales	Exposed (DAMS score >18) / Moderately exposed (DAMS 16-17)	***PART ONE***
		Moderate or sheltered (Dams score ≤15)	***PART TWO***
Warm moist	Mixed woodland		***PART THREE***
Warm dry	Mixed forest / pine	Moderate or low	***PART FOUR***

The species used in the Species Tables (Appendix 1) are drawn from the list in Table 6. Table 6 does include a number of minor native tree species not included in the Species Tables that could be used as minor components of any planting. It should be noted that this list of trees is not definitive but does include the majority of species likely to be chosen for planting in Wales.

Table 6: Table of tree species

Conifers	Broadleaves
Coast redwood (*Sequoia sempervirens*)	Alder - Common (*Alnus glutinosa*)
Cypress - Lawson's (*Chamacyparis lawsoniana*)	Alder - Grey (*Alnus incana*)
Cypress - Leyland (*Cupressocyparis leylandii*)	Alder - Italian (*Alnus cordata*)
Fir - Caucasian silver/ Nordmann's silver (*Abies nordmanniana*)	Alder - Red (*Alnus rubra*)
Fir - Douglas (*Pseudostuga menziesii*)	Ash (*Fraxinus excelsior*)
Fir - European silver (*Abies alba*)	Aspen (*Populus tremula*)
Fir - Grand *(Abies grandis)*	Beech (*Fagus sylvatica*)
Fir - Noble *(Abies procera)*	Birch - Downy (*Betula pubescens*)
Fir - Pacific silver *(Abies amabilis)*	Birch - Silver (*Betula pendula*)
Larch - European (*Larix decidua*)	Cherry - Bird (*Prunus padus*)
Larch - Hybrid (*Larix X eurolepis*)	Cherry - Wild (*Prunus avium*)
Larch - Japanese *(Larix kaempferi)**	Elm - Wych (*Ulmus glabra*) – Information across columns refers to Wych elm only) English Elm (*Ulmus procera*)
Pine - Corsican (*Pinus nigra var. maritime*)*	Eucalyptus - Cider gum (*Eucalyptus gunnii*)
Pine - Eastern White / Weymouth (Pinus strobus)	Eucalyptus - Shining gum (*Eucalyptus nitens*)
Pine - Lodgepole *(Pinus contorta)*	Holly (*Ilex aquifolium*)
Pine - Macedonian *(Pinus peuce)*	Hornbeam (*Carpinus betula*)
Pine - Maritime (*Pinus pinaster*)	Lime - Large-leaved (*Tilia platyphyllos*)
Pine - Radiata (*Pinus radiata*)	Lime - Small leaved (*Tilia cordata*)
Pine - Scots *(Pinus sylvestris)*	Maple - Big Leaf (*Acer macrophyllum*
Pine - Western white (*Pinus monticola*)	Maple - Field (*Acer campestre*)
Red-Cedar - Japanese (*Cryptomeria japonica*)	Oak - Pedunculate (*Quercus robur*)
Red-Cedar - Western *(Thuja placata)*	Oak - Red (*Quercus rubra*)
Spruce - Norway *(Picea abies)*	Oak - Sessile (*Quercus petraea*)
Spruce - Oriental (*Picea orientalis*)	Poplar cultivars (*Populus deltoides, Populus nigra, Populus trichocarpa*)
Spruce - Serbian (*Picea omorika*)	Rowan (*Sorbus aucuparia*)
Spruce - Sitka *(Picea sitchensis)*	Service tree – True (*Sorbus domestica*)

Western hemlock *(Tsuga heterphylla)*	Service tree – Wild (*Sorbus torminalis*)
Yew (*Taxus baccata*)	Southern beech - Rauli *Nothofagus alpina* (Syn. *N. procera* and *N. nervosa*)
	Southern beech - Roble (*Nothofagus obliqua*)
	Sweet chestnut (*Castanea sativa*)
	Sycamore (*Acer pseudoplatanus*)
	Walnut (*Juglans regia*)
	Whitebeam (*Sorbus aria*)
	Willow - Crack (*Salix fragilis*)
	Willow - Goat (*Salix caprea*)
	Willow - White (Salix alba)

* Planting is not currently recommended due to plant health issues (Phytophthora ramorum / dothistroma). The latest advice on plant health issues is available on the Forest Research website.

5.2 The importance of provenance and genetics

Appropriate selection of provenance is critical to successful establishment of many, if not all, tree species[11]. Alongside species and structural diversity, managing genetic diversity is a core component of increasing the resilience of woodlands in Wales. Genetic diversity is discussed in detail in Forest Resilience Guide 3 on Managing the genetic diversity of Welsh woodlands.

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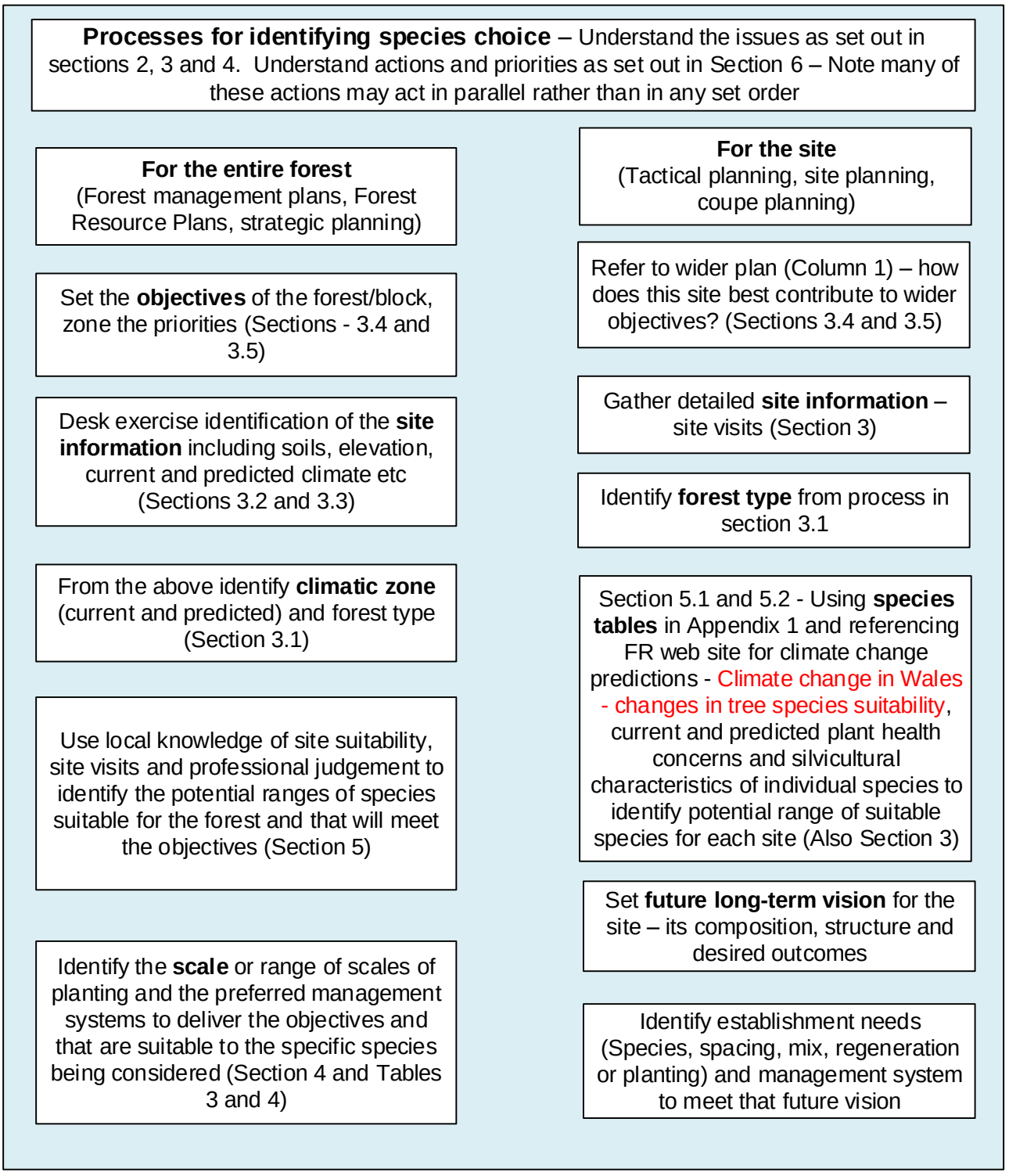
6 How to improve species diversity

This chapter recommends key stages involved in improving species diversity in Welsh woodlands (see Figure 4) and identifies priority actions for particular types of woodland. Desired outcomes may take decades to achieve and appropriate, targeted interventions will enable limited resources to be utilised where they will have the greatest effect.

[11] Lines R. (1987). Choice of seed origins for the main forest species in Britain. HMSO, London.

Figure 4: Key stages involved in addressing species diversity.



6.1 Recommendations for all woodland types

Recommendation 1: Identify and implement options for improving species diversity at every opportunity.

Recommendation 2: Prioritise change in woodlands in east and south Wales as these are considered to be most at risk from drought based on climate change predictions. Review

planting proposals for vulnerable sites in these areas, i.e. shallow soils, south facing, dry sites. Spruces are predicted to be at significant risk from drought in this area.

Recommendation 3: In west Wales, where opportunities for change are at lower elevations on better soils and timber production is the primary objective, look to increase the extent and range of “alternative” fast growing, high quality timber species such as Douglas fir or Western red cedar.

Recommendation 4: Explore **all** opportunities to increase species diversity in exposed upland areas due to the very limited species options available.

Recommendation 5: Prioritise and maximise opportunities to improve species diversity when restocking areas recently affected by outbreaks of forests pests and disease (e.g. replanting of areas of diseased Larch).

Recommendation 6: Identify opportunities to create stands of mixed conifer and broadleaf where it will suit management objectives.

Recommendation 7: Consider planting at a range of scales when planning tree species diversity.

Recommendation 8: Make increasing use of under planting to diversify and restructure existing stands and supplement natural regeneration.

Recommendation 9: Consider using existing or expected natural regeneration as a method of diversifying stands as long as the species you expect fit with meet your overall objectives and are well suited to the site.

Recommendation 10: When thinning or respacing, take the opportunity to retain minor species where they will contribute to the long-term objectives of the stand.

Recommendation 11: Where conifers are planted, the presumption is that Douglas fir and other alternative species will be preferred to Sitka spruce if they are well suited to the site and fit with management objectives.

6 Summary

To increase the tree species diversity of Welsh woodlands, the range of tree species currently used by managers needs to broaden. The aim is to diversify our woodlands which are largely dominated by a limited range of tree species and many are planted as single species monocultures. Improved tress species diversity will make our woodlands more resilient to climate change, and also improve outcomes and create oppotunties for biodiversity, the harvesting and marketing of timber and non-timber products and recreation.

This guide makes recommendations about how to improve tree species diversity, and provides useful tools (e.g. Species Tables) to aid decision-making.

Appendix 1: Species Tables (Parts 1-4)

PART 1

Climatic zone: ***Predominantly cool & wet***

Forest type: ***Upland Wales***

Exposure: ***Exposed*** (DAMS score >18) / ***Moderately exposed*** (DAMS 16-17)

Comments:

- Due to the very limited opportunities in these exposed peaty gley dominated uplands the presumption is that ALL opportunities will be taken to diversify species choice where better soils occur even where these are isolated pockets.
- Sitka spruce will remain the most productive conifer on these sites. Other suitable conifers primarily have fibre rather than timber potential but this should not deter their selection if site opportunities allow.
- Pines can be used as nurse species in line mixtures. If they are required as a permanent component within spruce crops, groups must be greater than 25 trees.
- The presumption is that all areas with deep peat will be reverted to open habitat as part of priority habitat restoration. Where the peat is so modified, native woodland may be appropriate.

Primary soil types	***Soil categories***	***Species choice***	
		Broadleaf	***Conifer***
Peaty gley. Other than brown earth, these are some of the most common soils found, particularly at higher elevation.	6, 5p	Downy birch Silver birch Sycamore Rowan Grey alder	Sitka spruce Lodgepole pine Serbian spruce Scots pine Macedonian pine Pacific silver fir Noble fir
Ironpan/intergrade. (Most of Wales is classed as Intergrade rather than full ironpans which allows a wider range of species to be suitable)	4	Downy birch Grey alder Sycamore Rowan	Sitka spruce Pacific silver fir Serbian spruce Noble fir Macedonian pine Lodgepole pine
Surface water gley	7	Downy birch Grey alder Sycamore Rowan	Sitka spruce Pacific silver fir Serbian spruce Noble fir Macedonian pine Lodgepole pine
Brown earth (At this elevation are *more likely* to be at the poorer end of the scale and classed as upland brown earth)	1, 1u	Downy birch Sycamore Grey alder Sycamore Beech Rowan	Sitka spruce Pacific silver fir Serbian spruce Noble fir Macedonian pine Lodgepole pine Pines, various
Skeletal/Rankers	13	Downy birch Sycamore Grey alder Rowan	Macedonian pine Lodgepole pine Scots pine Pines, various

PART 2

Climatic zone: ***Predominantly cool & wet***

Forest type: ***Upland Wales***

Exposure: ***Moderate*** or ***sheltered*** (DAMS score ≤15)

Comments:

- These sites have increased opportunity for species diversity and a wider range of species may be used as major components at a catchment/forest scale.
- A number of the species identified here are shade bearers that should be utilised for underplanting to increase diversity in single species plantations undergoing transformation to non-clearfell management. Some species such as ESF are suitable only for underplanting in non-clearfell systems.
- On better soils, Redwoods including Douglas fir, Western Red Cedar and Sequoias should all be favoured when exposure allows.
- Where suitable Grand and Noble fir will prove useful choices for fibre rather than timber production as an alternative to Sitka spruce. Many of these sites will have potential for biomass through short rotation forestry management.
- The presumption is that all areas with deep peat will be reverted to open habitat as part of priority habitat restoration. Where the peat is so modified, native woodland may be appropriate.

Primary soil types	***Soil categories***	***Species choice***	
		Broadleaf	***Conifer***
Peaty gley.	6, 5p	Downy birch Sycamore Ash (where more fertile) Silver birch Aspen Common alder Grey alder	Sitka spruce Norway spruce European silver fir (ESF) Grand fir (Less exposed areas) Noble fir Pines, various
Ironpan/intergrade. (Most of Wales is classed as Intergrade rather than full ironpans which allows a wider range of species to be suitable)	4	Birch Rowan Sycamore Silver birch Aspen Common alder Grey alder	Sitka spruce Douglas fir (Limited by exposure) Norway spruce Western Hemlock European silver fir Grand fir (Less exposed areas) Noble fir Pines, various
Surface water gley	7	Downy birch Sycamore Common alder Silver birch Aspen Grey Alder	Sitka spruce Norway spruce Western red cedar (limited by exposure) Pacific Silver fir Serbian spruce Noble fir Macedonian pine Lodgepole pine Scots pine
Brown earth	1, 1u	Downy birch Sycamore Ash(on best none acidic sites) Oak (sessile) Southern beech Beech (Only in nurses or as understory) Red oak	Scots pine Douglas fir Western red cedar Sitka spruce Western Hemlock Pines, various Norway spruce Grand fir European silver fir Pacific silver fir Serbian spruce
Skeletal/Rankers	13	Downy birch	Pines, various

PART 3

Climatic zone: ***Warm moist*** (currently mainly below 400m but predicted to increase from the east. This area include some "warm wet" (in the west) and "cool moist" (in the east)

Forest type: ***Mixed woodland***

Exposure: ***Moderate*** or ***sheltered*** (DAMS score ≤15)

Comments:

- Where conifers are chosen the presumption is that Douglas fir and other redwoods will be the preferred conifer species where site and exposure allow.
- On brown earth sites a wide variety of species are suitable and in no circumstances should Sitka spruce be selected if an alternative species will yield quality timber of a similar yield class
- The presumption in this zone is that non-clearfell management options will be possible in future and therefore a range of mixtures should be established to facilitate this.
- Managers should look for opportunities to establish mixed conifer/broadleaf stands with species such as redwoods, oak, ash and sweet chestnut. Where intimate mixtures are used careful selection of compatible species is necessary.
- Drought will become an issue for some species particularly in the east and south of Wales.

Primary soil types	***Soil categories***	***Species choice***	
		Broadleaf	***Conifer***
Peaty gley.	6, 5p	Downy birch Common Alder Grey alder	Sitka spruce Serbian Spruce Pines, various Norway spruce
Ironpan/intergrade. (Most of Wales is classed as Intergrade rather than full ironpans which allows a wider range of species to be suitable)	4	Downy birch Pendunculate oak Common alder Hornbeam Southern beech Silver birch	Sitka spruce Western hemlock Serbian spruce Oriental spruce
Surface water gley	7	Downy birch Pedunculate oak Common alder Red alder Grey alder Hornbeam	Norway spruce Western red cedar Sitka spruce Serbian spruce Pacific silver fir Pines, various
Skeletal/Rankers	13	Downy birch	Pines, various Douglas fir
Brown gley, brown earth	1, 1u	Sessile/Pendunculate oak Ash Sweet chestnut Southern beech Wild cherry Beech Lime Hazel Eucalyptus Norway Maple Aspen Poplars Red oak Sycamore Italian alder	Douglas fir Western red cedar Cypresses Silver firs Pines, various Japanese cedar Redwoods (Coast)
Calcareous (Where the pH is high or soils shallow) Deeper soils where the pH is relatively low will support a wider variety of species, see brown earth above.	12	Ash Silver birch Beech Sycamore Cherry Pendunculate oak Whitebeam Norway maple	Western Red Cedar European Silver Fir Leyland cypress

PART 4

Climatic zone: ***Warm dry*** (currently mainly under 50m, mainly in the south east of Wales but predicted (depending on CC scenario applied) to increase from the south and east to cover most of southern and eastern Wales)

Forest type: ***Mixed forest / pine***

Exposure: ***Moderate*** or ***low***

Comments:

- The presumption in this zone is that non-clearfell management options will be possible in future and therefore a range of mixtures scales should be established to facilitate this.
- Managers should look for all opportunities to establish mixed conifer/broadleaf stands with species such as redwoods, oak, ash and sweet chestnut
- A wide range of broadleaves including some with growth rates compatible to conifers have significant potential for increased use such as Sweet chestnut and Southern beech
- ***Susceptibility to drought*** will be the most limiting factor in this zone and the extent is predicted to increase significantly to the North and West in the future climate change predictions. Spruce should not be selected and the use of beech and ash may be limited.

Primary soil types	***Soil categories***	***Species choice***	
		Broadleaf	***Conifer***
Ironpan/intergrade (Most of Wales is classed as Intergrade rather than full ironpans which allows a wider range of species to be suitable)	4	Silver birch Pendunculate oak Common alder Hornbeam Southern beech	Western red cedar Douglas fir Western hemlock Pines, various
Surface water gley	7	Silver birch Pendunculate oak Sweet chestnut Red alder Grey alder Hornbeam	Western red cedar Pines, various Douglas fir Pacific silver fir
Littoral/dune	15		Pines
Brown earth	1	Silver birch Pendunculate/sessile oak Sweet chestnut Wild cherry Hazel Beech Walnut Red alder Grey alder Hornbeam Red oak	Douglas fir Cypresses Pines
Calcareous	12	Beech Ash Silver birch Sycamore Walnut Wild cherry Pendunculate oak Whitebeam Norway maple Italian alder	Western red cedar European Silver Fir Cypresses Pines

Appendix 2: Sources of further information

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Web links

Natural Resources Wales – planning for the future

Forest Research - Adapting forests and woodlands in Wales to a future climate

Forest Research - Climate change impacts

Forest Research - support tools to support species selection

Silvifuture

Forest Research - ForestGALES