Practical guidance
Module 4

Ancient woodland restoration:

Phase two: recovery of the wider ecosystem

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WOODLAND
TRUST

Contents

Front cover: Thinned pine plantation on ancient woodland site in Staffordshire. Good regeneration of oak, birch and rowan into the understorey and canopy, along with recovering woodland ground vegetation of sandy infertile soils.

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1. Introduction

This guide is the fourth module in a series on the restoration of ancient woodland sites. The first module is an introductory guide to the principles of restoration management. Module 2 looks in detail at the assessment process. This includes how to record remnant features and prioritise actions. Module 3 covers the first phase of restoration management, which deals with halting further decline in the most critical areas.

This guide is on the second phase of restoration management. It provides an overview of the actions that will help to restore the wider woodland ecosystem. Phase two is about starting to rebuild ecological integrity and progressing woodlands from a threatened to a secure condition. This can take a long time.

Restoring the wider woodland ecosystem through gradual thinning methods. Mid-Wales.
Alastair Hotchkiss/WTML

2. Planning the second phase of restoration

The planning of restoration is always underpinned by the survey and assessment process. The essential 'first-aid' management should already have halted further decline in critical areas. Phase two is an opportunity to get on the front foot with planning, and make a wider transformation. The assessment process helps prioritise action, based on condition and threat. This informs a restoration strategy and management plan. But operational constraints and objectives will also have implications for management.

2.1 Objectives

Phase two restoration is about restoring ecological integrity to ancient woodland sites (see box 1). It is not an aspiration to return a woodland to some past condition. To achieve this, phase two focuses on shifting the composition of the trees to native species. Phase two must make this shift whilst minimising further risks to remnant features. Maintaining wider ecological continuity is also important.

The longer term objectives of owners or managers will influence decisions during this phase. For any areas still in critical condition, the removal of threats remains essential. Elsewhere the restoration process may be balanced with other objectives, including commercial timber production. Appropriate silvicultural systems may support the recovery of the woodland ecosystem and deliver on other objectives, but it is important to ensure that remnant features never regress into critical condition.

Ecological Integrity

The aim of ancient woodland restoration is to maximise the ecological integrity of ancient woodland sites. Ecosystems with greater ecological integrity are richer and more resilient. They are characteristic of their locality and more self-regulating. Future ecosystems will have similarities to historic communities, but this is not the aim of management. Phase two restoration represents a shift in thinking. It is as much about the recovery of a wider woodland ecosystem as it is about protecting and maintaining remnants. This means recovering the full potential of a woodland in order to regain integrity. This includes the composition and abundance of native species, processes and rates of change. It also includes the physical elements such as water and air quality.

Following the rapid clearfell removal of a block of Sitka spruce, a lack of deer management has resulted in coarse vegetation, such as purple moor-grass, dominating and now inhibiting the establishing of natural regeneration of trees. Loch Sunart, Scotland.
Alastair Hotchkiss/WTML

2.2 Operational considerations and constraints

Various biological and physical constraints determine what is achievable. Practical aspects can result in certain management being economically unviable. Other factors influence how or when management goes ahead. There is thus a need to be flexible with objectives, and allow scope for adaptive management as phase two progresses. The table overleaf is a summary of these considerations and constraints, as well as some actions to address them as part of the second phase of restoration management.

Fenced exclosure in Lady Park Wood in the Lower Wye Valley, demonstrating the impacts of deer browsing on regeneration and woodland specialist ground flora. ›
Alastair Hotchkiss/WTML

Dense bracken dominating the ground vegetation beneath stand of thinned larch at Robson's Spring Wood in North Yorkshire.
Jim Smith-Wright/WTML

Extensive selective felling of conifer trees at a plantation ancient woodland site in East Anglia has resulted in vigorous bramble growth, dominating ground vegetation. Cambridgeshire.
Alastair Hotchkiss/WTML

Consideration	Constraints	Actions
Wild or feral herbivore pressure	The impacts of deer (and in some woods wild boar or feral goats) are a vital consideration. Deer populations can stop tree regeneration, especially of more palatable species such as hazel, oak, rowan, elm and aspen. When pressure is high, even less palatable species, such as spruce and beech, are browsed. Where felling has occurred, herbivores can also result in coarse vegetation dominating, making tree establishment more difficult and costly. Large mammals are part of woodland ecosystems. They also play a role in seed dispersal of woodland plants (Eycott et al. 2004) so the focus should be on the level of impacts and consequences.	• Precede any felling operations with monitoring herbivore impacts. A detailed herbivore impact assessment can identify specific issues. • Control deer or other feral herbivore numbers where impacts are significant. • Liaise and collaborate with local deer management groups. Management at landscape-scale is more effective.
Domestic livestock	Some overgrazed ancient woodlands show no regeneration across large areas. Excessive livestock grazing also alters ground vegetation. Some plants are susceptible, including bluebell, honeysuckle and greater wood rush. Others are less so, such as wood anemone and wood sorrel. Appropriate woodland grazing can drive important ecological processes. It can also help control brambles and bracken.	• The most direct option is to fence off woodland from adjacent pasture before felling operations, or immediately afterwards if harvesting pragmatism demands. • Where woodland grazing is beneficial, follow a well-thought-out grazing regime. This must consider suitable livestock and numbers, and the sensitivity of woodland plants. • Maintain constant control. Levels and timing will often need changing over time and across a site.
Coarse vegetation	Woodland flora and tree regeneration can benefit from increased light levels. But this can be offset by the competitive effects of coarse vegetation, such as bramble, bracken, tussocky grasses or gorse. These often respond to light, as well as climate and nitrogen deposition, and form long-lived seed banks. The seed banks of many woodland specialist plants are not as strong (Bossuyt & Hermy 2001). Most trees have very short-lived seed and cannot respond from the soil (Baskin and Baskin 2014). Problems can result from historical disturbance. Nettles dominate as a result of nutrient enrichment. Vegetation can be influenced by historical ground compaction or brash piles. Rosebay willowherb can abound on historical fire sites. The plants are often native components of semi-natural woodlands. It is important to focus on their impacts and consequences for achieving objectives. They often provide valuable resources for invertebrates, birds and mammals. For example, brambles are important for hazel dormice.	• Adopt a gradual approach to manage light levels. This can reduce opportunities for vigorous coarse vegetation growth. Understorey hazel and field maple can also suppress brambles. • Keep observing. Some sites remain free of coarse vegetation even under open conditions. Others may see coarse vegetation dominate under a largely closed canopy. This scenario is especially impactful, with tree shade compounding impacts of coarse vegetation. • Control coarse vegetation using machinery mounted equipment for mulching or flailing. Brush cutting or strimming can work for smaller areas, or where access is difficult. • In densest bracken, break-up and remove a deep humus layer. Usually this is where other woodland flora is absent or scarce. On exposed sites, bracken windrows can provide early shelter for establishing trees. • Avoid herbicide use as there is a risk to ancient woodland specialist flora. • Managed areas may need planting, which can be expensive to establish. *continued...*

Consideration	Constraints	Actions
...continued Coarse vegetation		• Animals help control some coarse vegetation. Hardy cattle can combine grazing with breaking-up bracken litter for example. Pigs can be effective but need very careful management, and are always temporary. The impacts of some coarse vegetation, particularly grasses, can be exacerbated by grazing animals.
Vegetation ecology	It is important to understand the kinds of vegetation that are characteristic of a woodland's locality and soil type. This can help acknowledge the response of a wood to management. It can also help determine what is appropriate.	• Rapid canopy openings present risks to shade-adapted flora (Brown et al. 2015). Consider retaining more canopy cover in these communities, where native trees also establish in low light. For example, in base-rich beechwoods (e.g. NVC W12 – Rodwell 1991) or ash–field maple woodlands with dog's-mercury (e.g. W8). • Be observant of regeneration in more acidic woodlands (e.g. W16, W17 or native pinewoods W18). Very light uniform thinning could limit regeneration of birch and oak. Plants like heather and wavy hair grass also benefit from light. Opening stands up too quickly can be bad. For example, it could reduce humidity in gill woodlands in Sussex or oceanic oak woods in Shropshire. • Some flora can be associated with patchy bare ground and shifting open glades. These include dog violets, wood spurge and climbing corydalis.
Invasive Non-Native Species (INNS)	The initial control of these issues is considered a 'phase one' type operation. But there will almost always be a need for some element of follow up control and monitoring of any INNS.	• Repeat monitoring and treatments throughout phase two. Felling activity can promote species such as rhododendron if these are not eradicated beforehand.
Pests and diseases	Tree diseases may determine what can or cannot be achieved. A statutory plant health notice for a disease like *Phytophthora ramorum* in larch will mean a rapid transformation. Other prevalent tree diseases on plantation conifers include *Dothistroma* needle blight on pine. The effects of ash dieback (*Hymenoscyphus fraxineus*) will have a significant impact on decision making. Some pathogens have less profile but can have considerable consequences for restoration. Oak powdery mildew (*Erisyphe alphitoides*) impairs the shade-tolerance of oak. Other pests impacting on restoration include grey squirrels. Specific growth stages can be more vulnerable, such as younger broadleaved trees, particularly those aged between 10 and 40 years. Some species are more affected, such as oak, birch and beech.*Phase two restoration management can help to create more robust and resilient woodlands.	• Any response to disease should always consider the ecological integrity of ancient woodlands. • All planted native trees used in restoration must be certified grown in the UK from locally sourced seed. Species must be appropriate to the location and character of a wood. • Where ash dieback is present, allow time to observe what changes are occurring, and the response of affected trees. Wherever possible, retain all mature ash and associated deadwood on site. Promote and retain ash regeneration. • Avoid shading of oak seedlings and saplings with oak powdery mildew. Do this gradually to mitigate the adverse effects of direct sunlight on mildew affected foliage (Lonsdale 2016). • Adopting gradual restoration methods and developing continuous cover and mixed species stands can reduce the impact and densities of insect pests. (Klapwijk et al. 2016). • Control pests like grey squirrel as part of a joined-up approach with other landowners and managers. Hormone control, seasonal management, and new traps may provide effective options. Pine marten increases may result in reduced impacts from grey squirrels.

Consideration	Constraints	Actions
Access	The access to and within the wood can determine what is achievable. Access can be improved, but sites with existing forest tracks and extraction racks are at a better starting point for phase two restoration. Particularly with a gradual transformation requiring repeated thinning interventions over many years. Permanent tracking and extraction rack systems are essential for harvesting machinery, as well as stacking areas and road access to landing areas for timber hauliers. Access to and within the wood is also important for other aspects such as deer management and for the control of invasive non-native plants.	• Always design new or upgraded track infrastructure in a way which avoids damage to remnants. Consider tree root zones cautiously. • Keep the extent of tracks to the least required to achieve restoration objectives. Weigh up construction costs, timber income and the ease of future management against the scale and potential for damage. Consider if there is another way. For example, ring-barking to create standing deadwood or felling to leave lying deadwood. • Stick to old routes to prevent further damage to the soil. Plants confined to old tracks may need considering. • Keep and replace topsoil to avoid trackside banks of subsoil. Use locally sourced and clean material for surfacing. • Ensure track profiles are engineered to keep flowing water in a topside ditch with planned sumps and culverts. Surface flow on tracks can be highly erosive and result in damage and expense.
Slope	The slope can determine what restoration management is achievable and how it may need to be carried out. Even with good tracking, a gradual successive thinning approach to restoration may not be practicable on the steepest and rockiest ancient woodland sites.	• Motor-manual felling with chainsaws may be required on very steep or rocky slopes. Most harvesters and forwarders cannot work these areas. • Extraction systems may involve cable cranes or skyline set-ups, or a tractor and winch. Sites with steeper slopes can need more track infrastructure to get this equipment in. • Create fallen or standing deadwood, where extraction is impractical. Where operators have less experience with ring-barking, chemical treatments can reduce the likelihood of windsnap.

Good infrastructures of permanent tracks are important as part of restoration harvesting operations. Forwarder stacking timber at a loading area at an ancient woodland site in Surrey.
Alastair Hotchkiss/WTML

Although harvested spruce timber is being forwarded by horse-logging, upgrading to a surfaced track has reduced the forwarding distances and enables a timber lorry to enter the wood to access trackside stacks. Privately owned PAWS restoration site in Powys, Mid-Wales.
Alastair Hotchkiss/WTML

The Woodland Trust's site at Loch Arkaig in Scotland. Whilst access to the lower slopes in Glen Mallie means that it is possible to extract timber from the spruce and larch PAWS, the lack of access to the higher slopes means that the spruce along the top edge will be managed for deadwood creation.

Alastair Hotchkiss/WTML

Steep valley-side PAWS stands at Fingle Wood, Devon. A restoration partnership site between the Woodland Trust and National Trust.

Paul Glendell/WTML

Consideration	Constraints	Actions
Watercourses	All normal considerations in forestry apply. This includes sedimentation, drainage and crossing watercourses as part of restoration management. The restoration of hydrology in ancient woodlands is considered in module 5.	• Maintaining canopy through gradual restoration methods can result in less risk to water quality by reducing nitrate flushes, soil erosion and run-off. It can also maintain continuity of stream temperatures. • Further guidance is available in the forestry and water section of the UK forestry standard (UKFS 4) for example.
Soils	Ancient woodland soils contain essential microorganisms and the life-supporting fungi required by all trees and plants. Certain soil types will influence when and how an operation should be carried out. Once a soil profile is damaged, it will result in an irreversible negative effect on vegetation growth and tree regeneration. This could be as a result of a single forwarder pass. Soil types also determine how significant other factors may be, such as wind (see below). It also determines plant communities, coarse vegetation, and the response to management.	• Gradual phase two restoration methods help retain essential mycorrhizal fungi which can be impacted by clearfelling (Sterkenberg et al. 2019; Simard et al. 2013). • Consider working at drier times of the year. Maintain control to withdraw work during very wet weather. Heavy clay soils can be hard to work during the winter months without doing excessive ground damage. Some very sandy soil profiles may be less vulnerable, but it is always an important consideration. • Use brash mats and other techniques for minimising excessive ground damage from machinery. Consider sacrificing more harvested material to go into brash mats where there is particular concern about soils. Brash quality ranges between tree species being felled. Always avoid a dense build-up of brash, particularly in obvious flora hotspots. • In well-developed selection forestry systems, brash can become limited. This is good, but it emphasises the need for permanent tracks and extraction racks. Slow movement of machinery will help reduce damage. • Horse logging may be a good low-impact solution for some sites. It is most effective where there is a quick-turnaround, so shorter distances to a trackside stacking area are more efficient.
Wind	All the above factors, as well as geography, altitude and aspect, can combine to make wind a significant issue. Particularly for plantation stands that are even-aged, mature, shallow-rooting, and with a poor thinning history. This could include soils with variable water tables and those which are often waterlogged. Or it could be stands which are on exposed windswept slopes. All this combines to make wind a significant hazard. It can determine which management options are appropriate. In some situations, a gradual approach, based on successive thinnings of a stand may not be practicable. Access is an important consideration, and the risk associated with having clear windblown trees is increased if this is poor.	• A more rapid and extensive transformation may be appropriate and practicable where stands are highly unstable. • Always base decisions on a prudent risk assessment. There are examples of thinned stands which have stood firm through extreme weather, even in exposed upland regions. Well-drained soils, even on thin soils, can sometimes result in more windfirm stands. • Regular thinning from an early age will increase the likelihood of windfirm stands. Irregular high forest systems are more resilient to wind. • Windblow can create structural diversity, forming small glades in otherwise uniform stands. Windblown trees can act as a barrier to browsing of regeneration by deer, for example. *continued...*

Consideration	Constraints	Actions
...continued Wind		• Where practicalities allow, windblown trees can be left. Rootplates and exposed mineral soils can benefit regeneration, and hollows provide microhabitats. But, in some situations, windblown trees can continue to regrow and create an issue.
Regulation, policy and standards	General permissions and consents are covered as part of delivering phase one restoration management (module 3). There may be additional considerations relevant to phase two. For example, Environmental Impact Assessments, planning permission or development orders required for tracking. Consultation with local authorities and utility companies may be needed. For example, when operations are occurring next to public highways, power line infrastructures or water. Many aspects of phase two restoration are also supported by the UK Woodland Assurance Standard (UKWAS).	• Always ensure that all relevant licences and consents have been considered and obtained. • Summer working may reduce risk of soil damage. Be aware of legislation protecting nesting birds, and plan work to ensure potential offences are avoided. • UKWAS requires "maintaining and enhancing or restoring features and areas of high conservation value within plantations on ancient woodland sites". A precautionary approach must be adopted, with actions prioritised based on the level of threat. There are also requirements around using natural regeneration wherever possible.
Communication and public access	The communication of objectives and proposed management can be important. This is vital where public access or community use are frequent, or the site is visible from public locations. This may also determine how management proceeds. Public access, safety and understanding or support for restoration are all important. Communication with neighbouring landowners and managers is often necessary.	• Work with neighbouring owners and managers as part of a coordinated approach to the control of deer and grey squirrels for example. The management approach of these will also be influenced by public access. • Working with other woodland owners to coordinate harvesting operations and timber sales can also be effective. • Make necessary arrangements where access for machinery and extraction must pass through adjacent land. Stacking and loading areas for timber hauliers may need to be located outside the woodland ownership. • Use gradual restoration methods to reduce the impact on landscape and aesthetic aspects of recreation and public access. • Communicate objectives and management in the most appropriate and effective way. This could range from signage to consultations and local meetings.

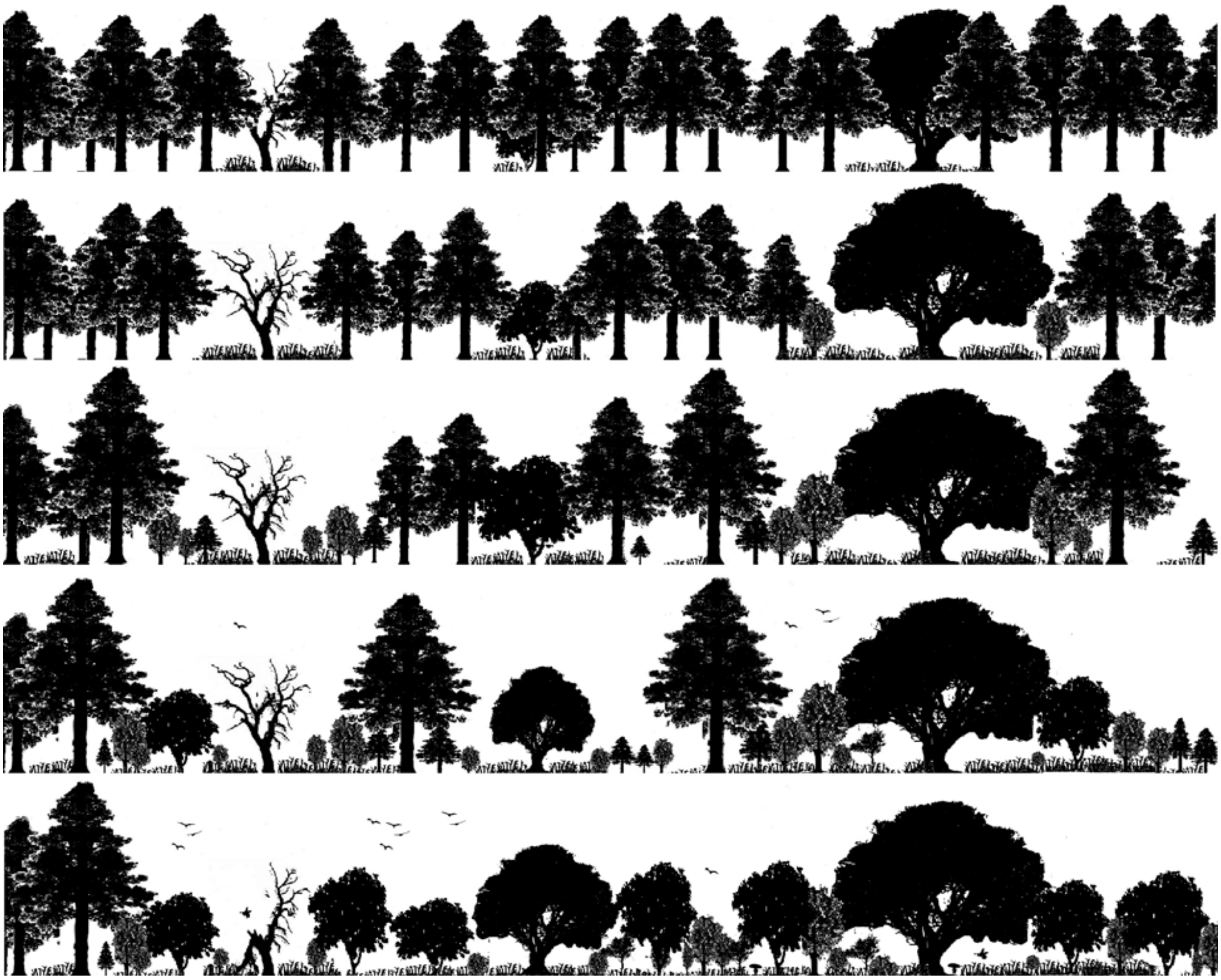

Diagram 1 – Scenario 1 – A gradual approach to restoration management.

Top Row (Year 0): Ancient woodland in critical condition, with relic veteran oak overtopped by plantation conifers, as well as broadleaved natural regeneration and pre-plantation standing deadwood being excessively shaded.

Second Row (Year 1): Phase one 'first-aid' restoration management carried out to halt further decline, by haloing remnants.

Third Row (Year 4): Phase two restoration thinning has been carried out to further release remnant relic trees and woodland specialist ground flora, as well as encouraging natural regeneration. Whilst remaining in threatened condition, the woodland is recovering.

Fourth Row (Year 10): Phase two thinning for regeneration has been creating complexity and recruiting regeneration into the understorey as part of wider ecosystem recovery.

Bottom Row (Year 18): Ongoing restoration thinning has resulted in ancient woodland in a secure condition, with broadleaved regeneration recruited into understorey and canopy, and specialist flora now dominating ground vegetation, with its remnant distribution now indiscernible.

Diagram 1 – Scenario 2 – The risks associated with rapid clearfell transformations of PAWS.

Top Row (Year 0): Ancient woodland in critical condition, with relic veteran oak overtopped by plantation conifers, as well as broadleaved natural regeneration and pre-plantation standing deadwood being excessively shaded.

Second Row (Year 1): Conifer stand is clearfelled over winter, harvesting operations damage standing deadwood snag, and subsequent storm event results in windblow of relic pre-plantation veteran oak. Ancient woodland specialist flora is further impacted by vigorous bramble growth and heavy deer pressures inhibit regeneration and recovery of flora. Site remains in critical condition.

Bottom Row (Year 10): Coarse vegetation has been managed mechanically and subsequently restocked with site native broadleaves which are now establishing. Deer management has improved and pressures are reduced. Remnant ground flora remains threatened and pre-plantation deadwood and remnant trees have been lost.

3. Phase two restoration management

A precautionary and gradual approach to restoration is considered to be best practice. This is based on research and experience of how remnant features in particular respond to management. Avoiding dramatic change, especially early on, is an important aspect of the precautionary approach.

In all circumstances, critical remnants should initially be opened-up gradually through phase one restoration. This ensures that remnant features are robust, reduces risks and keeps management options open.

A considered approach is important throughout phase two restoration. In many situations, continuing with gradual restoration methods will be most appropriate. These methods are described below and, as restoration progresses, it may be possible, or even desirable, to apply these methods at increasing scale or intensity. This progression should take an adaptive approach, based on careful observation and consideration of the likely outcomes of successive operations.

A lack of restoration management remains the greatest threat to ancient woodland remnants (Curtis et al. 2018). It also fails to progress the recovery of the wider ecosystem. Therefore, gradual phase two restoration doesn't mean different areas or compartments being dealt with one by one. Rather, it is the progressive transformation of entire stands and woodlands.

Moreover, gradual does not imply a lack of urgency. There is often a need to press on with restoration through phase two. Wider ecosystem recovery can only be achieved through regular or continual management. Without this, there is a risk that remnant features could regress into critical condition or even be lost.

The time taken to plan and undertake more extensive phase two interventions should not delay urgent work on critical features. However, income generated by phase two operations may be important to support some more costly phase one procedures. Woodlands will also vary considerably within a single site or across a larger estate. As a result, different phases of the restoration process may be undertaken simultaneously.

Repeating the survey and assessment process at least once every 4-5 years, as well as more regular observation, will provide important information to support management decisions.

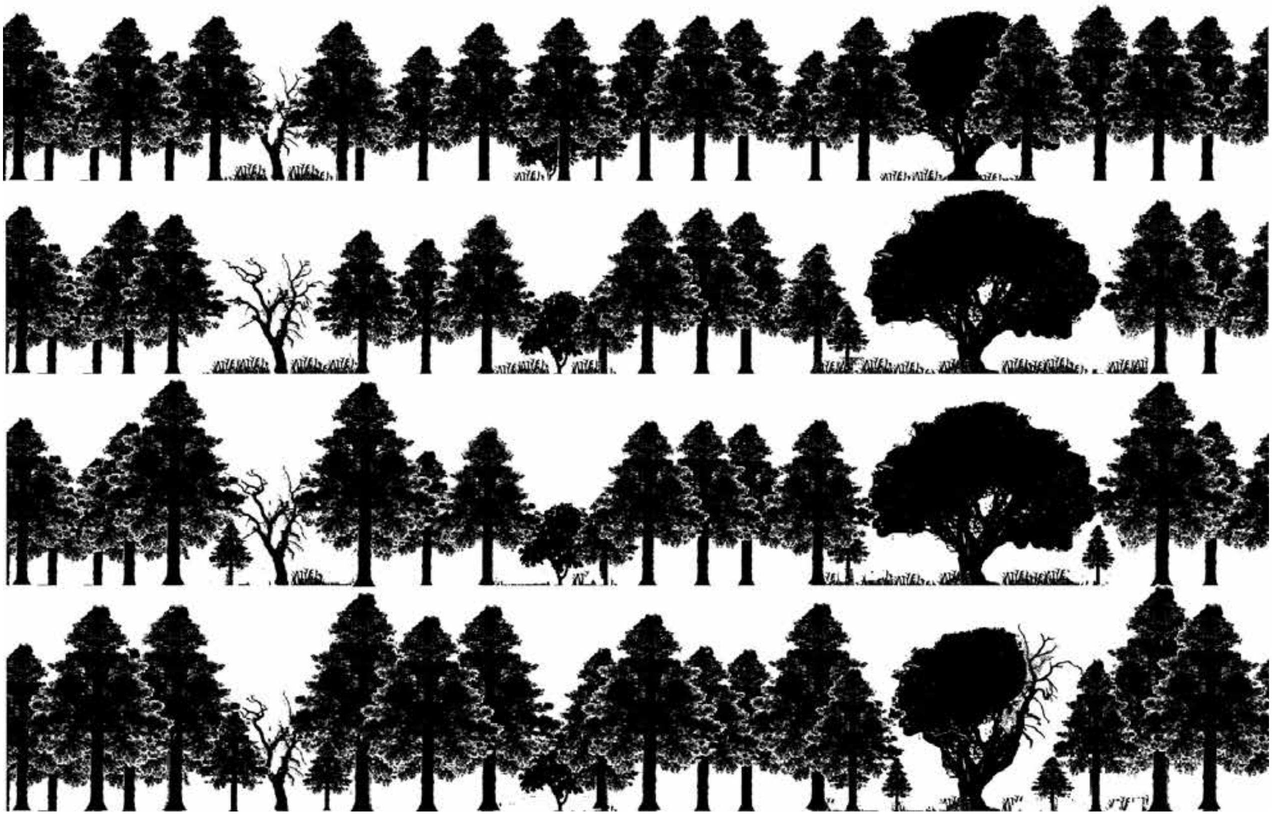

Diagram 1 – Scenario 3 – The need to progress with phase two restoration.

Top Row (Year 0): Ancient woodland in critical condition, with relic veteran oak overtopped by plantation conifers, as well as broadleaved natural regeneration and pre-plantation standing deadwood being excessively shaded.

Second Row (Year 1): Phase one 'first-aid' restoration management carried out to halt further decline, by haloing remnants. Woodland specialist flora has responded from seedbank to increased light.

Third Row (Year 4): No phase two restoration management has been undertaken, and growth of surrounding conifer stands have now largely closed back. The woodland flora which responded from seedbank is declining once more.

Bottom Row (Year 10): Remnants have declined further and lack of management has resulted in loss of specialist flora as well as declining condition of relic pre-plantation oak.

3.1 Gradual phase two restoration methods

Restoration thinning

There is a distinction between thinning to optimise tree growth and thinning for restoration. Silvicultural thinning is the process of removing trees to result in a temporary reduction in 'basal area'. Basal area is the area of land occupied by the cross-section of tree trunks, usually expressed in m^2/ha. In most production-focussed systems this is about accelerating the growth of other trees in the stand, as well as for stand stability, even growth and timber quality. Most conventional forestry systems intend to have a 'final-crop' removal. This situation should be avoided in most gradual restoration scenarios. Restoration requires a different approach to thinning. Part of this is about responding to opportunities, such as patches of native tree regeneration and woodland flora. This will result in adjusting intensities and variation (Thompson and Hope 2005). Restoration thinning must therefore be more intuitive.

In the early stages of phase two, initial restoration thinning can adopt systematic approaches. These are more similar to conventional commercial thinning. For example, a first intervention could involve line-thinning (the systematic removal of all trees in a line). Usually, this is at regular intervals, such as every 10-20m or every 6th or 8th line where plantation rows are clear. Where native components are more frequent within a stand, the interval should be greater. This early intervention helps establish 'racks' for extracting timber. Some selective thinning can occur between racks, to remove a higher proportion of the trees. This is important where native trees and regeneration occur in the matrix between. Aim to develop existing native trees by selectively removing crown-competing plantation trees next to them. The intensity of this selective thinning depends on the situation and risks, but as a rough guide, this first intervention could typically remove between 20-30% of the plantation trees.

Some sites may already have clear hotspots to work with in this early part of phase two. But, in other areas there may be few existing native trees, and ground flora may be scattered. In these situations, the selection process could favour other objectives, such as timber quality. Selective restoration thinning always allows for decisions to be made over individual trees.

Thinning for regeneration and complexity

The initial thinning to bolster remnants is different to thinning required for regeneration and ecosystem recovery. The two cannot be combined, and regeneration may not be forthcoming after a first thinning.

Recovering the wider ecosystem often involves transforming tree species composition. This requires stimulating native tree regeneration at ground level. Saplings then need to be recruited into the understorey and canopy. Continuous cover forestry systems are often considered appropriate for many ancient woodland sites. The structural aims and dynamics can be complementary to restoration. But in many restoration scenarios, the aim is not just transforming an even-aged stand to an irregularly structured one. It is about changing the dominant canopy tree species. This requires a focussed approach.

To promote desired native regeneration, restoration thinnings must often successively reduce basal area. It is always important to observe and respond, and not fall into standard defined cycles of management. Although it depends on thinning intensity, and risk, it may be beneficial to carry out a second thinning after two or three years. Repeated interventions on shorter-cycles may help develop the required regeneration. Wherever possible, a 'little-and-often' approach can work well. This can involve frequent or even continual intervention.

Creating complexity and variation in basal area across a stand or woodland is beneficial. Complexity is an important aim for forest management (Fahey et al. 2018). So, it is important to adopt silvicultural

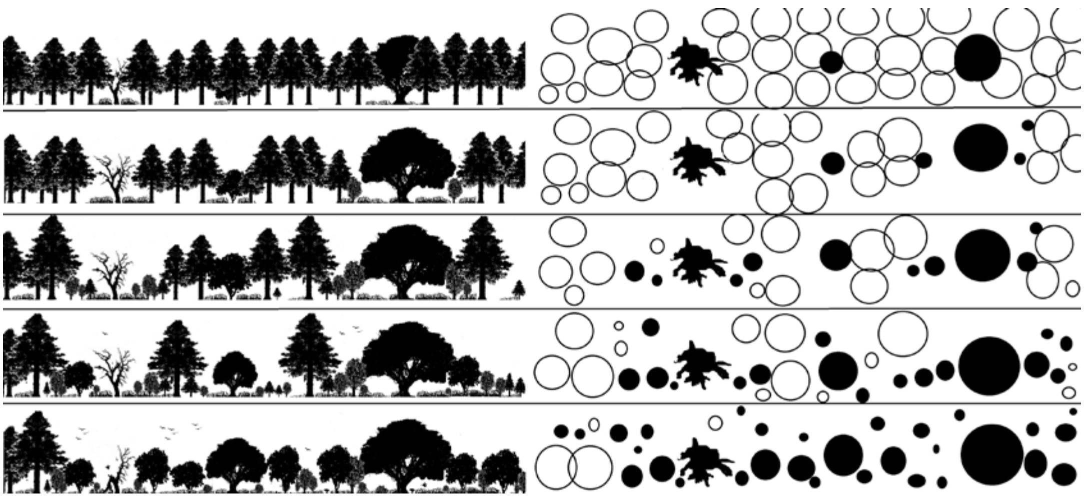

Diagram 1 – Scenario 1 – A gradual approach to restoration management. Diagram showing approximate crown projections of trees, to illustrate how the distribution of native components influences the thinning selection over several interventions. White circles are plantation conifers, black circles are native broadleaved trees, and the other black mark is the relic pre-plantation standing deadwood.

Early phase two restoration thinning can adopt a more systematic removal of trees, such as line thinning which will both increase light levels as well as the practicality of creating extraction racks for harvesting. Scots pine thinning to favour broadleaved components of ash and elm, Reffley Wood, Norfolk.
Alastair Hotchkiss/WTML

Line thinning of western red cedar in ancient woodland site in Snowdonia, North Wales.
Alastair Hotchkiss/WTML.

Where important hotspots of ancient woodland remnants occur, thinning interventions can continue to focus on opening these up further.
Alastair Hotchkiss/WTML.

Where regeneration already occurs, restoration thinning should aim to release these in the same way as remnant pre-plantation trees or woodland ground flora. Pocket of ash and hazel within western hemlock plantation.
Alastair Hotchkiss/WTML.

Some plantation ancient woodland sites have few relic or existing native trees, and ground flora may be evenly distributed or scattered. Thinning selection criteria can be influenced by other objectives, such as favouring better quality timber trees. Beech plantation on ancient woodland site in Shropshire.
Alastair Hotchkiss/WTML

⌃ Thinned conifer stand on ancient woodland site near Haslemere, Surrey. Complexity and irregularity is starting to develop with wider range of ages, sizes, spacing and distribution as well as species present. Sub-canopy birch can now develop stronger crowns, and existing regeneration of hazel and birch can become more established in the understorey.
Alastair Hotchkiss/WTML

systems that help achieve this. Uniform production systems deliberately reduce complexity (Puettmann et al. 2009). But, complexity in woodlands can increase without reduction in productivity (Susse et al. 2011). Selection systems can provide more stable long-term incomes and reduce risks in forest management (Roessiger 2011). Most conventional uniform thinning programmes and intensities are based on tables and yield classes. These revolve around the concept of 'fully-stocked stands'. This is where all growing space is occupied to develop existing crop trees. Terms like 'fully-stocked' are of little use to ancient woodland restoration, and will hinder progress.

Methods such as variable-density thinning can help increase complexity across a woodland. This accelerates the development of stand structures and ecological communities associated with much older woods (Harrington 2009). It can also benefit natural regeneration by creating more microsite opportunities. Variable-density thinning simply involves creating some more open areas, and also retaining some denser patches. For example, 10% of an area could be 'skipped' to leave denser groves of trees which are largely or completely unthinned. Across 15% of the area, thinning should result in more open conditions, with only scattered individual trees

⌄ More open gap-glades as part of variable density thinning at Brede High Woods in East Sussex. Owned and managed by the Woodland Trust. Phase two restoration management of non-native pine has resulted in strong regeneration of birch and oak in particular, as well as important structural variation for woodland insects including the rare speedwell flea-beetle, for which this is the only known site in the UK. It relies on heath speedwell plants which occur on the more open sandy patches.
Alastair Hotchkiss/WTML

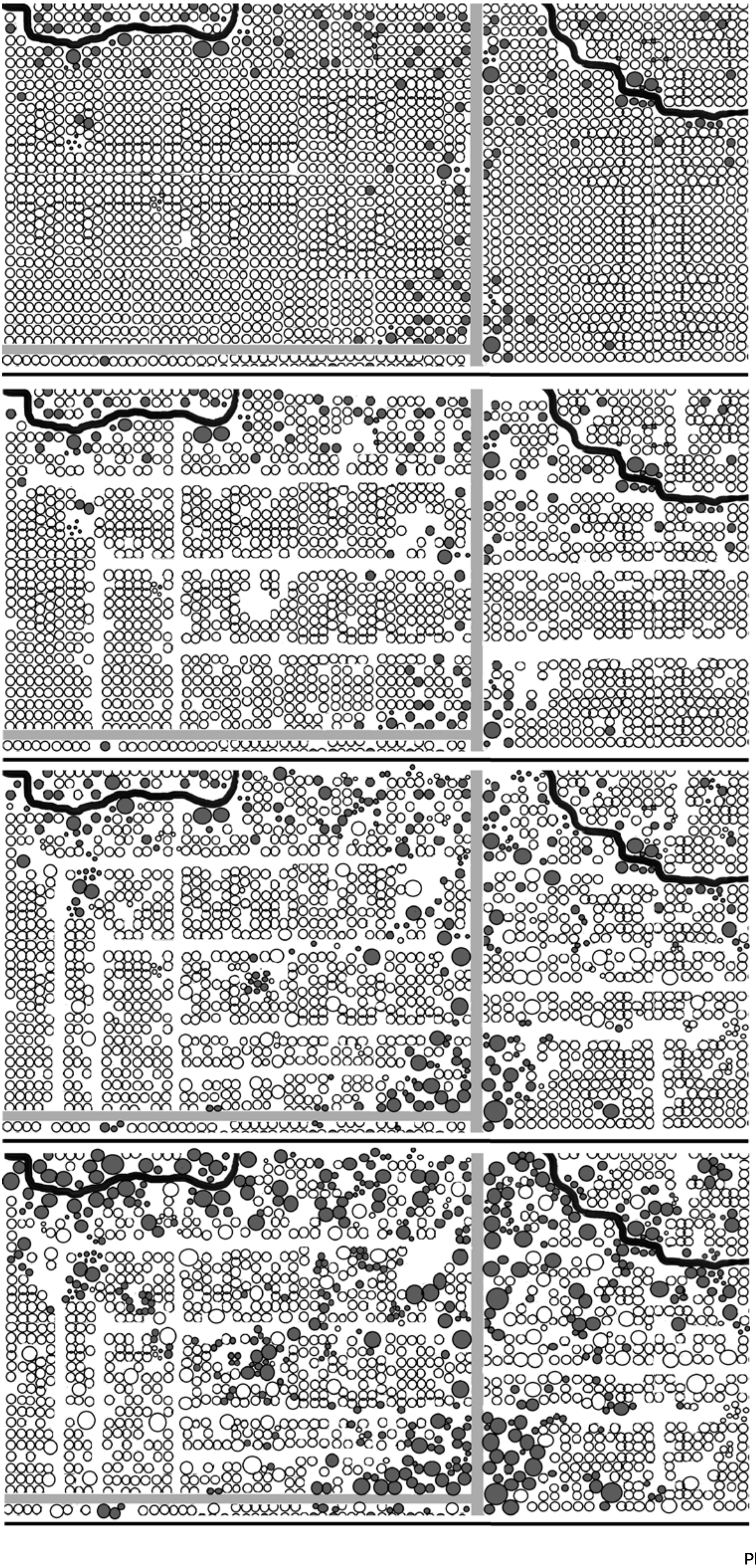

Diagram 4 – Variable-density thinning as part of restoration management.

Top Row (Year 0): Ancient woodland in critical condition, dense even-aged stand of 27-year-old spruce, with remnant broadleaved components scattered mainly alongside the streamside areas, and track edge, and increasingly shaded by surrounding plantation trees. Remnant woodland specialist ground flora only present where broadleaved components occur.

Second Row (Year 1): Restoration thinning has adopted a variable-density, as phase two restoration has also incorporated urgent 'first-aid' management (phase one and two combined). The marking-up of plantation trees for felling and extraction involved selecting trees which were competing with crowns of existing native trees. Where these components did not occur, variable-density thinning prescribed that approximately 10% of the stand was retained largely unthinned as 'skipped-groves', especially in the SW edge of the wood in the face of prevailing wind. 15% was thinned at greater intensity to create largely open 'gap-glades'. Across the rest of the stands, thinning intensity would be more regular, with systematic line-thinning to create a permanent infrastructure of extraction racks, with some selective thinning to develop better quality stems by removing the worst formed conifer trees.

Third Row (Year 8): Phase two restoration thinning has continued at a variable-density, resulting in more variation in size and growth rate of remaining trees. In places, gap glades from earlier interventions have resulted in good native broadleaved regeneration. Remnant features have been maintained, and are no longer in a critical condition.

Bottom Row (Year 14): Continued phase two restoration thinning has resulted in an increasingly complex and irregular structure. Native broadleaved components are strong in parts of the wood, and ground flora has recovered well. Remaining conifer trees include many of high quality and within structures which are benefitting ground flora recovery as well as increasing populations of breeding birds and woodland insects. Regeneration of both native and non-native species is occurring across different parts of the stand, and the understorey is being managed.

or even small clear gaps. These 'skipped groves' and 'gap glades' should occur as a series of small patches, dotted within a stand. Each need not be much larger in diameter than the top height of canopy trees. This could range between 300m^2 up to 900m^2, but should mesh into the wider stand rather than being clearly distinct blocks. This provides conditions for small regeneration clumps of even light-demanding species like oak (Ligot et al. 2014). The rest of the stand is thinned using a more consistent intensity. But the selection process will still create further irregularity.

This variation across a stand will give an opportunity and impetus to see differences in response across the site. This includes natural regeneration, flora seedbank and coarse vegetation. It can be adopted to favour areas with stronger semi-natural components where thinning intensity is greater. It can also be used to manage risk from windthrow by retaining denser groves of skipped trees towards the prevailing wind. The process of observing and responding through adaptive management is a key part of phase two.

Group felling and larger gaps

Group felling involves the removal of a group of trees within a distinct area. This creates open gaps, wedges or strips. They vary in size, but are considered small-scale, relative to the stand and wider woodland context. In most situations, group felling need not be a distinct system to impose on a specific area. The creation of more open areas can be achieved through variable-density thinning across wider stands. This creates more variation in light, and increases microsite opportunities for regeneration across a larger woodland area. It also means that individual trees can be retained where they have values which are worth retaining.

It can be appropriate to remove some small non-native plantation stands as a group felling operation. This is usually where small stands are set within larger semi-natural woodland blocks. They could be less than 1-2ha for example, although it depends on the surrounding context. It should only be carried out where there is negligible risk to remnant ground flora or relic native trees. There are other associated risks, such as vigorous response of coarse vegetation. But these may be outweighed by the ongoing risks with retaining them, such as prolific seeding and regeneration from a small western hemlock stand.

Regeneration is beginning to establish within a relatively small group felling within a large (100ha+) plantation ancient woodland site at Longbeech North, Kent. Rather than considering group felling as a separate system, more open gaps can be prescribed through a selective variable-density thinning across a wider stand or woodland area.
Alastair Hotchkiss/WTML

Variable density thinning of overstorey Douglas fir along with respacing and management of mixed regeneration in the developing understorey. Operations have helped develop and recruit regeneration of downy birch, rowan, holly and oak, as well as conifer regeneration where this was not in competition with native broadleaves, or overly shading ground vegetation. Dyfnant Forest, Mid-Wales.
Alastair Hotchkiss/WTML

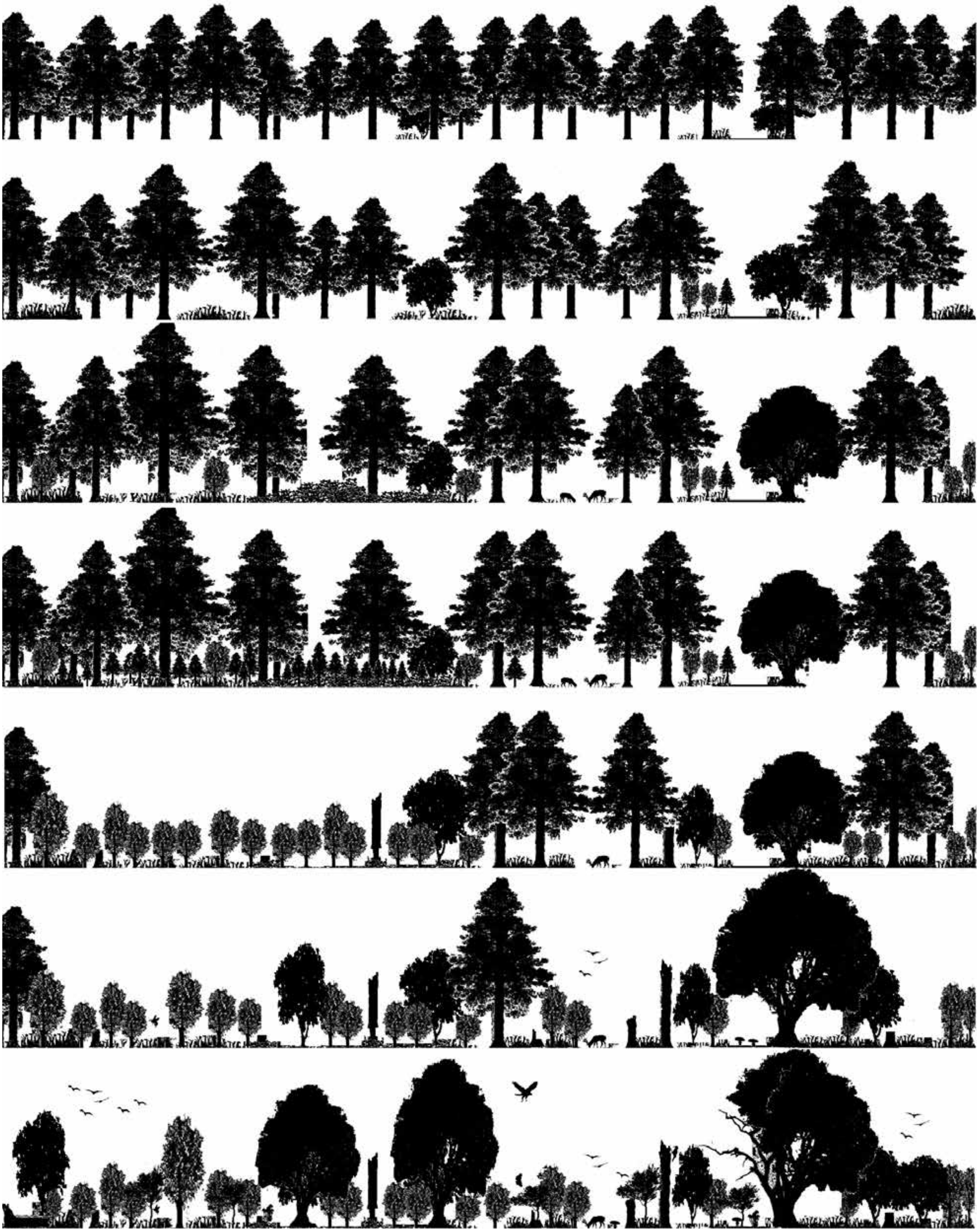

Diagram 5 – An adaptive management approach involving group felling of mature western hemlock stand.

Top Row (Year 0): Ancient woodland in a critical condition. Dense conifers include western hemlock to the west and predominately Norway spruce to the east. Woodland specialist ground flora in critical condition and native broadleaved trees are scarce (young ash and field maple).

Second and Third Rows (Years 3-7): Phase two restoration thinning has progressively opened up canopies of broadleaved trees. Ground flora has responded well in some areas, with brambles dominating in patches. Regeneration is not abundant and predominately ash, western hemlock with some sycamore and hazel.

Fourth Row (Year 8): Continued thinning of mature conifers has resulted in mass of dense hemlock regeneration in west of site.

Fifth and Sixth Row (Years 10-15): The discrete small stand (<1ha) of mature seeding hemlock is removed as a group selection felling, along with thinning the understorey to remove young hemlock component. Some standing deadwood is created by ringbarking several of the mature conifers. Gaps regenerate with predominately birch. Continued thinning interventions gradually remove remaining spruce component.

Bottom Row (Year 20+): Secure ancient woodland with an irregular high forest structure, and rich ground flora. Some mature native trees are developing veteran characteristics and will be retained as old-growth components, but other native trees will be harvested for hardwood timber as part of ongoing management.

3.2 Natural regeneration of trees and shrubs

Promoting and recruiting natural regeneration is a key part of phase two, and the first step in thinking beyond remnants. Its occurrence is a signal that phase two is progressing. But, different tree species respond and establish under different conditions. Understanding woodland types, light-levels and soils helps inform which native trees are appropriate. The availability of nearby seed sources and seed dispersal is also crucial. This is also vital for ground vegetation recovery.

Vegetative regeneration

In some instances, there may be opportunities for vegetative regeneration. This can involve species which regrow from coppicing or layering. This includes ash, hazel, oak, willow, alder, hornbeam and lime. These can be individuals within plantation stands or it could be the restoration of overstood coppice. Ensuring there is enough light and controlling herbivore impacts will help them respond. Suckering is possible in some species such as aspen, wild cherry or blackthorn. Fallen trees also have the ability to respond and continue growing from their branches. This is a phoenix tree. All windblown native trees should have an opportunity to respond like this.

Most conifer plantation species do not respond from vegetative regrowth, or suckering. The few that can (e.g. redwoods and Japanese cedar) are rarely a component of plantations on ancient woodlands. Many non-native plantation broadleaves do have the ability to regrow, such as American red oak or sweet chestnut. Regrowth can produce more impactful conditions, casting wider shade at ground level.

Promoting native regeneration from seed

Regeneration usually involves new individuals from seed. Seed dispersal is vital, because tree and shrub species do not have persistent seed banks (Warr et al. 1994). The viability of tree seed can also decline after even one year (Granstrom and Fries 1985). It is essential to consider the proximity of native seed-producing trees, and the likelihood of seed dispersal. Mapping sources could help inform management.

Acorns dispersed by jays.
Peter Preece/WTML

Birch seeds.
Phil Formby/WTML

Wind dispersed seeds include birches, willows, elms and conifers, as well as the larger winged seeds of ash, maples and limes. Even small-seeded species like birches actually have limited dispersal distances. Individual seeds can travel further on strong winds. But for significant amounts of regeneration, seed producing trees must be within a few hundred metres. Birch can produce seed from a young age though. Water can also transport alder seed, for example on rivers and streams. Smaller seeds can also be dispersed by soil caught on the fur and hooves of larger animals like deer or livestock.

Many tree seeds are only dispersed by animals. Jays and nuthatches move acorns and hazelnuts, for example. Most seed dispersed by animals will be within a few hundred metres. Some species have 'mast years' where they produce more seed. This includes oak, beech and Scots pine. Mast years may result in more regeneration, but it doesn't mean they will travel further. The dispersal distance of beech by yellow-necked mice is further in non-mast years (Zwolak et al 2016). Fruiting species may be spread further by birds. For example, thrushes transport rowan and hawthorn berries, and wild cherry must pass through birds to break dormancy. So, fruit producing trees often regenerate near where birds have perched, in many cases some way from the seed tree. Perching opportunities can be an important feature to enhance regeneration (Zanini & Ganade 2005) and more of these are retained within variable-density thinning than open clearings.

Managing non-native regeneration from seed

Regeneration of non-native trees from seed presents a significant risk. Species which regenerate abundantly and dominate the understorey are concerning. This varies depending on location and soils. Western hemlock can be prolific, as can others such as western red cedar or Sitka spruce in some situations. Do not create blanket prescriptions though. Regeneration can be variable, and it is important to observe and respond if it occurs.

This threat can result in a site proposed for a more rapid and extensive clear-felling, to attempt to remove the continuous risk of non-native regeneration. Particularly in larger woodlands where management is less direct or infrequent. Regeneration of non-native trees will still occur after canopy removal. Felling non-native trees may remove the source, but it can stimulate regeneration from seed released before harvesting. Most conifer seeds remain viable for a few years.

Seeding age of crop trees is important. This varies between species. Pines can set seed from a young age, such as 10-15 years. But the first significant coning and seed crop for most conifers happens from about 25-30 years. This includes Norway spruce, Sitka spruce, Douglas fir and western hemlock. Larches, western red cedar and Lawson cypress could produce significant seed a bit earlier, around 20 years. Some plantation broadleaves take several decades before they produce significant seed. North American red oak is about 30-35 years and non-native beech about 45-50 years.

There are risks associated with different approaches. Thinning the overstorey will result in remaining non-native trees being bigger and with larger crowns. These have the potential to produce more seed. If regeneration can be managed, then this may be practicable, but it can be problematic. A stand may be next to an area of ancient semi-natural woodland which is difficult to access and manage. Removal of the non-native seed-sources would be important here. This may result in a more rapid removal.

Managing light and recruiting regeneration

Where seed is deposited, light and other environmental conditions influence its regeneration and successful establishment. Many plantation broadleaves and conifers are more shade-tolerant. They perpetuate themselves in lightly thinned stands. A lot of our native tree species are more light demanding.

The table below gives an indication of the variation of trees in relation to how light-demanding or shade-tolerant they are. But, care should be taken not to attribute these characteristics too strongly. Those very shade-tolerant species will be able to establish with less light. But some shade-tolerant species such as Sitka spruce, western hemlock or hazel can also act as pioneer species.

Those more demanding of light tend to be the pioneer species, and colonise open ground more readily. However, these can sometimes still regenerate under some shade. They often require light as they develop. Rowan and birch, for example. Birch regenerates abundantly on open felled sites. But birch seedlings do not need full sunlight. Its success in clearings is also partly because of exposed mineral soils and reduced competition. It is as birch trees mature that they do not tolerate shade (Cameron 1996), and trees need to be opened up to develop. Similarly, lime seedlings and saplings can survive in dense shade,

Conifer regeneration is dominating the understorey and impacting birch and other broadleaved regeneration as well as the ground vegetation dominated by bilberry, heather, wavy hair grass and mosses. Respacing and thinning the understorey can favour the birch, as well as developing the better formed conifer stems as part of the process, where this is an objective. Ancient woodland site in North Wales.

Alastair Hotchkiss/WTML

but their growth in the third and fourth year needs more light for successful regeneration (Pigott 1991). It is therefore vital that thinning provides sufficient light to further develop and recruit existing saplings. Other factors can also affect the shade tolerance of individuals, such as oak powdery mildew. This impairs the shade tolerance in oak seedlings and saplings.

It is not necessary to create large open spaces to regenerate certain species. Dappled side-light within irregular stands can be significant when managing the understorey. Variable-density thinning can help to ensure different microsite opportunities for regeneration. Irregular forest structures increase the number of potential sites for the establishment of a wide-range of tree species. Particularly in stands with variation in light conditions, heterogeneous age distribution and the presence of large trees (Tinya et al. 2019). These same factors also support diversity of other species such as birds (Alder et al. 2018, Mag & Odor 2015) and woodland beetles (Hjalten et al. 2017).

Species	General light demand
Birch, aspen	Very light-demanding, mostly pioneer species
Scots pine, Lodgepole pine	
Rowan	
European larch, Japanese larch	
Pedunculate oak	
Alder, wild cherry	Light-demanding
Sessile oak, Corsican pine	
Ash, field maple grey willow, goat willow	Intermediate
Norway maple	
Norway spruce, Sitka spruce	
Wych elm, small-leaved lime, sweet chestnut	Moderately shade-tolerant
Douglas fir, hornbeam	
Sycamore, large-leaved lime, hazel, holly	
Beech	Very shade-tolerant
Western red cedar, Lawson cypress	
Western hemlock	
Silver fir, grand fir, yew	

Enrichment planting and seeding

Natural regeneration of native trees is preferable as this will promote individuals that are better adapted to local soils and site conditions. Native trees in the UK are shown to have a very high degree of genetic variability within their populations (Whittet et al 2019). Natural selection, via natural regeneration, is important and can drive site-based adaptation. Whilst we have a limited range of native trees and shrubs, they are considered to have strong potential to respond and adapt to rapidly changing environmental conditions.

The range of gradual restoration operations described in this section can provide light conditions suitable for natural regeneration of all native trees. If the more light-demanding species are still absent then further consideration must be given to additional operations, as part of adaptive management. But, there are situations where planting would be most appropriate and potentially necessary:

- Isolated woods or stands, where seed-producing trees of native species are scarce or absent. Particularly native trees that are key characteristic components of an ancient woodland's vegetation and soil types. Although variable between species, if seed-producing trees are scarce or absent within just a few hundred metres, then consideration should be given to planting or direct seeding.
- Following mulching, cutting and mechanical treatments of dense or vigorous patches of coarse vegetation, such as bracken and bramble. These areas could be subsequently planted where there is risk that the coarse vegetation will respond quickly and regrow. Establishing hazel can be used to supress vigorous coarse vegetation. This may also be applicable to some areas where invasive non-natives have been eradicated.
- Minor native species which are absent. Particularly those that are less able to disperse and re-colonise even short distances naturally. Examples may include small-leaved lime, aspen or wych elm which can produce seed infrequently, but only where appropriate to the location and character of a wood.
- As part of a response to serious impact from tree pests and diseases where these are considered to be affecting remnant ancient woodland features or inhibiting the recovery of the woodland ecosystem.

Enrichment planting should never be seen as simply 'the more species the better'. Native trees and shrubs planted in ancient woodland should be species which are appropriate to the location and character of an individual wood, soil and vegetation type. Introducing planting stock always presents a risk to the genetic integrity of an ancient woodland and can risk introducing new pests and diseases. For this reason, only locally-sourced planting stock should be used, and only certain tree nurseries are suppliers of accredited UK Sourced and Grown stock.

Direct seeding of appropriately sourced native tree seed can be a successful method, with advantages over planting (Löf et al 2019, Willoughby et al. 2019). These include lower costs of establishment, as well as producing trees which are more resilient.

For example, reduced impacts of drought on direct seeded oak because of naturally developed taproot. Direct seeding of appropriate mixtures of native trees could help develop more irregular and complex regenerating stands. However, there are more uncertainties, particularly with seed predation by rodents, so regular observation is required.

Adaption and resilience to climate change is important, but this should be achieved through restoring ancient woodland ecosystems. These must also be part of more ecologically permeable landscapes. Allowing natural processes to determine the species and genetic responses to environmental change is more appropriate than attempting to artificially increase the diversity of tree species, or planting more southerly provenances. This will rarely result in maximising the ecological integrity of an ancient woodland site, nor ensure its ecological resilience (Ennos et al. 2019). The projected rate of climate change is unprecedented; more regular phases or continual recruitment of natural regeneration may be necessary (Whittet et al. 2019). The increased generational turnover enables trees to better respond to rapid change.

Underplanting with oak, hazel, birch, rowan and holly within a deer fenced exclosure. Bovey Valley, Devon.
Alastair Hotchkiss/WTML

Managing the understorey

Non-native trees in the understorey need controlling when in competition with native regeneration, as well as when they are a threat to ground vegetation recovery. Deer can compound the impacts of non-native regeneration. Preferential browsing often impacts more palatable broadleaves. In some situations, it will be prudent to remove non-native regeneration immediately. Especially where management is infrequent or indirect.

Douglas Fir PAWS at Wentwood in South Wales has been thinned to favour the crown development of mature oak within the stand, as well as to encourage natural regeneration. Although bramble and bracken have responded strongly to these conditions, there is also regeneration of birch and oak which can be further developed, as well as Douglas fir which will be removed. These thinned stands of Douglas fir are more significant now that large other parts of the Woodland Trust's ownership at Wentwood have had to be clearfelled for Phytophthora ramorum infections in Larchn.
Alastair Hotchkiss/WTML

But, increasing structural complexity in otherwise uniform plantations is beneficial. Particularly in the early stages of phase two. It can benefit species of birds, invertebrates and other fauna. It can also manage levels of moisture and shelter, which can benefit native regeneration. So, it is acceptable for some non-native trees to form part of the understorey, but only where management of a site is more frequent, direct and adaptive. Rather than complete removal, respacing or thinning of the understorey can be preferable.

This can be time-consuming and costly, but respacing and thinning the understorey as it develops can be very important. The process of respacing or thinning regeneration can maintain desired species. It can benefit selected individual trees. Where prolific, it can ensure regeneration does not impact on the recovery of ground vegetation. But, dense understorey thickets are vital for many birds and other fauna. So it is useful to maintain some denser patches of regeneration.

Gradual restoration and longer-term retention of non-native trees

Non-native trees can provide continuity of woodland habitat and high-forest functioning. Often for an extended period. Insects live in mature conifer canopies, and are prey for other insects, birds or bats. The trees maintain important cover and woodland conditions. Some non-native trees share ectomycorrhizal fungi with native trees. These essential fungi live on tree roots, helping the uptake of nutrients and water. Gradual restoration means that these fungi can move onto and support regenerating native trees (Simard et al. 2013; Sterkenberg et al. 2019).

Ecological systems are complex and adaptive. Some non-native trees can fulfil similar (albeit less optimal) roles to native trees, and this can contribute to the resilience of a woodland during the restoration process. For example, sycamore is likely to provide continuity for wildlife associated with ash trees in decline. But, there is an ongoing management need to ensure sycamore does not become dominant and shading. Retaining non-native conifer regeneration to an age when it produces seed also creates risk and additional management. This lack of self-regulation means that ecological integrity is not maximised. Where owners want to retain non-native timber, gradual restoration means that these trees can be kept for longer. The selective thinning process can also improve the quality and the standing value of the remaining trees within a wood.

With conservation as the primary objective, phase two restoration should be reducing non-native trees to insignificant proportions. These may be scattered individual trees within stands dominated by native trees, but not discrete blocks, however small. Complete removal may be necessary to maximise the ecological integrity of ancient woodland sites. It will remove any further risk associated with regeneration.

Continuing with a single-tree selection of Douglas fir by felling to permanent extraction racks will help promote development of maturing oak crowns. Some management of the understorey ensures regenerating broadleaves become established and conifer regeneration does not dominate. But there is potential to retain conifer components within this system. Somerset.

Alastair Hotchkiss/WTML

Mixed understorey of native broadleaves (predominately birch, some oak and rowan) and conifer (Douglas fir, spruce and western hemlock) has been respaced to favour broadleaved components, and to remove western hemlock. Some remaining Douglas fir and spruce regeneration is retained where not competing with native regeneration or impacting on ground vegetation recovery, and will form part of the transition into continuous cover irregular high forest. Mid-Wales.

Alastair Hotchkiss/WTML

Case Study 1:
Bovey Valley Woods – Houndtor Wood.

Case Study – The ancient wooded Bovey Valley on the edge of Dartmoor, Devon. Blocks of conifer plantations have been established throughout the ancient woodland.
Alastair Hotchkiss/WTML

The ancient wooded Bovey Valley is on the eastern side of Dartmoor in Devon. Owned and managed by the Woodland Trust, Houndtor Wood contains plantation stands of mainly mature Douglas fir on ancient woodland sites.

Since the Woodland Trust took ownership, most stands have been thinned three times. There was an initial light thinning, followed by one further thinning intervention. Several experimental exclosure plots were set up to observe changes. This highlighted the dominance of Douglas fir regeneration. It also revealed the compounding impacts of deer browsing. Deer were selectively removing native regeneration. Within some fenced exclosures, underplanting of hazel, birch, rowan, holly and oak has all established well. Douglas fir regeneration has been removed. Ground vegetation recovery has also been good. This included woodland specialist plants like bilberry, wood sedge, slender St. John's-wort, wood sorrel and honeysuckle.

The third thinning has been an adaptive response to this situation. It has been at a variable density, with some areas of the stands being more heavily thinned than others.

Douglas fir stand within Houndtor Wood, Dartmoor, showing the mass of conifer regeneration occurring outside the deer exclosure where conifer regeneration has been weeded to help establish planted and regenerating native broadleaves.
Alastair Hotchkiss/WTML

Most recently, thinning at Houndtor Wood in Dartmoor was carried out at a variable-density, which has resulted in patches with significantly reduced basal areas to try to encourage more broadleaved regeneration.
Alastair Hotchkiss/WTML

Deer management has also increased. The heavier and more irregular reduction in basal area is setting the woodland on the right trajectory. Phase two restoration and recovery of the wider ecosystem is progressing. But management and respacing of the understorey will need to continue.

This highlights the need to adapt to situations faced through phase two. It also demonstrates the flexibility of gradual approaches, and the ability to respond. Although this has been challenging, a more rapid transformation by clearfelling would have presented risks. Wider ecosystem functioning and continuity has been maintained, including for important ancient woodland remnant species.

The Douglas fir stand supported rare Barbastelle bats. These woodland specialists were roosting within cavities on a single drawn up broadleaved tree. Rapid removal of the plantation stands around them would have exposed these colonies. Southern red wood ant nests also occur within the stand. These ants feed on honeydew produced by aphids on the canopy trees. With the absence of aphids on mature broadleaved trees, they use the conifer aphids. Wood ants and their nest mounds reduce after clearfelling (Johansson & Gibb 2012). The gradual transformation allows aphids to build-up on establishing broadleaved components. Tree aphids are a keystone in many woodland ecosystems. As well as honeydew, they are prey for other insects like hoverflies, ladybirds and the birds that feed on them. Rare old-growth woodland invertebrates like the blue ground beetle also occur in the Bovey Valley. This species feeds on tree slugs and ash-black slugs in particular. These woodland specialist slugs are highly sensitive to rapid exposure. It can take a century for them to recolonise clearfelled woodlands (Kappes 2006).

Nest mound of southern red wood ants (*Formica rufa*) within the Douglas fir stand at Houndtor Wood in Dartmoor. Maintaining canopy trees and restoring the ancient woodland through a gradual thinning approach ensures that the ants maintain access to honeydew producing aphids in the canopy.
Alastair Hotchkiss/WTML

3.3 More rapid and extensive transformations

These methods are rapid 'transformations' rather than 'restorations'. A large clearfelled site restocked with native trees may give the impression of a quick win. But this will not achieve the restoration of ecological integrity. It presents risks to remnant features, and fails to maintain ecological functions and processes. But it should not be assumed that there is no role for rapid transformations within phase two.

A rich woodland flora has recovered at Chalkney Wood, including herb paris (*Paris quadrifolia*).
Alastair Hotchkiss/WTML

Extensive selective felling

Extensive selective felling involves the removal of specific elements within a stand. For example, the removal of all individuals of a certain species making up a proportion of the stand. This could be appropriate in situations where a robust native tree canopy remains, such as where they have been underplanted with shade-tolerant non-native species. A more rapid and wholesale removal of these trees could be achievable with few risks. A good example is Chalkney Wood in Essex. The rapid de-coniferisation by the Forestry Commission involved the selective felling of all conifers. The high proportion of surviving native trees contributed to the success of this rapid approach, particularly vigorous small-leaved lime and hornbeam. A strong seed-bank response occurred from rich ancient woodland flora. Crucially, these had not spent too long (<20 years) in unfavourable conditions (Rackham 2003).

Ring-barking can be used to create standing deadwood as part of a selective felling operation. Ring-barking is tricky to get right. It works best where a chainsaw is used to cut a wide (approx. 30cm) band around the tree. This must be shallow enough to ensure that the tree will not snap, but deep enough to ensure it is effective. If done right, the tree will stand firm. Where operators have less experience with ring-barking, chemical treatments can reduce the likelihood of windsnap.

Majority of conifer component has been removed in one intervention where the woodland retained a strong proportion of native broadleaves. Ground vegetation will likely recover well and expand out from existing pockets. Ausewell Wood in Devon.
Alastair Hotchkiss/WTML

Selective felling of conifer component to create lying deadwood. There has been a good response to this operation, where native broadleaved components already featured quite strongly. College Wood, Buckinghamshire.
Tim Hodges/WTML

Rapid selective felling removal of planted conifers has resulted in an excellent recovery of native trees and ground flora at Chalkney Wood, Essex.
Alastair Hotchkiss/WTML

Clearfell required by Statutory Plant Health Notice (SPHN) for a stand of larch infected with Phytophthora ramorum at Wentwood, South Wales. The plant in the foreground is small teasel (*Dipsacus pilosus*) – an ancient woodland specialist plant which benefits from sporadic ground disturbance and light, and could benefit from this operation. But otherwise, this rapid transformation has impacted on ecological continuity and the recovery of the wider ecosystem.

Alastair Hotchkiss/WTML

Before and after image of clearfell on privately owned ancient woodland site in Ceredigion, West Wales. Rapid transformation was considered appropriate to remove a stand of large mature unthinned western hemlock on very steep rocky slopes. Hemlock regeneration was abundant throughout all adjacent stands and ancient semi-natural woodland areas, and a gradual approach through repeated thinning interventions was impractical and inappropriate.

Alastair Hotchkiss/WTML

Clearfelling

In some situations, a gradual approach, based on successive thinnings, may not be practicable. Restoration involving the clearfelling of non-native trees may be more appropriate, for example where the constraints covered earlier are significant. This could be stands with a highly unstable, unthinned mature plantation crop. Particularly where exposed to strong winds. Or it may be a requirement of a Statutory Plant Health Notice to prevent the spread of disease.

The rapid removal of spruce stands as part of historical restoration work at Loch Arkaig has resulted in large areas of young birch between the remnant old native Scots pine trees.

John MacPherson/WTML

Rapid canopy changes introduce new threats to ancient woodland features. It is vital to always use targeted phase one felling before a clearfell. This 'first-aid' should be done in the years leading up to clearfelling operations. This can help ensure remnants are robust enough to cope with a more rapid and extensive transformation.

Diagram 6 – Restoration involving clearfell – the importance of 'first aid' before phase two interventions.

Top left (Year 0): Conifer plantation on ancient oceanic oak-birch woodland, with remnant sessile oak in critical condition, and supporting old-woodland lichens such as tree lungwort (*Lobaria pulmonaria*) and barnacle lichen (*Thelotrema lepadinum*). Remnant ancient woodland ground typical of oceanic (NVC W17) woodland is confined to hotspots of broadleaved trees and is in critical condition. Some standing deadwood occurs where ancient birch has been overtopped by the conifers. The conifer crop is unthinned and exposed to strong winds, and with the addition of challenging access and steep slope, a gradual thinning restoration approach is not feasible.

Top Right (Year 1): Targeted phase one restoration has halo-thinned all relic veteran oaks which were identified and mapped as part of the survey and assessment process. Felled material is left as lying deadwood.

Bottom Right (Year 6): Subsequent clearfelling of conifer stand was carried out two years after the targeted restoration work, all remnant mature oaks and deadwood were protected during operations and remain standing. Although the ancient woodland is still considered threatened, natural regeneration of downy birch, sessile oak and rowan have established, and ground vegetation is recovering.

Bottom Left (Year 6 alternative scenario): No ancient woodland survey and assessment process was carried out, and clearfelling and restocking operation was carried out on the site with no targeted phase one management. Standing deadwood damaged during extraction, and mature relic sessile oak have subsequently blown over in strong winds.

Clearfelled conifer PAWS with restocking of oak and natural regeneration of birch and rowan at a site in Surrey
Alastair Hotchkiss/WTML

Restocking

Clearfelling results in large open areas that must regenerate with woodland cover. A clearfelled site is vulnerable, and the subsequent costs of re-establishing tree cover can also be expensive. It can consume significant amounts of any income made from harvesting operations. Natural regeneration should always be considered as the first option, but the same considerations apply here as covered under enrichment planting. This includes situations when planting or direct seeding is appropriate. It is also necessary when there are concerns about ensuring quick site capture. Restocking may also be a requirement.

Where replanting is necessary, ground preparation should be minimal. Other intensive post-clearfell operations should be avoided, such as the use of herbicides or pesticides. The costs of deer protection, fences, tubes or other protection can be significant.

Native broadleaved restocking on clearfelled conifer plantation on ancient woodland site.
Alastair Hotchkiss/WTML

Restocked sites must not be considered to be restored. Replanting is not the end of the story. The ongoing management of young stands is vital to develop the functioning and recovery of ancient woodland ecosystems.

Managing regeneration following a clearfell of mature western hemlock on ancient woodland site. Seed from the previous stand, and adjacent stands of mature hemlock, has resulted in mass of hemlock regeneration. Part of the area (foreground) has been managed to remove this.
Alastair Hotchkiss/WTML

Thinning of young larch stand on ancient woodland site in Staffordshire.
Alastair Hotchkiss/WTML

Managing young stands – thickets and pole stage

After restocking or regeneration, the next decade will see the development of a thicket on clearfelled sites. Dense pole-stage material will then develop. Dense young stands can often produce the most impactful conditions for remnant woodland ground flora. Management of these young stands can be very beneficial. It can set the direction for the stand, and support many objectives. It can ensure that proportions of native species are maintained. Particularly where naturally regenerated native broadleaves are mixed with planted non-native species.

Managing pole-stage stands begins to establish structure, and benefits restoration. It can support other commercial objectives by improving stand quality. It is important in developing continuous cover systems and helps create windfirm stands. The time at which this begins may be determined by the point material can be marketed and sold. For example, for small diameter fencing materials or as chip for biomass, this could be from around 12-15 years.

But, there may be a restoration need for earlier intervention. Especially where there are risks of losing native regeneration. Also, where specialist ground flora is deteriorating. It is beneficial to keep small areas as unmanaged denser thickets for birds such as willow warbler. The survey and assessment process will inform when this is critical. At a very young age (i.e. under 10 years), it is possible to go through thickets and cut unwanted trees at

Thinning a stand of young larch has benefitted development of timber trees as well as increasing light within the stands and along extraction racks where woodland flora including climbing corydalis have responded and solitary bees and wasps favour the sunlit sandy soils. Staffordshire.
Alastair Hotchkiss/WTML

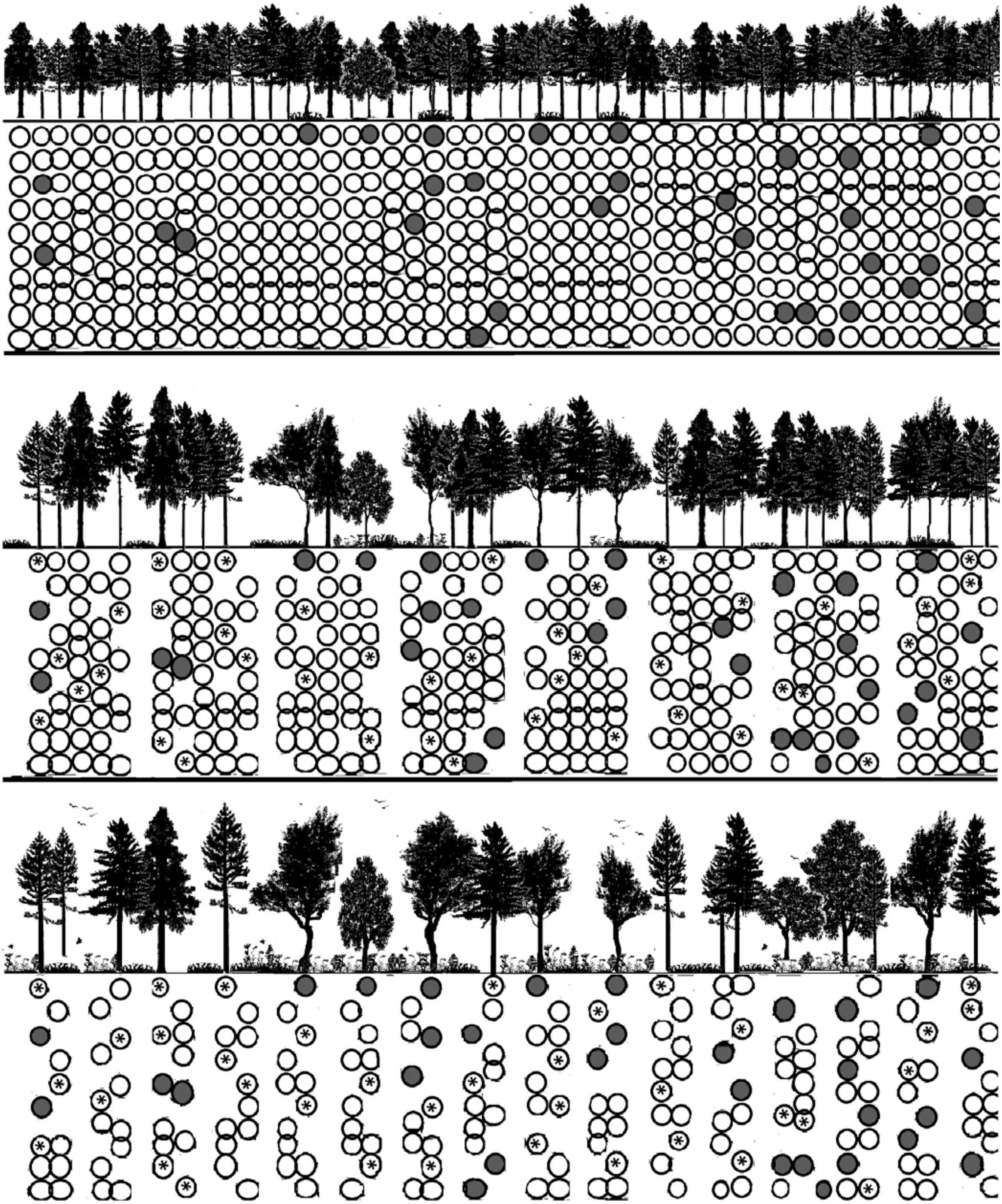

Diagram 7 – Graduated density thinning of young plantation stands on ancient woodland sites.
This method of thinning young stands can be used as part of early transformation to continuous cover systems. It can help create more windfirm stands, and the selection process can be adapted to suit objectives. In this scenario a classic 1 in 6 graduated density thinning is carried out to favour the semi-natural broadleaved components (grey circles) that have naturally regenerated within the stand of two planted conifer species (white circles). The selection process was aimed at releasing these components where they existed, but elsewhere, it was used to favour the best quality and formed conifers remaining in the stand (marked by *), and to remove the poorer quality stems.

Top Row (Stand Age: 12): Mixed cohort of Douglas fir – 80%; hemlock – 10%; and broadleaves (mostly birch and oak) – 10%. Most conifer material still too small for fencing or other markets.

Middle Row (Stand Age: 16): First extraction racks taken out (1 in 6 rows) with 30% stems removed from adjacent rows, and 20% removed from the second rows out from racks. The operation was anticipated to break even, but thinning makes a small profit due to high prices for biomass.

Bottom Row (Stand Age: 21): Second thinning creates another rack and further selective thinning adjacent to further develop native broadleaves and better quality conifers to retain. The systematic establishment of racks may sometimes mean sacrificing some proportion of broadleaved regeneration, although where this is significant, racks could be moved, or other systems such as 1 in 8 could reduce systematic removal of trees where this is likely. After this point, the third thinning will become a completely selective system, and further thinning interventions will continue to favour crown development in broadleaved components. By this time, some further natural regeneration may begin to occur, with opportunities to favour this and begin to develop a more irregular age structure.

ground level. There is usually no need for snedding (debranching) or cross-cutting.

The management of pole-stage stands often involves systematic thinning methods. These include line-thinning at regular intervals to establish a series of racks. It can also include more selective removal. Graduated-density thinning is a useful method for ancient woodland restoration. This method developed from commercial forestry for early transformation to continuous cover. It is effective in establishing windfirm stands. It can set the trajectory of young stands, but it can also work on more mature stands. Graduated-density thinning involves the removal of racks, with a decreasing proportion of trees removed from rows between. This presents opportunities for crown development of native natural regeneration where it occurs. It offers opportunities to develop better formed timber trees.

Graduated-density thinning of young (18 year) Douglas fir stand on a privately owned ancient woodland site on a farm in Powys, Mid-Wales. This second rotation conifer planting follows removal of mature larch and the rich ancient woodland flora was rapidly deteriorating under dense pole stage conifers. Thinning has favoured oak, hazel and other broadleaves within the stand, as well as removing the poorest formed Douglas fir for biomass. The operation has made a profit, and the stand is in a better condition in terms of ancient woodland restoration and timber quality.

Alastair Hotchkiss/WTML

A young 16-year-old stand of restocked Douglas fir and Western hemlock, along with natural regeneration of birch, rowan and oak. Privately owned ancient woodland site, where owner carried out work directly. No material was extracted, and the operation was therefore at cost, but the thinning will benefit the development of birch crowns in particular as well as the few oak, and some retained Douglas Fir. Western hemlock has been removed. Woodland flora has responded well from the seedbank including slender St. John's-wort and wood sage.

Alastair Hotchkiss/WTML

Plantation ancient woodland site on a farm in Powys, Mid-Wales. The previous clearfelled larch was replanted with 2500 stems/ha of Douglas fir approximately 18 years ago. The bluebells within the stand were etiolated and not flowering as young conifer stand has developed. Other flora includes broadleaved helleborine orchids and wood horsetail. The site was thinned using graduated-density thinning to begin the restoration process and as an early stage CCF transformation. A 1 in 6 system was established with selective thinning focussed on removing trees around regenerating broadleaves (oak regrowth, birch, willow, rowan, hazel and aspen), as well as to favour the best quality Douglas fir by removing the poorest swept forms. The operation made profit, and extracted material was sold for both fencing material and biomass at roadside. The resulting stand is in considerably better shape in terms of restoration, and the resulting Douglas fir stand will continue to develop into a valuable future timber source. A second thinning will occur in approximately 4-5 years and will involve a second rack creation and the same prescription on adjacent lines.

Alastair Hotchkiss/WTML

Case Study 2: Coed Mitchen.

Coed Mitchen is a privately owned 11ha plantation ancient woodland site in Mid-Wales. Prior to acquiring the site, a storm event had created windblown spruce and larch trees. This was cleared by the owner to create small glades. The following February, further windblow occurred in stands of 30-year-old Sitka spruce. Woodland specialist ground flora was limited to even scatterings throughout the stand. Only 3 mature oak occurred, and were on tracksides. On infertile acidic soils there was a low risk of coarse vegetation response, and the site had no impacts from deer. So, the risk of a clearfell could have been perceived to be low. It was a practicable option given the windblow threat and thinning history.

Yet, despite this, a gradual thinning approach was pursued. The owner wanted to restore the ancient woodland by transformation to continuous cover forestry. As a professional horse-logger, he wanted to thin and extract timber himself. A local market was found, as fencing materials. Extracted spruce logs were stacked at roadside and sold in 26-tonne lorry loads.

Following thinning of all the spruce stands in recent years, windblow has been limited and manageable. The risks were managed through a variable-density thinning. This retained denser patches of spruce at the leading edge of the prevailing wind. Thinning intensity was focused on opening up the crowns of mature and regenerating native trees. Mainly downy birch with some sessile oak and rowan. Small denser groups of spruce were retained in places.

The lemon slug (*Malacolimax tenellus*) populations are benefitting from the retention of canopy cover and large woodland mushrooms associated with the roots of both plantation and regenerating native trees.
Alastair Hotchkiss/WTML

The initial ancient woodland assessment survey was carried out in spring. But, several years later, an autumn visit revealed masses of woodland fungi. Many

Thinning of spruce at Coed Mitchen has been carried out to develop groups of regenerating birch, oak and rowan.
Alastair Hotchkiss/WTML

large fruitbodies of mycorrhizal mushroom species occurred. These fungi grow on the tree roots of both native birch and oak, as well as the spruce. Feeding on the large bolete mushrooms was a population of lemon slugs *Malacolimax tenellus*. These are scarce ancient woodland specialists. These remnant species feed on woodland fungi. These mycorrhizal fungi and the lemon slugs would not tolerate clearfelling (Kappes 2006). This emphasises the precautionary nature of gradual phase two restoration. There is always a risk that rapid and extensive transformations will result in the loss of ancient woodland remnant species. Especially those that are hidden for most of the year, or are not picked up through the assessment process.

Pied flycatcher (*Ficedula hypoleuca*) is successfully breeding at high densities within Coed Mitchen. Powys.
Richard Becker/WTML

Maintaining high-forest conditions has also retained habitat for pied flycatchers. These birds were absent and did not nest in the wood. They now occupy 50% of the nest boxes the owner has erected, at high densities. The dappled sunlight of the thinned woodland provides small insect prey and trees for perching. Species like this can signal the recovery of the wider woodland ecosystem, as part of thinking beyond remnant features alone.

Case Study – Stacked spruce timber from PAWS restoration work at Coed Mitchen, Powys, Mid-Wales
Alastair Hotchkiss/WTML

3.4 Operations and contractor management

This is not a comprehensive guide to the technicalities of contract management. It is an overview of its relevance to the ancient woodland restoration management described in this guidance.

There are many options for delivering restoration management on the ground. On some smaller woodlands it may be achievable to directly carry out work, where owners are willing and able. Phase two restoration often requires forestry contractors to carry out more extensive operations. Forest managers or agents can help develop harvesting and marketing plans, and supervise works.

As part of working up a harvesting programme, there are different options for selling timber. This can be done by standing sales to contractors, selling timber at roadside, or delivering timber into the buyer. Whilst the latter commands a higher price, there is increasing risk in the process. The most straightforward option is to sell the timber standing. This is where a contractor gives a price for purchasing the timber standing. They account for their costs in having to harvest and extract the timber. But it is vital to maintain control during standing sales. A key part of this is ensuring that stands are well marked-up and that there is absolute clarity over what is to be done. Appropriate supervision of works is also important, marking either a sample or every tree for thinning where necessary. It is important to ensure that decision-making is not led by timber buyers. There is a need for some flexibility, and contractors will be well placed to advise on how practical and feasible something is.

Contractors using combination of manual felling of Norway spruce with chainsaws with a tractor and winch for extracting timber at a privately owned ancient woodland site in Mid-Wales.
Alastair Hotchkiss/WTML

Marking-up stands for thinning is very important, and ensures control over which trees are selected for removal.
Alastair Hotchkiss/WTML

Contractor selection and effective contract management and monitoring is vital. Clearly written, specific contracts are particularly important. Especially if the contract supervision is passed to a third party. This can ensure the restoration objectives are achieved. Different systems of harvesting and forwarding timber may be appropriate in different scenarios. Many forestry contractors employ fully mechanised systems of forestry harvester and forwarder machinery. But, in other situations, systems involving chainsaw felling, tractors or even horses may be effective.

Protection of remnants, regeneration and other features

It is vital that phase two management is carried out in a way that ensures remnants remain protected. Damage to other important features such as natural regeneration must also be avoided or minimised.

Rich trackside vegetation – a) at a site in Devon, with important populations of royal fern, along with hard fern, greater wood-rush, honeysuckle, yellow pimpernel and remote sedge.
Alastair Hotchkiss/WTML

b) trackside populations of early purple orchid, bluebell and wood anemone. Restoration management in adjacent stands needs to ensure these trackside hotspots are protected during harvesting.
Robert Read/WTML

Phase two restoration has progressed well at Brede High Woods in East Sussex, where regeneration is being recruited into the understorey and woodland canopy as the dominance of pine is being gradually reduced.
Colin Varndell/WTML

Some actions to address this include:

- Avoid hotspots of remnant ground vegetation and woodland specialist plants during operations. This is often relevant to rides and track edges which are well used during harvesting. Avoid stacking along tracksides where ancient woodland specialist flora occurs. Time operations to minimise ground damage.
- Ensure remnants and other important features are identified and mapped. This is achieved through the survey and assessment process. But where works are planned within a stand, re-walk an area. If necessary, demarcate particularly vulnerable remnants or other components such as regeneration. It may be necessary to produce constraints mapping to inform contractors pre-commencement.
- Avoid using machinery and mechanical extraction over old relic stumps and large woody debris. Make sure extraction rack systems are not over root systems of relic trees. Avoid extraction systems resulting in turning or pinch points where damage to stems of relic trees is possible. Take a precautionary approach to considering how far the root systems of these trees may extend.
- Well-planned permanent extraction rack systems can help avoid repeated damage to areas of natural regeneration and soils. This limits access by machinery. Try to plan and establish turning areas and routes in and out of racks to minimise vehicle movements. Consider the use of low impact tyres to further reduce potential damage.
- Carefully consider timing to ensure that sites are not worked during periods of the year when there is a risk of serious soil damage.
- But, do not to be overly cautious about disturbance. Some small-scale soil disturbance, such as where logs have been skidded, can be beneficial to woodland ecosystems. Without large heavy wild mammals in many woods, small patches of disturbance often only occur with timber harvesting.
- It is important to avoid leaving any relic native trees vulnerable to windblow on or close to archaeological features. Also take care to remove brash mats after use.
- For archaeological features such as banks, look for existing gaps to use, and if going over it is essential, use brash and logs to make a ramp. For levelled areas like charcoal platforms, they will have been dug by hand and the downhill side is not very compacted. These are best avoided, but if crossing is essential, then keep the uphill half and cover the whole area with brash.
- Where passing over archaeological features is unavoidable, brash mats are required. These must always be subsequently removed. For Scheduled Monuments, permission will be required.
- Avoid a dense build-up of brash, particularly in obvious flora hotspots. Remember that ride and ride edges are important so avoid build-up of brash here. Try to stack or row brash and ensure that as much ground as possible is free of brash following an intervention. Brash should never be stacked up against the base of any relic pre-plantation trees.

4. Progress and the final phase of restoration

Phase two restoration can take a long time. Management needs to be reviewed and adapted following regular observations. This will inform how the wood is responding to management.

As part of an ongoing evaluation process, there will be certain aspects to focus on. In the early stages of phase two, these include specific observations, such as whether the site shows significant regeneration into the understorey. Other observations include whether ground vegetation is spreading or re-establishing in new areas. This also helps to understand how the wider ecosystem is recovering.

This can all be understood by repeating the survey and assessment process (outlined in Module 2) at least once every 4-5 years. This provides an ability to look back and compare information captured for each zone, to get an idea of how things have changed. This will help determine whether a threatened stand is recovering, declining or when there is no change. The recovery of threatened ancient woodlands also represents an increase in ecological integrity. The features recorded as part of the assessment act as proxies for wider complexity. But, this thinking about how to maximise ecological integrity marks the move towards the final phase of restoration.

The end-point to phase two restoration activity is a 'secure ancient woodland site' (SAWS). By this stage, remnant features may no longer be threatened, impacts are limited, and the woodland may have regained some of the complexity and richness of ancient semi-natural woodlands. But more is still required to maximise ecological integrity. Therefore, these should never be considered 'restored'.

Moving into the final phase of restoration

The third and final phase of restoration is all about what more can be done to maximise the ecological integrity of an ancient woodland site. This can often overlap with phase two. But phase three restoration is also equally applicable to all ancient woodland sites. Not only those plantation sites which have progressed through phase two.

Ongoing management within the woodland boundary can continue to build complex adaptive systems. Continued silvicultural activity can also drive important processes and dynamism. As part of this, phase three considers what is still missing from these woodland ecosystems. It looks at how management can help develop the functions and microhabitats that are currently absent. The succession of old trees and deadwood is a key focus. These are the old-growth characteristics which are missing in many ancient woodlands. Management systems may also need adapting earlier in phase two as part of developing this 'future old growth'. For example, by selecting individual trees and allowing them the space to develop and be retained indefinitely, phase three can ensure that enough native trees gain veteran characteristics and become ancient in age. Ongoing management must also develop significant volumes of large standing and fallen deadwood. Novel management can help bridge the gap. This includes speeding up the provision of decaying wood and other veteran microhabitats. Consideration is also given to reintroductions and species translocations. These may help restore important functions or processes in particular. This also includes thinking about ecological disturbance, dynamism and ecotones – the transitions between denser wooded groves and more open glade habitats. Again, it may be appropriate to give thought to this earlier in the restoration process. But, phase three also looks at how natural processes can determine more of the future trajectory of a woodland.

Phase three also considers how individual woods fit within a wider landscape scale restoration. The influence of external pressures and environmental change will always be significant. This includes the restoration and expansion of other wooded and scrub habitats in the landscape. Phase three also examines how factors outside the boundary of a wood can strengthen or impede its ecological integrity.

As phase two restoration progresses, there is an increasing need to look towards the final third phase of ancient woodland restoration and look for opportunities to further maximise the ecological integrity of the woodland. Old Wood, Skellingthorpe, Lincolnshire.
Alastair Hotchkiss/WTML

Ongoing management through phase three can continue to build complex and adaptive ecosystems. There is also a need to consider what niches and microhabitats are still missing from ancient woodland sites, and how old-growth characteristics can be developed.
Alastair Hotchkiss/WTML

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