Practical Guidance
Module 5

Ancient woodland restoration

Phase three: maximising ecological integrity

WOODLAND TRUST

Contents

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ALASTAIR HOTCHKISS

1 Introduction

This is the fifth module in a series on ancient woodland restoration. It is a guide to maximising the ecological integrity of wooded ecosystems and is the final phase in the restoration process.

This phase applies to all ancient woodland, including secure restoration sites and other semi-natural woodland. Some phase three actions can be carried out alongside earlier restoration activity, and many need considering with other factors that influence woodland management. This is relevant to other woodland owners who will balance other objectives against the extent to which they journey into phase three.

2 How to maximise ecological integrity

Restoration is about developing future ecosystems with greater integrity. It is not about returning a woodland to some past condition or fixed composition.

'Maximising ecological integrity' is a desired outcome. It pays equal attention to the identity of a community, and to its structure and functioning[160]. It is about ensuring a place can achieve and maintain a healthy and full biological expression. This can be dynamic and is always strongly characteristic of its locality. Embracing natural processes is vital and gives greater capacity for self-regulation. But maximising ecological integrity does not mean stepping away completely from the outset. It can require actively preserving or creating certain features and processes. This involves balancing management interventions with natural processes (examples of both are given throughout this document). It requires the meshing of observations and decisions at landscape, site, stand, and individual tree scale[6,7].

Phase three is a vision for the future. It requires looking beyond what 'ancient woodland' is, as a concept. The current state of most 'ancient semi-natural woodlands' should not be seen as the 'baseline' or pinnacle for restoration. This reflects the necessary step-change in our approach to woodlands and nature recovery[5]. This is not about protecting what we have, but embracing a new, restorative approach to create a more resilient natural environment for the benefit of wildlife and people.

Maximising ecological integrity is key to addressing the biodiversity and climate crises together. Climate change impacts are exacerbated in degraded ecosystems[1,2]. Those with greatest ecological integrity are best able to mitigate and adapt to climate change[3], and meet global and local biodiversity objectives[4].

EMMA GILMARTIN

The presence of old trees is essential to maximising the ecological integrity of wooded ecosystems. Beech rich with wood-decay habitats at Windsor Great Park, Berkshire, Surrey.

2.1 More 'old-growth characteristics'

The concept of 'ancient woodland' captures important continuity in soils and vegetation. But it does not include the age of trees or other old-growth characteristics. Without these, the integrity of wooded ecosystems is always hindered.

Every effort should be made to expand and accumulate more old-growth characteristics[9]. These include trees that are ancient in age or with veteran characteristics[72], decaying wood in all its forms[8], and all associated species. Where these are already frequent, 'old-growth ancient woodland' should be recorded as key features within management plans and maps[10].

Woods with old-growth characteristics provide significant and efficient carbon storage[11,12,13,261] and are more resilient in the face of climate change, compared to younger growth[14,15]. So landscapes richer in old-growth characteristics will help sustain ecosystem services in a rapidly changing world.

ALASTAIR HOTCHKISS

Ancient 'granny' pine above Allt na Feithe Duibhe, Glenmore Park in the Cairngorms.

EMMA GILMARTIN

Old oaks of Sherwood Forest, Nottinghamshire.

ALASTAIR HOTCHKISS

Ancient field maple at the Woodland Trust's Park Wood, Chilham, Kent.

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Oak at Wistman's Wood, Dartmoor, Devon.

2.1.1 More old trees

Large old trees are the keystone 'megaflora' of wooded ecosystems. They provide unique structures and microhabitats not offered by younger, smaller trees[16,17].

There is an ever-increasing shift towards younger and smaller trees[16,261]. The most recent National Forestry Inventory (NFI) data indicates that about 98% of woods in Britain have no veteran trees within 20ha[18]. Yet woodland ecosystems rich in old-growth characteristics may have in the region of 4–16 trees/ha over 3m girth and over 200 years old[262,292]. Some woodland ecosystems may be in a collapsed state where the number of hollowing or cavity-bearing trees has fallen below one per hectare[293].

To maximise integrity, it is essential that a significant proportion of trees within all wooded ecosystems are developing veteran characteristics and becoming ancient in age. UK Woodland Assurance Standard (UKWAS) requires action to maintain continuity of veteran trees by protecting those that already exist, and managing or establishing suitable trees to eventually take their place[162].

Let natural processes create old trees

Old trees develop through natural processes and time. For most long-lived trees, including oak and beech, key old-growth characteristics can take 200 years to develop naturally[19,20]. Some take even longer[21].

Natural disturbances can create and maintain space, allowing individual trees to persist and age. The oldest trees are often those which grow virtually all their life with limited or no crown competition from neighbours[22]. These occur where terrain and other factors maintain sufficient space *(see 2.2)*. They often have greatest biodiversity value[23] and richness of associated species (e.g. wood-decay beetles[24,25]). Old trees have generally survived better where management of trees has been limited but where extensive grazing or hunting were the main land uses[8,26] *(see 2.2.2)*.

Woods with minimal silvicultural intervention can contain more old trees *(see 2.1.3)*, hosting more associated old-tree microhabitats[17]. But within densely competing closed-canopy stands, most trees have narrow crowns. Their capacity for natural retrenchment growth (the crown 'growing downwards' in old trees) can be limited. Few, or none at all, may become dominant, so elite large-diameter trees are very slow to develop[27].

Use management interventions to maintain and develop more old trees

Management interventions can maintain and accelerate the development of large old trees[28,29,30,31]. They can be more predictable and with reduced risk compared to relying on natural processes alone[29]. This can bridge continuity gaps in old tree populations. Interventions also create variation in structure, tree sizes and ages, and can elevate carbon storage[29,32,33].

'Legacy trees' are permanently retained trees and focal points for management. Their selection is a way of proactively planning and managing to develop large old trees at the individual-tree level. This positive selection can ensure considerable space for crown development, by removing or significantly reducing competition from surrounding trees. This accelerates their development into larger trees[31]. It also ensures a network of trees that will never be felled[34]. Actions include:

- Ensure a significant number of 'legacy trees' are identified within all ancient woodland. As a guide, aim for about 5–20 identified legacy trees within each hectare. In some areas, these can be more aggregated, and others more dispersed[34]. Ensure these are recorded, mapped and marked if necessary. Any natural losses should be replaced with new selections.

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Old trees provide unique opportunities not found on younger trees. The larvae of the cobweb beetle (*Ctesius serra*) live under flaking bark and crevices, feeding on the dried-up remains found on spider webs.

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The bark of ancient trees supports unique communities of lichens, including *Cresponea premnea.*

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The ant *Lasius brunneus* lives in crevices and tunnels under the bark of old trees, where it tends tree aphids for sugary honeydew.

JILL JENNINGS

Many other species use features on old trees, such as the nuthatch caching food for the winter.

CLAIRE MILLER

Managing for old-growth characteristics at the Woodland Trust's Little Doward Woods in the Wye Valley. Legacy trees have been identified and management has targeted the removal of surrounding trees. The wood-decay habitats at Little Doward Woods support rare insects.

- All existing ancient and veteran trees must be selected as legacy trees. Carrying out individual tree management plans for all ancient and veteran trees will help inform arboricultural interventions and wider silvicultural ones. These may be remnant components from earlier restoration phases. Phase two restoration can begin to develop space around them. But critical remnant trees should always be opened up gradually through phase one.
- Always select 'future veteran' legacy trees from the widest range of age classes available. For younger trees, choose those with deeper crowns or with particular growth forms and features, such as snapped limbs[35]. This can be important for the crown development of very young trees, as in dense pole-stage birch stands.
- Make sure that legacy trees represent the diversity of all native tree and shrub species within any site. Trees all have different functional roles. For example, while oak and beech are of great value for wood-decay fungi and invertebrates, willows and elder can be a vital source of nectar and pollen, or a substrate for bryophytes[36,37].
- Ensure legacy trees develop good lateral growth with limited competitive crown pressure. For long-lived trees (e.g. oaks, ash, beech, limes, hornbeam, Scots pine), this ensures variation in branch systems and crown structure. This means they can develop secondary crowns (retrenchment) with age, and respond to disturbance events. For shorter-lived trees (e.g. birch, aspen, willows, alder, wild cherry, rowan, wild service, wych elm), it helps ensure they persist.
- Maintaining open canopy space around legacy trees can result in more regeneration in these areas. This can require more management, and ensuring this for the entire life of a long-lived tree is problematic. Consider the frequency of interventions needed alongside other ways to maintain space *(see 2.2)* in wooded ecosystems. For longer-lived legacy trees, some lateral characteristics could be developed if management ensures they become 'elite', by getting well above the average canopy. But space will still be required later in life, to support retrenchment.
- Make sure that smaller legacy trees and shrubs (e.g. hazel, field maple, holly, hawthorn, crab apple, dogwood, spindle, bird cherry) are never substantially overtopped[28]. Space and light can often also increase flowering and seed production and help dispersal and regeneration elsewhere[38].

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Legacy trees should represent the diversity of all native trees and shrubs in a woodland. Space can be maintained not just through silvicultural intervention, but through natural processes, including grazing animals. Wild service in Busketts Wood, New Forest, Hampshire.

Some parts of the New Forest have exceptionally high volumes of decaying wood. Parts of Denny Wood have more than 290m^3/ha – with 200m^3/ha as fallen logs and 90m^3/ha as standing snags[262]. Few other places in the UK have such high levels, with a richness of associated species.

2.1.2 More decaying wood

The decay processes associated with old trees and standing and fallen woody debris produce essential microhabitats. Wood-decay fungi have complex interactions with invertebrates[39,40]. Many birds and bats use decay features on living and standing dead trees[41]. In parts of Europe over 25% of all woodland species are associated with wood decay, with up to one million known wood-inhabiting species globally[42].

Today, decaying wood is not only recognised as a key element for biodiversity, but is known to play an important role in carbon storage, water retention and tree regeneration[43].

It is vital to retain and develop all microhabitats associated with decaying wood. This includes decay within the heartwood of old living trees and snags (standing decaying wood). It also includes large woody debris like fallen logs and branches[44,45] Even small twigs contribute to the richness of wooded ecosystems[46,47].

UKWAS requires planning and taking action to accumulate a diversity of both standing and fallen deadwood over time in all wooded parts of a site[162]. Nearly 90% of native woods in Britain have less than 40m^3/ha decaying wood, and 45% have practically none at all[18].

Large-diameter snags are rare across many woods in Britain[50], but provide essential microhabitats[17]. This large oak snag at Gregynog, Powys, supports rare lichens, including the British endemic *Enterographa sorediata* which is confined to old-growth woodlands.

Fallen woody debris promotes greater diversity of plant species[60], bryophytes[61], fungi[44,69] and invertebrates[49]. They act as 'nurse logs', facilitating growth of other tree and plant seedlings[62], for example, where coarse grasses dominate[43], in wet woods, or as refuges from grazing animals[159]. A fallen log at Castle Eden Dene, County Durham, with wood sedge, bryophytes, buckler ferns and ash seedlings.

Recommended volumes are as follows:

- Every hectare must have at least 40m³ of decaying wood[43,48,83,50,35,161]. Below this threshold, the habitat is considered functionally fragmented for certain groups.
- Parts of every wooded landscape must contain at least 150m³/ha. As a guide, these volumes should occur within at least one hectare for every 15–20 hectares of woodland. This is essential for some processes and species[43], and many old-growth woods in Europe contain these volumes and more[44,51,27,262]. Less than 2% of British woodland is thought to have 150m³/ha or more[18].
- It is vital that decaying wood comprises a wide range of forms and decay states. This must include a proportion as standing decaying snags. As a rough guide, approximately 10–25% of trees could be standing decaying snags. This could be a basal area of 1.5–5m²/ha.

Standing decaying pine above Allt na Feithe Duibhe, Glenmore Park in the Cairngorms.

IMAGES: ALASTAIR HOTCHKISS

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The beauty of a fallen log turned crimson with liverwort *Nowellia curvifolia* (rustwort) with the green *Bazzania trilobata* (greater whipwort), a characteristic species of humid woodland in the northern and western parts of Britain.

JANE COREY/WTML

The fungus chicken-of-the-woods (*Laetiporus sulphureus*) is an important provider of wood-decay habitats.

SARAH HENSHALL/BUGLIFE

Stumps created by felling can provide resources for species of hoverfly, lichen[66] or beetles like Cosnard's net-winged beetle[67] pictured here. Clean-cut stumps are not produced through natural processes, but in some situations they can provide important resources[67].

MAURICE WALKER/WTML

Lesser spotted woodpeckers are associated with decaying wood in standing trees. In the late 1960s, increases in lesser spotted woodpecker were considered to be linked to dying elms[288], and the population last peaked during this outbreak. The species has declined since 1980 and low breeding success due to chick starvation suggests food availability is limiting the population.

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Water-filled rot-pools or hollows within trees are a unique microhabitat. The soup of decaying leaves, wood and other material hosts invertebrates like the larvae of the batman hoverfly (*Myothropa florea*) shown here, and other specialists such as tree-hollow mosquitos.

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Standing snags and the sheltered crevices or exposed lignum of old living trees support specialist lichens and microfungi known as 'pinheads' (e.g. *Chaenotheca* pictured here).

Box 1 – Rough guide to estimating decaying wood volumes

Decaying wood can be estimated in a number of ways. It can be easier and more meaningful to look at the ratios between the wood of living trees and decaying wood, either standing or fallen. This also accounts for variation in volumes due to differences in productivity between woods[52]. As a rough guide, look for 20–50% decaying wood to living trees[44,53,52]. But you can obtain volume estimates by recording material within sample areas or transects[27,161]. For example:

- Walk a representative transect of 100m in length (roughly 100 paces), using a random start point and direction.
- Measure the length (in metres) and central diameter (in metres – i.e. 0.20 for 20cm) of all material where it falls within 5m either side of the transect.
- Measure the diameter (in metres) of all standing decaying wood 'snags' within 5m either side of transect, and estimate the height (in metres).
- Recording extra information can be informative. For example, the decay state (e.g. highly decayed, fresh material) or the tree species (oak snag, ash branch, etc.).
- Work out the volume for every piece: Divide the diameter (in metres) figure by two and then square it (times it by itself). Then times that by the length (in metres). Multiplying this by 3.14 will give a rough volume (m^3). Volume = length x $(\text{diameter}/2)^2$ x 3.14.
- Add up all the volumes to give a measurement for the transect. This represents $1000m^2$ so you need to multiply that figure by 10 to give you a figure per hectare (m^3/ha).
- Taking an average from more than one transect will give a more accurate figure.

In many instances, a rapid visual estimate will be needed. As a very rough guide:

- $40m^3$ is equivalent to:
  - 7 trees of 20m height and 60cm diameter at breast height (DBH)
  - 24 trees of 15m height and 40cm DBH
  - 80 trees of 15m height and 20cm DBH.
- $150m^3$ is roughly equivalent to:
  - 27 trees of 20m height and 60cm DBH
  - 90 trees of 15m height and 40cm DBH
  - 330 trees of 15m height and 20cm DBH.
- A log or snag of:
  - 5m length and central diameter of 25cm = $0.25m^3$
  - 5m length and diameter of 50cm = $1m^3$.

The volumes in the 125-year-old stands at Lady Park in the Wye Valley have been measured at 47–129m^3/ha. Most of this has accumulated through natural processes since 1945 (over about 70 years) when wood became a minimum intervention reserve[27].

Like the majority of woodland in Britain[18], the Woodland Trust's Gaer Fawr Wood in Powys has volumes well below $40m^3$/ha. This part of the site has approximately $18m^3$/ha, with $12.5m^3$/ha as fallen material and $6.5m^3$/ha as standing. Most has probably accumulated since the Trust acquired the wood in 1984 (36 years – about $0.5m^3$ per year). All material was of relatively small diameter (below 25cm).

IMAGES: ALASTAIR HOTCHKISS

Let natural processes create decaying wood

Natural processes create decaying wood and develop veteran characteristics on living trees. Decaying wood accumulates naturally over time. Even from small-scale disturbances, woodland with low initial amounts can build up 0.5–1.5m^3/ha/year of decaying wood[51,27]. This means, where it is not removed, many woodlands could accumulate between 50 and 150m^3/ha over just one century.

Wind snaps branches, splits trunks and uproots trees. Neighbouring trees are crushed and damaged. Survivors are naturally veteranised or regrow as phoenix trees. Storms can instantly double decaying wood volumes[50], and catastrophic stand blowdowns, such as in the 1987 storms, can result in 100m^3 to 400m^3/ha generated overnight[27]. But most of this will always be in approximately the same decay state.

Disease can be significant, and with at least 80% of the UK's ash predicted to succumb to dieback[54], significant decaying wood will accumulate, as it did with elm disease from the 1960s[27]. But decay characteristics vary between different species, and have different associated fungi and fauna. So it should not be assumed that ash dieback will provide all the decaying wood required.

Drought creates standing snags and veteranises surviving trees, with shallow-rooted and thin-barked trees most vulnerable[55]. For example, the 1976 heatwave resulted in large volumes of standing decaying beech and birch[27,262]. For more tolerant species, like Scots pine and sessile oak, drought may contribute less decaying wood. But drought events are likely to increase in future[208,261]. Lightning strikes, snowfall, fire and animals also play a role in generating wood decay and unique features[56,57].

Natural mortality from competition between trees is an important process[262]. This 'self-thinning' is highest in young even-aged groups. This can result in a drop from 4,000 stems per hectare of a 30-year-old stand, to stabilising around 650/ha after 145 years[27]. In some scenarios, the basal area of snags can increase by over 1.3m^2/ha over just 30 years as a result of natural processes[27]. Decaying wood can be provided on some living trees as a result of the shading and dying back of lower branches.

IMAGES: ALASTAIR HOTCHKISS

There is no substitute for naturally created decaying wood and the development of veteran features on living trees.

Always retain decaying wood created by natural processes. Do not regard either small or large-diameter fallen material as saleable. All standing and fallen decaying wood must be left in situ, with main large-diameter fallen branches remaining uncut where they fall. Where material must be moved (e.g. public rights of way, etc.), then do it as soon as possible, and leave in largest possible sections.

Fallen trees have the ability to respond and continue growing. This is a phoenix tree. All trees should have an opportunity to respond like this Scot's pine in the Cairngorms.

Where decaying wood is not removed, many woodlands could accumulate between 50 and 150m^3/ha over just one century. The Mens, Sussex.

Use management interventions to maintain and create more decaying wood

There is no replacement for naturally created decaying wood[58]. But management interventions can restore characteristics faster than natural processes[59]. This can be essential to the continuity and development of decaying wood, especially where it is otherwise scarce. Interventions are most appropriate for younger-growth stands (e.g. trees approximately 20–120 years old). It also depends on the abundance of trees of any given age across a site.

Actions to help create decaying wood include:

- Create fallen logs by felling trees and leaving in-situ, or winching to create fallen trees and vertical rootplates. But never rush to create a lot of decaying wood at once by using one method (e.g. chainsaw felling)[58]. Variation in decay state is important[44], and it may take decades or centuries to produce highly decayed logs[53]. Within wooded groves, a beech log of 1m diameter might be fully returned to the soil within 30–40 years, whereas a 60cm oak limb could take up to 100 years[22]. This influences the soil nutrient pattern and vegetation for centuries.

MATS NIKLASSON

With the help of an arborist, a ripped beech has been created in an otherwise uniform stand of beech. A living branch remains under the rip on the trunk. The nature reserve Osbecks bokskogar, Laholm municipality in Halland County, Sweden.

- Provide standing decaying snags by ringbarking or girdling entire trees, particularly where snags are rare or absent. This creates 'fresh' standing decaying wood quickly, which is readily used by invertebrates and woodpeckers[64]. Its effectiveness varies between native tree species. For example, much diversity associated with Scots pine relies on decaying dead trees[65]; whereas with oak, much relies on decay and features on living trees. But the purpose of ringbarking is often two-fold. It also gives space to other trees, including nearby legacy trees.
- Where standing decaying wood is scarce and continuity is important (e.g. because of known associated interests), then consider re-erecting trunks. Do this by winching, or strapping recently felled or fallen woody material in an upright position to living trees. In all other scenarios, always avoid any temptation to move material. Do not remove large dead branches still attached to trees, or create wood piles on top of large-diameter wood.
- Clean-cut stumps are not produced through natural processes, but can offer opportunities for various insects and lichens for example[66,67]. But they may be suboptimal decaying wood habitats, hosting lower fungal diversity than lying logs[68]. However, creating high stumps (c. 1.5–2m) is an easy way to increase deadwood. These decay relatively slowly and will not require further interventions if safety is a concern.

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The creation of standing decaying oak snags in Wyre Forest, Worcestershire. As well as generating standing decaying wood, this has reduced crown competition with surrounding trees.

MATS NIKLASSON

A young, former production-managed beech forest where experiments with veteranisation of trees have been carried out.

- Create rips to mimic wind-snapped snags by partially cutting higher up trunks (e.g. from approx. 4–15m), and winching material to create rips and splinters. Methods to create snags using explosives[70,71] have been trialled, but are less predictable and less cost-effective.
- In woods with few natural opportunities, boxes provide artificial habitat for cavity dwellers. They are readily occupied by bats and birds, such as pied flycatcher, while others, like marsh tits, are reluctant. Ivy-covered trees may also provide opportunities for some of these species. Rot-hole boxes are the equivalent for invertebrates, and can be filled with sawdust, woodchips, leaves and bird manure. These can attract specialist insects which occur in decaying wood mould in hollowing oaks or beech trees[73,74].

JOHN BRIDGES/WTML

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Willow tits use nest cavities excavated in small diameter, soft decaying trees like birch. They can benefit from high stumps being created of small-diameter (10–20cm) birch and other trees (including conifers as part of phase two restoration).

Veteranisation techniques can create wood-decay habitats on living trees

Veteranisation interventions use tools to mimic damage from natural processes like storms, branch failure or woodpeckers[70,73]. Trees survive the treatment, as they would natural damage, but it is significant enough to create decaying wood habitat.

There is no substitute for natural development of these features on living trees, particularly of heartwood decay and large hollows. So the emphasis must always be on retaining and developing legacy trees. No veteranisation interventions are appropriate on trees already developing veteran characteristics. But where these are scarce, early veteranisation helps to direct focus and ensure their retention as future veteran legacy trees.

Much of this is novel management. It is important to conduct small-scale trials first, or seek further advice. Record where interventions take place, details of what was done, and take images before and after. Monitor, and if considered successful, then conduct more widely.

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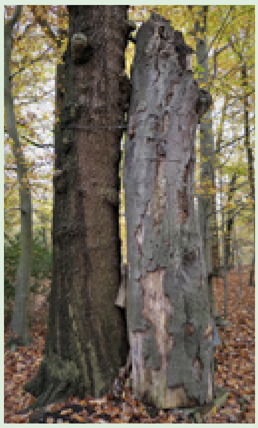
VIKKI BENGTSSON

Veteranisation interventions draw inspiration from natural processes. For example, mimicking damage by wild animals (such as horses) by slicing bark and living tissue off about a quarter the girth of the lower trunk, or by using a heavy hammer[70], as shown here at Clumber Park, Sherwood, Nottinghamshire. Other methods include ringbarking branches to create decaying wood in the canopy. Holes mimicking natural cavities can be cut into the centre of trunks[275].

Some examples of veteranisation actions include:

- Topping crowns to mimic storm damage, ensuring at least half of the live crown is retained[70]. Use a pruning cut that emulates a natural fracture[163]. Similarly, carry out heavy crown reductions (e.g. more than a third of the live crown) using natural fracture cuts and rip cuts. This impacts the root system and encourages decay in the branches that have been cut.
- Pollarding is a veteranisation technique, as it encourages hollowing more quickly than trees which are not pollarded[75,76]. Existing pollards are often the oldest trees on a site. Taking steps to bring lapsed pollards back into a pollarding cycle, or reducing their crown size, can prolong their life. Maintaining space around pollards is important[76,77], so creating new pollards as ‘future veterans’ will help keep these trees more open.
- Ringbark/girdle larger branches (e.g. over 10cm diameter) to provide canopy wood decay, which is an important resource for many species[78]. Like ringbarking entire trees, cut a wide (approx. 20–30cm) band all around. This must be shallow enough so it will not snap, but deep enough to ensure it is effective.
- Use your imagination and draw inspiration from nature. This can involve mimicking damage caused by wild animals to lower trunks, or cutting holes into the trunk to mimic cavities[70], or at forks to create water-filled rot-hole habitat[79].



EMMA GILMARTIN

Where standing decaying wood is scarce, then consider re-erecting fallen or felled trunks. Windsor.

2.1.3 Old-growth groves

Denser groves of trees can produce unique conditions, processes and associated species. Moisture levels and humidity can be an important feature. This is vital for associated species like bryophytes[61], and soil dwelling old-growth craneflies[82]. The thick leaf litter provides for molluscs[83], earthworms[84] and specialist money spiders.

Ensuring that parts of every landscape receive no significant human intervention can help develop these conditions and features[28]. These can be within a matrix with more managed areas[34]. These minimum intervention areas can also have more decaying wood, old-growth microhabitats and wood-decay organisms[27,28,41,44,68,80,262]. They can support Barbastelle and Natterer's bats, nesting woodland raptors, and higher densities of marsh tit and treecreeper[27,85,86,41]. However, some species may use more open or managed woodland structures at different times of year[85]. Long-term carbon stocks are also generally greater in stands where no harvesting occurs[81].

Minimum intervention areas are those areas with no silvicultural management, including felling. All trees complete natural senescence and decomposition[34] and only natural regeneration is acceptable[95]. Under UKWAS, operations that are usually permitted include fencing and control of invasive plants, path maintenance and safety work[162].

Minimum intervention can involve the management of grazing animals, often in conjunction with surrounding land[88]. This is important, because animals drive important space and dynamism, and can reduce the need for silvicultural intervention *(see 2.2.2)*. 'Rewilding' is about reinstating natural processes (including natural grazing) to enhance the environment and the species it supports[89,90]. So minimum intervention is essentially rewilding forestry[91,92,93].

It is vital that minimum intervention management is applied carefully. It is sometimes considered inappropriate for conservation objectives[87,55,88]. This is because of the fragmented state of most ancient woodland in the UK, and the lack of certain vital natural processes across landscapes *(see 2.2)*[88].

Our knowledge and understanding of the relative significance of natural disturbance events has benefitted greatly from the long-term study of Lady Park Wood in the Wye Valley[27], one of the longest and most detailed studies of any wood in temperate Europe. This reveals much about the results of minimum intervention in UK woodlands.

Use minimum intervention wisely to help develop old-growth characteristics

The application of minimum intervention should be a conscious decision. It must contribute to the ecological integrity of woodlands across the site and landscape-scale. Never apply it through convenience or ignorance of the implications. Some actions include:

- Within all woodlands always establish some areas as 'legacy groves', with minimal silvicultural intervention. These can be as small as 0.25ha (e.g. 50x50m), and still maintain some functional components[94]. This can be achieved in even the smallest woods by retaining patches. Even for larger woods, these need not be much larger than 3–6ha. This creates stepping stones of denser groves among a matrix of managed stands[34] (see also 2.2.3). For semi-natural native woods, UKWAS requires that at least 5% of the total woodland area (covered under a plan or management area) is permanently identified and managed under minimum intervention[162].
- Legacy groves can include areas where management is less realistic or inappropriate; for example, very steep or rocky slopes, very wet ground, or existing old-growth stands. But do not confine legacy groves only to marginal sites. Minimum intervention areas should represent all topography and soils at the landscape level[34]. While no silvicultural interventions should occur, consider the role of animals, and manage as a natural process *(see 2.2)*.
- Always be mindful of the possible implications of minimal silvicultural intervention. Consider this within the context of missing natural processes and climate change. It is important not to rely on 'managing-for-habitat' without being 'species-aware'[106]. Implications could include:
    - The loss of tree species diversity. This includes light-demanding or less competitive species, which are often shorter-lived; for example, birch, willows, wild cherry, aspen, alder and field maple. These can decline and disappear within a few decades as a result of

EMMA GILMARTIN

Sheathed woodtuft fungus (*Kuehneromyces mutabilis*). Groves with minimum intervention can increase diversity of wood-inhabiting fungi, and fungi associated with tree roots[68]. Water availability is important for fungal fruit-body development. Some are more vulnerable to desiccation than others (e.g. smaller, thinner or more ephemeral fruit bodies). For mushroom-forming fungi, humidity is crucial to the mechanism of spore drop. Robust perennial bracket fungi on tree trunks, by contrast, are not so vulnerable.

BRIAN EDWARDS

Plants like yellow bird's nest (*Monotropa hypopitys*) and bird's nest orchid (*Neottia nidus-avis*) can occur in shady wooded groves with little other ground vegetation. These unusual plants evolved a relationship with the mycorrhizal fungi associated with beech roots, whereby they obtain their nutrients. So they do not need light to photosynthesise.

STEVEN FALK

The cranefly *Epophragma ocellare*. Numerous groups of flies are also dependent on dense, damp and dark woodlands, such as certain craneflies, lauxaniid, heleomyzid and platypezid flies. Many feed on decaying plant material within moist woodland soils, but are also often associated with fungi or very damp decaying wood.

STEVEN FALK

Spider diversity is strongly influenced by habitat structure from the litter and ground layers into the canopy[281]. Spiders such as the triangle spider (*Hyptiotes paradoxus*) shown here and *Cyclosa conica* can occur in shaded, dense woodland, and often make use of darker evergreen components (e.g. yew and holly) within broadleaved woodland[272].

increased dominance of shade-tolerant climax species like beech and lime[27,96]. It is important to select legacy groves in areas where key species will not be lost from a site as a result. These include native tree and shrub species which are scarce across the woodland. Maintaining tree species diversity may need more direct management[97] *(see 2.2.31Introduction)*. Management can also accelerate the development of old trees *(see 2.1.1)*.

- Reduced regeneration from seed and genetic turnover. While vegetative regeneration (e.g. from fallen trees) still occurs, regeneration from seed can be limited[27]. This has implications for climate adaptation and resilience. Genetic turnover can be accelerated by regular natural regeneration of native trees from seed. This helps woods and trees adapt faster to changing environmental conditions[97].
- The loss of wider diversity. For example, the knock-on impacts of losing tree-species diversity. This will result in decreasing diversity of mycorrhizae and decay fungi[98,68], insects like moths or aphids which rely on specific tree species, and leaf-litter composition, affecting earthworms[84,99] and molluscs[83]. Many birds favour the presence of different tree species within a landscape or a stand[98].
- Declines in flora richness and diversity occur at both small and wood-scale as a result of shading, leaf litter and lack of disturbance[27,100]. Some may respond from seed banks after disturbances, but many will not[27]. Within earlier phases of restoration (phase one and two), shade (e.g. from conifers) is considered to have a significant impact. It is important not to always consider this as negative or over-react to it during phase three restoration. A reduction in plant species diversity and richness could be a rebalance of the integrity in landscapes that have long been culturally modified[101].
- Remember that species benefitting from increasing decaying wood and leaf litter are often less obvious. Yet these may contribute more to ecological integrity than plant species richness alone[102]. We may need to value woods more for these features[103]. High site biodiversity is not always coupled with high site integrity[104]. Restoration should not always aim for high biodiversity, but for a community with high ecological integrity which contributes to landscape-scale diversity[105].

ALASTAIR HOTCHKISS

Small teasel (*Dipsacus pilosus*) is associated with disturbance in ancient woodland, and is an example of a species which can be lost from a wood as a result of minimum intervention[27]. Other light demanding plants can sometimes fail to colonise tree-fall gaps readily[27].

2.2 Better space and dynamism

The continuity of soils and wooded conditions has resulted in the richness and importance of ancient woodlands. This could give the false impression they are static or unchanging. Continuous change is being driven by processes and disturbances that operate at different scales of space and time[15].

Disturbances offer new opportunities and resources. This influences the growth of trees and the distribution of plants, fungi, and fauna. Paradoxically, disturbances within wooded ecosystems result in the stability of species richness[15,107].

Well-grounded principles of disturbance ecology underpin phase three restoration[15]. It is vital to realise what natural processes can deliver, and allow this dynamism to operate wherever possible[108].

But with approximately 85% of UK woodland lacking quality open space[18], there is a need to consider what processes are missing, and how management interventions contribute.

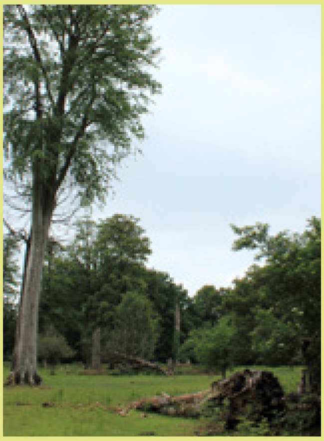
2.2.1 Let natural processes create space and dynamism

Natural processes drive space and dynamism. Each disturbance impacts unevenly, affecting some species more than others, or in different parts of a wood[27]. It is important to accept these, and consider them in the context of what else might be missing (e.g. the impacts of large animals).

Windblown trees result in space, soil disturbance, hollows and mounds[59]. This leaves new areas free of vegetation[109]. Disturbance-associated woodland plants include annuals, such as climbing corydalis and three-nerved sandwort. They also include perennials like dog-violets and wood spurge. Some tolerate shade for a time, but flourish and seed only in light or dappled shade. Water-filled hollows form temporary aquatic habitats for insects and amphibians like newts.

Most canopy gaps created by wind are smaller in width than the height of surrounding trees[55], and

ALASTAIR HOTCHKISS



Extreme drought can result in death of beech trees. When combined with grazing animals it can result in open grassy glades developing within a degenerating centre of a grove. This is shown here in Denny Wood in the New Forest. In this way glades develop in the central part of the grove.

IMAGES: ALASTAIR HOTCHKISS

Small gaps can be formed by windblown trees. Vegetative regrowth can be prolific, as in the case of lime at Lady Park Wood in the Wye Valley[27].

often close after a few years by crown expansion of remaining trees[27]. But storms can result in catastrophic disturbance, with large areas blown down, as in 1987. Devastating winds may have historically only recurred in an area every 200–300 years[55], but the frequency and intensity of extreme storm events are considered to increase with climate change[110].

Disease or insect-driven disturbances can create significant space, especially in even-aged, low-diversity stands[111]. Diseases also affect animals, for example the Myxoma virus on rabbits which resulted in oak regeneration events[112].

Landslides and erosion affect many woodlands on steep slopes, maintaining dynamism in locations where grazing of large herbivores is less likely. Increased winter rainfall as a result of climate change may mean more sites are waterlogged and vulnerable to this[35].

The influence of fire is negligible across most UK woodland[113,35], except perhaps boreal birch and pine woods in the north[35], and those with thin nutrient-poor soils[114]. Flooding is a fairly limited process for space and disturbance, mainly because floodplain woodlands are virtually extinct as habitat in the UK[115].

Human activity continues to influence many of these natural processes. Rapid climate change is leading to increased drought and storm intensities, affecting woodland dynamics[261]. Globalisation has contributed to increased tree diseases and insect impacts. These may be unpredictable and occur infrequently, but they have long-lasting implications and influence over woodland development.

At the Woodland Trust's Bisham Woods in Berkshire, the catastrophic storms of 1987 resulted in the entire stand of beech being blown down. The subsequent decades led to a dominance of ash regeneration, which is now being heavily impacted by ash dieback disease.

Box 2 – Ecotones – the essential grey areas

'Ecotones' are the ill-defined transitions between more densely treed groves and glades or other more open habitat. Environmental factors can dictate ecotones within woodlands. These include hydrology and soils. Ecotones with wet open habitats (e.g. deep peat) are important natural transitions. For example, the 10-spotted pot beetle relies on scattered birch and willows on the fringes of sphagnum peatlands[116].

But ecotones are also created and maintained by some form of disturbance[35]. Large wild herbivores in Europe would have influenced the composition of the forest canopy for millenia[117]. They would have contributed to maintaining a landscape which probably comprised a continuum of densely treed groves, ecotones, and more open glades with scattered trees and scrub[118]. The use of domestic livestock as surrogates for wild processes can result in ecosystems with these same features. This is a key factor for high species richness and microhabitat density of pastoral woodlands[119].

The diversity once found in a single interrelated system has become artificially fragmented[118], with sharp divisions between densely treed and open land. Across most UK landscapes the ecotones are missing. This is an expression largely of property boundaries and modern land management, not natural processes[263]. Restoration of ecological integrity can be hampered by the compartmentalisation of habitats and land uses[106].

ALASTAIR HOTCHKISS

An ecotone-rich landscape in South Snowdonia, with patches of old-growth wooded groves and more open heath and mire vegetation, along with regeneration of many age cohorts across most native tree species that would be expected. Meirionnydd, North Wales.

Trees, bushes, rough grass and bare soil each provide something specific. But combined, they can foster biodiversity[126]. Moths of 'calcareous grassland' can be more abundant where woody vegetation provides shelter[125]. Many ancient woodlands are now refuges for species associated with more open habitats. Many have disappeared from more intensive management surrounding woodland[124,27].

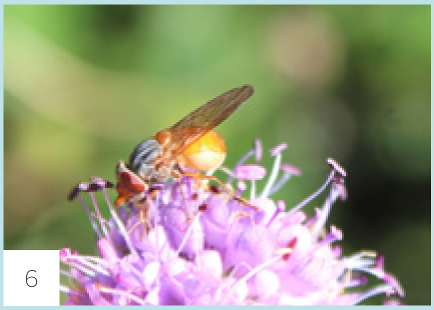
EMMA GILMARTIN

Transition between denser oak-birch woodland and glade of more open heath and grass vegetation, with scattered open-grown birch and oak. Sherwood, Nottinghamshire.

The same processes resulting in space in woodlands also drive the development of large open-grown trees *(see 2.1.1)*. Many old-growth lichens occur where ancient tree bark or exposed lignum are in more open situations. Species depend on ecotones and mosaics of habitat. These include those with different resource needs throughout annual, seasonal or even daily cycles[120]. For example, insects whose larvae live in decaying wood, soil and leaf litter often use sunlit open-structured flowers (like those of hogweed, hawthorn or brambles) as adults[121,122]. At different times of year, resident birds, such as great spotted woodpecker, shift between more open woodland to denser areas[95].

There is important difference between promoting the ecotones and 'edges' in woodlands, and with issues around habitat fragmentation. Species like nuthatch have been studied in depth with regard to woodland fragmentation, and demonstrate the impacts well. But there is little evidence that nuthatches avoid woodland edges. Breeding densities can be high in areas with scattered trees, and within denser woodland blocks, a significant proportion of nests can be within just 25m of 'the edge'[280].

Some stories told by the species on the edge



1 A rich ecotone plant community with saw-wort, betony and bitter-vetch. Rackham describes these as 'circumboscal species', which occur around (circum) woodlands (boscal)[289]. While descriptive of today's landscapes, the term really highlights the juxtaposition of our landscapes – between dense closed-canopy 'woodland' and completely open agricultural land. To maximise integrity, these species should be 'interboscal' or within and among the wood. Mid Wales.

2 Nettle-leaved bellflower *Campanula trachelium*, a species which is characteristic of wooded ecotones with more open vegetation. Occurring here at the Woodland Trust's Lineover Wood in the Cotswolds. The autumn crocus (*Colchicum autumnale*) occupies a similar habitat at this site.

3 Birds like redstart and tree pipit are characteristic of wooded ecotones, edges with scattered trees and similar transitions.

4 Butterflies, such as the grizzled skipper, also typify the edge, and can occur in sheltered pockets of vegetation within wooded ecosystems.

5 Wooded ecotones are required by rare and much-declined insects like hazel pot beetle (*Cryptocephalus coryli*), which is associated with scattered birches on the ecotone between denser wooded groves and more open heathy-glades.

6 The hoverfly *Rhingia rostrata* is possibly associated with mammal dung in old wooded habitats as larvae (e.g. badger latrines). But it uses flowers within sunny glades for food as adults, as here on devil's-bit scabious (*Succisa pratensis*). Like many plant species that are now most strongly associated with open 'grassland' or other treeless habitats, devils-bit scabious is a part of natural forest ecosystems[263]. The modern habit of classifying species by their current habitats must be challenged.

7 Numerous old-growth woodland species can require more open conditions. Lichens like *Lecanographa lyncea* require the characteristics of bark on ancient trees, but usually

There is a strong link between the development of old-growth characteristics and space and disturbance in wooded ecosystems. Ancient hornbeam and decaying wood with sunlit glade, short grass and taller herb and scrub vegetation. Hatfield Forest, Essex.

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where this is well-lit. Gregynog, Mid Wales.

8 Species such as the pinewood mason bee (*Osmia uncinata*) tell an important story about the interaction between old-growth characteristics and disturbance and space. The larvae live within the tunnels of longhorn beetles in decaying Scots pine wood, but the adults feed mainly on the flowers of bird's-foot trefoil which occurs in more open areas with patchy bare ground.

9 Similarly, many longhorn beetles themselves require decaying wood as a larval habitat, but the adults often feed on blossom in sunlit locations. *Alosterna tabacicolor* on hawthorn blossom.

10 In the UK, waxcap fungi (*Hygrocybe* spp.) are considered associated with open 'grassland' habitats, though some species, notably *H. viola* and *H. quieta*, do occur in woodlands. Some believe that waxcaps may have evolved in grassier woodland glades[290], where the more robust fungi associated with tree roots (ectomycorrhizae) are less abundant. Oily Waxcap (*Hygrocybe quieta*) in Mid Wales.

11 Yellowhammer is usually considered as a 'farmland' bird in the UK[279], but is probably a species of forest ecotones and glades[276,123]. It has become restricted within traditional agricultural landscapes, which create open areas with hedges and clumps of trees[282]. There is an important difference between a 'fundamental niche' (the full range of situations a species can occupy/use without limiting factors which constrain the population) and its 'realised niche' (a subset of this, where something is occurring, influenced by present conditions). If conservation is focused only on the yellowhammer's realised niche (as a 'farmland' bird of hedges and arable fields[269]), then we may miss the real goal of the species' fundamental niche.

12 Black hairstreak butterflies breed on mature blackthorn growing in sheltered but sunny situations. However, they benefit from the presence of mature trees close by, where they can feed on aphid honeydew. Glapthorn, Northamptonshire.

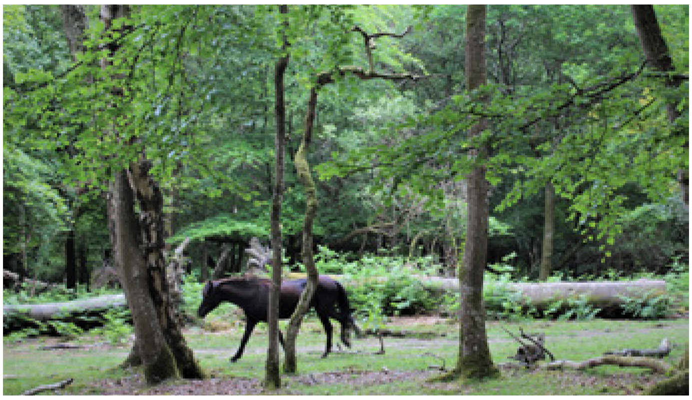
PHOTOS: ALASTAIR HOTCHKISS: 1; 2; 4; 7; 9; 10; 12; ALASTAIR HOTCHKISS: 3; DAVID FOKER/WTML: 5; TREVOR AND DILYS PENDLETON: 8; STEVEN FALK: 11; DENNIS JOHNSON/WTML.

2.2.2 Manage animals as an essential natural process

Many small-scale animal processes affect woods in the UK, from the activities of earthworms[100] to small rodents[27]. The non-native grey squirrel represents a significant risk to restoration and may hinder the development of old-growth characteristics[262].

But with the exception of deer and badgers, most woods in the UK are missing key natural processes driven by larger wild animals. Species are extinct globally (aurochs – wild cattle, tarpan – wild horses), within the UK (e.g. bison, lynx, brown bear, grey wolf), or regionally (e.g. beaver, wild boar, pine marten). The absence of these animals has huge consequences for ecosystem functioning[127].

Wild native deer (roe and red) are an important remaining part of the UK's large fauna. They have a vital role in balanced woodland ecosystems[128]. But deer numbers are higher than at any time in the last 1,000 years[129]. The absence of carnivores means deer are so numerous that regeneration is inhibited in many woods[55]. There is no predator-avoidance behaviour, which further impacts vegetation structure.



IMAGES: ALASTAIR HOTCHKISS

Pony in the New Forest

High pressures of any grazing animal mean declines of palatable flora (e.g. bluebells, bilberry). Heavy and sustained animal presence can result in compaction, trampling and excessive nutrient inputs. This impacts less palatable plants like wood anemone and fungal mycelia in the soils[132]. It has implications for birds[130] and dormouse[131]. Prolonged wood-pasturage land management risks the loss of palatable trees, such as hazel, aspen, elm or small-leaved lime[262]. As a result of wind, leaf litter can be lost from heavily grazed woods, with implications for associated processes and species.

Extensive cattle grazing in the ecotone-rich ecosystem on the northern slopes of Cadair Idris in southern Snowdonia. Denser boulder-strewn groves of oak, birch, ash and rowan support old-growth lichens like *Sticta* and *Parmeliella* and the awl-fly *Xylophagus ater* associated with beetle larvae on dead branches. Yet these mesh seamlessly into open marshy vegetation, with marsh fritillary butterflies feeding on devil's-bit scabious, globeflower, frog orchid, and slender, green feather moss. Dotted with regenerating willows, oak, rowan, birch, hazel, hawthorn, ash and blackthorn, these slopes have an age structure and diversity of trees which is lacking across many ancient woodlands. The larvae of the welsh clearwing moth develop inside the wood of old birches which are in sunlit spots. Species such as the rowan bud weevil *Anthonomus conspersus* occur in similar situations on blossoming old rowans within sheltered sunlit glades in otherwise denser wooded habitats[271].

But low-level grazing provides a greater diversity of vegetation structure and species composition than either overgrazing or complete absence of grazing[133]. Naturalistic grazing of domestic animals produces a patchier and ecotone-rich vegetation in wooded ecosystems[134,135]. Animals drive other key processes. Cattle, horses, deer and boar are all dispersers of plants[136,137]. They are important instruments in restoration, especially in fragmented ecosystems, providing effective functional connectivity[138,139].

Tree regeneration can be promoted by associated disturbance, exposed soils, breaking up brambles, bracken or competing grasses, and where thorny shrubs offer protection for young trees[140,141,142]. It is important to consider this during earlier restoration phases (e.g. as part of transforming even aged plantation stands). Nutrient transfer results from dunging, urination, and death, with carcasses enriching soils locally[143,144]. These are vital processes, particularly in less fertile ecosystems, but even in naturally nutrient-rich woods. Grazers often avoid foraging near carcasses, contaminated water or parasitic flies[145]. This create more patchiness of vegetation. Various birds, mammals and specialist beetles, flies and fungi also rely on dung, carrion or bones.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PHOTOS: 1; 3; 4: ALASTAIR HOTCHKISS; 2 AMY LEWIS/WTML; 5: DAVE FOLKER/WTML; 6: STEVEN FALK/WTML

1 Three-nerved sandwort (*Moehringia trinervia*) is able to survive under a closed woodland canopy, but shows enhanced growth in gaps resulting from uprooted trees or disturbances by wild animals[291].

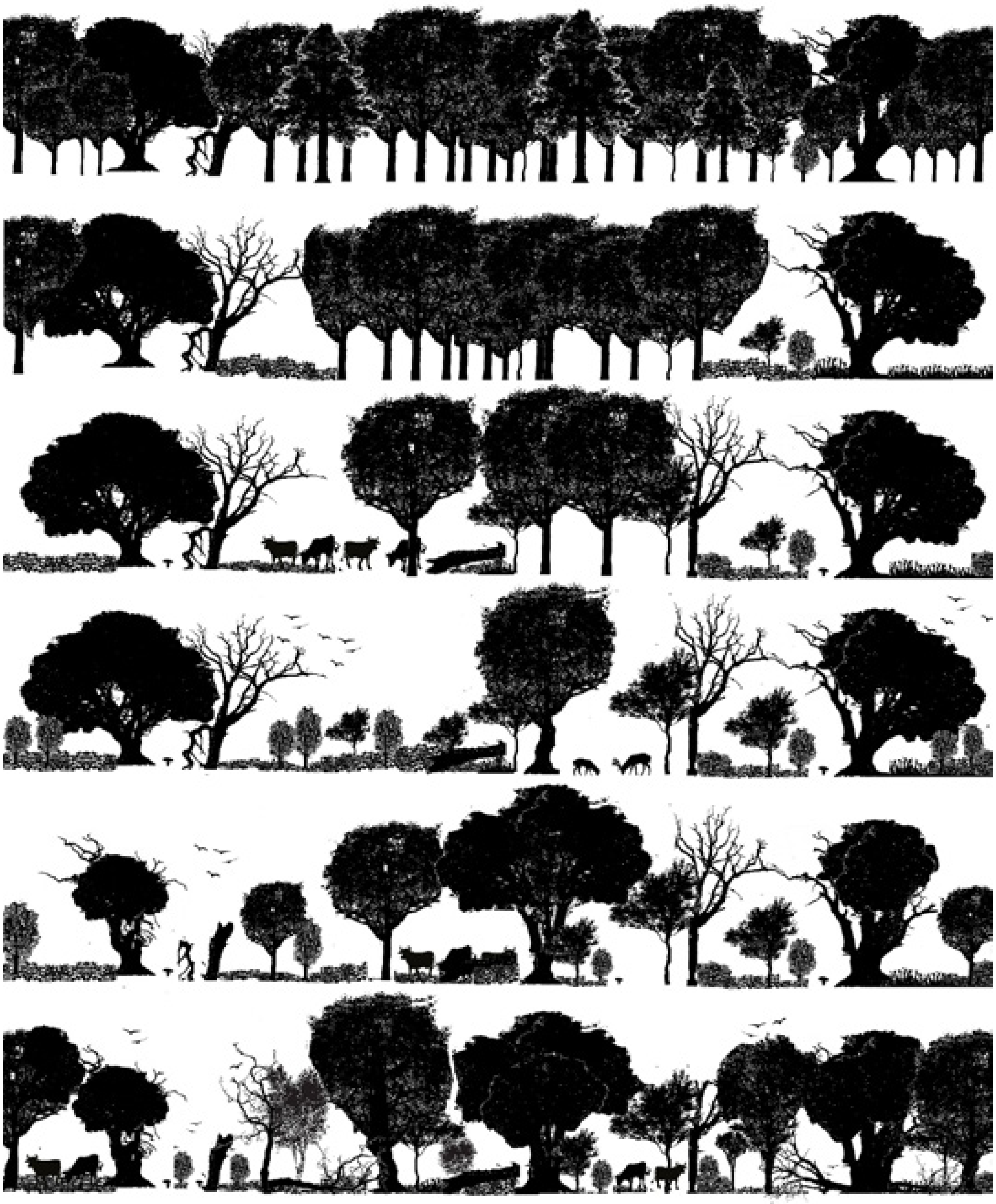
2 Many animals rely on mechanical disturbance processes. Given their size and anatomy, robins are unable to turn over large debris and significant leaf litter, and are evolutionary adapted to follow large mammals which create ground disturbance, exposing invertebrate prey items hidden beneath[277].

3 Disturbed ground created by cattle in the Wyre Forest, Worcestershire.

4 Ground disturbance like this can enable the establishment of woodland flora like dog violets, which are the larval foodplants for pearl-bordered fritillary butterflies.

5 The grazing of cattle in Wyre Forest is also supporting the recovery of adders.

6 Woodland grasshopper *Omocestus rufipes*. This is a species of wooded glades and ecotones with more open marshy or grassland vegetation. But it can decline as a result of consistent heavy grazing of an area. Like many ecotone species, it uses varied vegetation structure, including some taller vegetation which is lost through excessive grazing[273,274]. While some grazing is possibly the best option for creating variation in vegetation height and structure, monitoring is vital. Grasshoppers may be good indicators to inform this, as it appears they respond quickly to interventions[273,274].



Top row (year zero) – Dense even-aged beech plantation has been established on more open ancient woodland with old-growth characteristics like ancient and veteran oak and birch, standing decaying wood, as well as species associated with more open glades, such as pearl-bordered fritillary butterfly, adder and tree pipits. Relic trees and deadwood are in critical condition (phase one restoration).

Second row (year 5) – Phase one restoration was carried out in year one to remove some beech around remnant ancient oaks and standing deadwood. Bracken has responded in some areas, but some regeneration of oak and birch has also established.

Third Row (years 8–10) – For the past few years, phase two restoration has involved a continued thinning programme to thin beech which has further opened up the wood. Some ringbarking has created standing beech snags, and some material has been felled to create lying decaying wood and rips. Ground flora has recovered well in places, and hardy cattle have been extensively grazing across the woodland for the past few years, with some trampling and creating paths through bracken.

Fourth row (year 18) continued phase-two restoration management has created a more open woodland with light cattle grazing providing both the right levels of disturbance and grazing as well as ensuring some patches of regeneration of mostly oak, birch, rowan and hawthorn. Birds, such as redstart, occur in the wood, and the adder and fritillary butterflies have reached good numbers. Some mature beech from the plantation remain and will be retained to develop further veteran characteristics.

Bottom row (year 40+) – The ancient woodland is re-developing strong old-growth characteristics as well as a new cohort of mature broadleaved trees in patches. Insects and birds associated with decaying wood are benefitting. Ground vegetation is varied and the intermittent grazing by cattle continues to create important dynamics for associated insects and plants.

In this example **(top row)** an existing plantation ancient woodland site is clearfelled of larch due to *Phytophthora ramorum* disease, with adjacent stands of mainly mature Douglas fir, with some young even-aged broadleaved stands. On fairly infertile soils, vegetation is mainly bracken and bramble dominated with some heather and wavy hairgrass. One trajectory **(middle row)** is to restock with native broadleaves, and consider 'the woodland' as largely closed canopy, with some traditional ride management for permanent open space. However, through the inclusion of extensive grazing of hardy cattle and managed deer populations, a considerably more complex ecosystem can develop, with denser groves, more open glades and richly scattered ecotones in between.

In many ways, restoring ecological integrity to wooded ecosystems must involve recapturing the true language of 'forest'. This should be understood in its historic meaning: as extensive tracts of land with a mosaic of different semi-natural vegetation of all kinds, including denser wooded areas as well as the more open areas. A more dynamic, heterogeneous and functionally connected natural environment is likely to help species adapt to a changing climate. This provides conditions and microclimates that will help current species persist and new species to colonise, facilitating range shifts and helping conservation across a landscape[285,286,287]. Large animals can drive this variation in vegetation across a landscape.

Consider restoration as more than just managing the trees

Restoration silviculture must think 'beyond the trees'[150]. Instead of defining tree density limits, 'woodlands' must be acknowledged as complex systems which include areas that are more open, and that are important for biodiversity largely because of that structural patchiness[151]. Considering woodlands as being more than just places with trees could also help achieve the restoration of old-growth characteristics. Paradoxically, with less focus on the trees, it could ensure that more old trees actually occur in future landscapes.

EMMA GILMARTIN

Longhorn cattle in Sherwood Forest.

Large animals drive space and dynamism in a unique way. The behavioural characteristics and the resulting impacts of large animals are impossible to replicate using any other form of management[147]. The interaction between animals and other disturbances is important, such as maintaining glades arising from storms[148]. Large animals must operate alongside other natural processes in order to restore vital interdependencies and interactions[118,149].

Actions include:

- In the absence of wild animals, consider the role that domestic animals can play. Cattle are a vital part of old-growth woodland ecology from areas as different as oak-beech woods of the New Forest[156] and the pine woods of Speyside[157]. Hardy native cattle breeds are best (e.g. Highland, Dexter, Belted Galloway) or ponies (e.g. Exmoor, Dartmoor or Carneddau/ WelshMountain)[135,287,158].
- Where domestic animals occur in ancient woodland, try to manage these as 'disturbance events'. They should not be a continuous presence or influence to preserve or develop certain prescribed patterns or vegetation types[152]. Grazing animals offer the potential for wider non-timber forest products[153], but they should not be the defining land use.
- Take it slow, observe and maintain control at all times. Ideally, managed grazing should be naturalistic and extensive, so over as large an area as possible. Year-round free-roaming behaviour will result in the strongest influence on landscape, as a result of seasonal food-sources[135]. This is best considered at a landscape-scale, and may require working with neighbouring landowners.
- It is important not to simply follow prescriptions, but to observe closely and adapt to the site. But as a rough guide, consider year round grazing of approximately one cow per 3–6ha, for more fertile lowland woods[72,156,166]. This can allow regeneration to occur in patches[156,267] and ecotones with more open space can be maintained[101]. A lighter level of one pony per 5–15ha could be appropriate[156,166]. Take a precautionary approach and reduce levels for more infertile or upland woods.
- For smaller woodlands, the disturbance and grazing by animals may only need to be very infrequent, and will usually mean periods of years where grazing animals are not present[101]. Fences to restrict grazing should generally be a last resort. There

ALASTAIR HOTCHKISS

Tree regeneration can occur with the combination of extensive and naturalistic grazing and development of scrub and patchy disturbance. Seedlings of all the species of trees and all the other species of shrubs can grow on the fringes of thorny scrub[118], depending on availability of seed sources and dispersal (covered in Module 4). Here, birch and oak are regenerating within hawthorn in an area of probably less than 100m^2 with probably relatively high herbivore levels.

are increasing options with electric ring fencing and collar systems. But for domestic animals, it may be needed for handling and gathering. Diverse woodland ecosystems require naturalistic herbivore management across larger areas[155]. Always consider the role of grazing animals across both existing wooded areas and more open adjacent land where woodland expansion could be achieved *(see 2.4)*.

- Domestic animals bring issues that wild or feral animals do not. Worming drugs are persistent and toxic to invertebrates[72], and livestock antibiotics impact soil microbial communities, with consequences for ecosystem functioning, decreased carbon use efficiency, and altered nitrogen cycling[154]. Where possible, avoid these in ancient woodland. Support appropriate reintroductions of wild animals where this can contribute towards dynamism and space *(see 2.5)*.
- Management of the impacts of wild deer is considered as part of phase one and two restoration. Always maintain systematic monitoring of deer impacts, and implement management strategies collaboratively at a landscape scale wherever possible[128]. Mixtures of domestic cattle and ponies with wild native deer (red and roe) can be beneficial. For less fertile landscapes and many upland areas, the density of deer should probably be as low as one deer per 15–25ha to allow regeneration. and even lower in most exposed situations[164,165]. In more fertile lowland woods, levels of one deer per 8–10ha could be appropriate[166], and in some lowland woods regeneration can be frequent with higher deer numbers. In all situations, the influence of wild animal populations can be determined by numerous factors such as adjacent land uses and landscape features.
- It is vital to ensure regular cycles of natural regeneration of native trees to help woods adapt faster to changing environmental conditions[97]. Historically, distinct regeneration pulses may have occurred as a result of periods of heavily reduced grazing[167,262]. New cohorts of trees may have established every few decades (or even every century), with very little regeneration in between. Ecologically, this may have been sufficient to maintain continuity for associated species. But with rapid climate change, a lack of regular genetic turnover presents a risk to the adaptive capacity of trees[97]. It is acceptable for regeneration to be repressed in some areas (e.g. a few hectares), for some time (e.g. a few years), but it should not be permanently prevented across space or time[168]. Fallen trees and large woody debris *(see 2.1.2)* play an essential role for regeneration within wooded ecosystems, providing natural refuges against large-animal browsing[159].
- Where possible, consider the retention of animal carcasses within wooded ecosystems. Carrion is particularly scarce in the anthropogenic Western-European landscape[143], and some associated species are almost globally extinct as a result[146]. This may be largely limited to wild deer within the UK, because of laws and constraints surrounding domestic livestock[135].

Always consider the role that large animals can play in developing space for individual trees to persist and age. Old trees often occur within more open ecotone-rich treescapes. Burnham Beeches, Buckinghamshire.

IMAGES: ALASTAIR HOTCHKISS

In some situations, the development of these old trees is serendipitous. The management objectives for this area of more open heath vegetation are probably not primarily about developing these oaks as long-term legacy trees. Yet, these open-grown oaks probably represent an excellent opportunity to develop old trees in this historically intensively coppiced landscape. The Blean, Kent.

2.2.3 Use appropriate silvicultural interventions

Silvicultural management interventions create dynamism and space within wooded ecosystems. With some natural processes missing or out of balance, many species rely on disturbances associated with forestry management[100,102,169]. Plants can benefit from resulting light conditions, litter removal or activation of seed banks[80,170171]. Ephemeral aquatic habitats can be created and colonised by specialist water beetles[172]. Brash piles can benefit birds, like wren[173]. But many of these benefits are consequential rather than intentional. They can be at scales, intensities and frequencies which are not optimal.

Woodland restoration management interventions should be based on evidence of natural processes and disturbances[15,175,176], rather than a set of ideals founded on tradition or cultural management of land[15,53]. They must be informed by, and involving of, natural processes. This is a move away from a 'command-and-control' approach to woodland management[150].

Large-scale, catastrophic stand-replacing natural disturbances are rare and unpredictable. So management should not seek to replicate these, but draw from the more regular natural gap creation as a guide to felling[27,124]. These partial disturbances produce a finely patterned mosaic[175]. Uniform-thinning on a large scale is inappropriate as the resulting structures do not happen in nature[27].

Interventions that create disturbance and dynamism must always be considered alongside the development of old-growth characteristics. While some interventions can replicate natural disturbances, they often fail to retain trees as

HENRIK MALM, COUNTY ADMINISTRATIVE BOARD OF HALLAND, SWEDEN).

Restoration silviculture is based on evidence of natural processes and disturbances and involves combining the disturbance and dynamism with the development of old-growth characteristics. Interventions can combine this by creating more open gaps, along with decaying wood generation and veteranisation, to create features on legacy trees *(see 2.1)*. The forest nature reserve Osbecks bokskogar, Halland County, Sweden.

JIM SMITH-WRIGHT

In some scenarios, the silvicultural management of phase three is a continuation of the same approach taken in phase two restoration (Module 4 of this series). It is about thinning for complexity and developing space for legacy trees. The beech in the background here is one of many remnant trees within this plantation ancient woodland site, where phase two restoration has been carried out. In the foreground, a small holloway would have run down to an old iron forge downstream. Forge Wood, part of the Dallington Forest Project in East Sussex.

ALASTAIR HOTCHKISS

In many ancient woodlands, silvicultural management can be essential to maintaining certain functions and species that contribute considerably to the ecological integrity of a place. Management here is supporting the conservation of dormouse and the rare narrow-leaved lungwort (*Pulmonaria longifolia*). Briddlesford, Isle of Wight.

permanent legacies[178] or the accumulation of decaying wood *(see 2.1)*. When natural processes result in trees being over or dying, the gaps are irregular, and they often leave any survivors within them in grand isolation[27]. Remaining trees subsequently have vast space and opportunity to develop more open crowns. These become larger and older. Interventions to actively create disturbances and gaps can involve the treatment of trees in and around the gaps to induce the formation of old-growth microhabitats (exposed deadwood, hollows, etc.)[174].

Even after large-scale catastrophic disturbances (e.g. storms), many trees usually remain and there is also a high abundance of decaying wood[179]. The systematic and repeated removal of woody biomass from a large area as a result of clearfelling or intensive and repeated coppicing traditions can have serious consequences for species associated with old-growth characteristics. These include fungi[68], lichens[180], mosses[181] and molluscs[49], which can take centuries to recover[49]. Soils also become progressively impoverished, leading to changes in chemistry and nutritional status.

The accumulation of decaying woody biomass is essential before timber extraction becomes a primary management objective. Most ancient woodlands have a significant deadwood debt to repay first *(see 2.1.2)*. Restoration of old-growth characteristics can mean that it is inappropriate to extract any timber from the ecosystem[174].

But management requires financing, so an appropriate balance must be struck between the income from timber and contributions to decaying wood (e.g. actions described in 2.1). It is important to consider the need to meet demand for wood products. The UK is a net importer of timber, and decreases in domestic production could result in increased imports, shifting impacts on biodiversity and carbon stocks to other countries[182,183]. Ancient woodland represents approximately 18% of total woodland cover and forestry in the UK[184].

Some plants within wooded ecosystems can benefit from the disturbance resulting from silvicultural interventions, such as the scarce narrow-leaved bittercress (*Cardamine impatiens*) and the common herb-robert (*Geranium robertianum*) pictured here thriving on the side of an extraction track following the thinning of a conifer 'plantation on ancient woodland site' (PAWS). Breidden Hill, Montgomeryshire. Patchy bare ground and disturbance within treed ecosystems is also vital for other specialist plants, such as the rare upright spurge (*Euphorbia stricta*), as well as many insects, like solitary bees and wasps[123]. Similarly, woodland management can contribute to the conservation of species, such as nightingale.

Use near-to-nature forestry to create better space and dynamism

Near-to-nature forestry can help achieve structural complexity and patchiness across a wooded area[28,29,188]. For all woodlands and forestry in the UK, there is a need to shift existing plantation-origin forests to a more naturalistic composition, function and structure[189]. Patchiness and variation across a site and landscape is an important driver of biodiversity and carbon storage[190,191,192]. Natural structures, patterns and dynamics are many and various, and no one-size-fits-all approach is appropriate[27].

Near-to-nature forestry provides some appropriate silvicultural actions and can support high ecosystem integrity[177]. These include:

- Variable density thinning (introduced as part of phase two restoration – see Module 4) can continue as part of phase three. Apply this across as large an area as practicable. This can be combined with the development of 'legacy' trees *(see 2.1.1)*and interventions to create decaying wood *(see 2.1.2)*, mimicking many natural disturbance events[28,193].

This intervention involves treating some areas as 'gap-glades' where thinning intensity is very high but where

MATS NIKLASSON

Always consider combining silvicultural interventions for space and disturbance alongside the generation of old-growth characteristics. A created gap in a young, previously production forest in the nature reserve Osbecks bokskogar, Halland County, Sweden. A number of trees in the middle have been partially sawn and then split into a standing high stump and a lying decaying trunk. To the right is a ringbarked tree. All of the biomass has been retained within the ecosystem.

individual trees can remain. It also includes patches which are untouched. These 'skipped-groves' are where no trees are felled during an intervention. The remainder of the area (approximately 60–80%) is treated using a more consistent thinning intensity, but it should not be evenly distributed. Further smaller-scale patchiness can be achieved by the selection process.

- 'Gap-glades', for a single thinning intervention across a larger area, should add up to approximately 10–20% of a treated area. For more regular management, it might be appropriate to consider gap-glades as equivalent to 0.5–1% of an area annually[174].
- The location of gap-glades can be partly informed by the legacy trees *(see 2.1.1)*. The two can be combined where legacy trees are located within or on the edge of gap-glades. The emphasis is as much on what is left behind as on what is taken out. Where these are more clustered, it may mean numerous gap-glade areas closer together.
- Gap-glades should typically vary in area from about 300m² up to 1500m² [27,38]. These should not be clearly delineated but meshed into the surrounding stand as part of a thinning treatment across a larger area (i.e. don't consider them as group fellings or coppice coupes). A relatively centrally located legacy tree within a gap-glade of around 500m² should remain open long enough for even a less shade-tolerant tree species to successfully recruit into the overstorey[38].
- 'Skipped-groves' should add up to approximately 10–20% of an area. The location of the skipped-groves can include smaller, temporarily unmanaged areas where some felling may occur in the future. These can be a similar area to gap-glades, from about 300m² up to 1500m².

RICHARD BROWN

Combine variable-density thinning with the management for old-growth characteristics. In many instances, more open gap-glades can be partly informed by the location of legacy trees. Here, younger dense beech and ash have been felled to give space to a legacy beech. The Woodland Trust's Little Doward Woods, Herefordshire.

ALASTAIR HOTCHKISS

Woodland management and regeneration in the Wyre Forest, Worcestershire.

ALASTAIR HOTCHKISS

Timber can be harvested as part of variable density thinning operations. But the emphasis should usually be more on what's left behind than what is taken out.

Variable-density thinning diagram – This is a highly stylised diagram attempting to represent 6ha of woodland which has been treated using variable density thinning. This has been combined with developing old growth characteristics through legacy tree management and creation of decaying wood. The 6ha is part of a bigger woodland of 29ha.

Before (top). The majority of the trees are oak and birch of approximately 30–50 years old. Some older, veteran and ancient trees occur among them. These were remnants from the previous spruce plantation on ancient woodland site (PAWS). Other remnant areas from the site's plantation history occur along the main river, stream and on damper soils where mature ash and alder are frequent. Decaying wood volumes range between approximately 5m^3/ha to around 15m^3/ha, where some larger diameter decaying wood already occurs. Standing deadwood (snags) are rare, apart from a small cluster by the river.

After (below). The 6ha area was thinned using a variable-density pattern. This included approximately 1ha (16% of area) of gap-glades where thinning intensity was considerably higher. This comprised 12 gap-glades (3x400m^2, 4x800m^2, 3x900m^2 and 2x1500m^2). Another 1ha (16% of area) was spread across five skipped-groves. The skipped areas include two permanent legacy groves (0.3ha and 0.4ha) as well as three smaller temporary skipped-groves (3x900m^2). The permanent legacy groves include part of a core riparian area which already supports some of the richest old-growth characteristics in the wood. The remainder of the wood was selectively thinned using a more consistent intensity. Within all parts of the area, legacy trees were identified and selected. This included existing ancient and veteran trees as well as legacy trees of all younger age classes, of all native tree species occurring in the wood. These legacy trees informed the thinning. The majority of felled trees were extracted and timber sold at roadside, but a proportion were left as lying decaying wood. Some of the income was also used to fund more novel veteranisation interventions on standing trees, as well as ringbarking, to create standing snags. Woody debris dams were also created along the stream tributary. A small herd of four highland cattle has been present across the whole woodland for most of the past year, and this is being monitored.

But they should include some permanent legacy groves *(see 2.1.3)*, which should be larger, from a minimum 0.25ha (2500m², e.g. 50x50m) up to a few hectares (e.g. 3–6ha). These should be among a matrix of stands where management interventions are used to develop old-growth characteristics[34,94].

- Developing individual legacy trees has similarities to using crown thinning to develop future timber-quality trees. The difference is that legacy trees usually require more space for substantial branching and growth response[194]. Future timber trees may require more control of light levels to draw up and maintain steady growth[185] where some competitive shading of lower parts of trees is necessary. But this is an opportunity to create more patchiness by selecting some trees to develop as future timber trees, alongside those selected as legacy trees.
- Near-to-nature forestry can result in provision of goods, such as timber[29], and timber quality can often be increased alongside increasing stand diversity and structural complexity[185,186,187]. Wherever timber is extracted, consider ways to maximise deadwood retention. Abandoning crowns or creating high stumps can contribute decaying wood[185] *(see 2.1)*.
- Forestry management for space and light has often focused on rides and tracksides as permanent open features. These are often maintained separately from the rest of the wood through prescribed cutting or mowing. As a temporary transition, this will often need to continue, particularly where there is a risk that species will be lost without these efforts. But in order to maximise ecological integrity, it is necessary to develop more self-regulated systems, where space and ecotones occur as much more integrated and dynamic components within and across the wooded ecosystem[195]. Management interventions can try to shorten the time to achieve natural gap dynamics while preserving existing features in the meantime[174].
- A coppicing response (i.e., a tree regrowing from the base after cutting) is an inevitable consequence of cutting many native trees. But an area of land should not be defined by this management. In some woods, individual coppiced trees can be the oldest trees, and areas uncut for decades can develop into richer communities[53]. Even in the most intensively managed historic coppice-woods, wood-decay species will benefit from increasing and diversifying decaying wood supply[122]. Many of the structures and functions of different ages of coppice regrowth can be supported through other irregular high-forest ecosystems[85], where carbon stocks are also higher[197]. While 20% of rare woodland invertebrates need more open conditions, and 65% require old trees and decaying wood, only 0.5% are considered threatened by a lack of coppicing management[53]. Coppicing can also be highly damaging to lichen communities[37,196].

IMAGES: ALASTAIR HOTCHKISS

Traditional ride management in the Blean, Kent (top). Many of these interventions are carried out to try and conserve species like the heath fritillary butterfly. In many situations, this sort of traditional approach probably needs to continue, alongside attempts to create more appropriate dynamism and space across wider woodland areas. Wood-white butterfly (middle) populations can be highly dependent on carefully prescribed ride and trackside management. The management and grading of forest tracks generates important ecological disturbances and creates good breeding habitat, but this is temporary and vulnerable. While their populations can persist on these intensively managed areas of 'permanent open space', the ecological integrity of a woodland would be greatly increased if species like this occur across a more dynamic network of patches throughout and within the trees. A glade at the Woodland Trust's Glover's Wood (bottom) in Surrey is maintained by regular cutting, in order to sustain populations of plants, such as betony, devil's-bit scabious and the insects which use the flower-rich vegetation.

2.3 Better physical health

When an ecosystem shows attributes of 'health', it is often said to have integrity[160]. The health of ecosystems can be hindered by the state of physical (abiotic) elements. It is therefore essential to consider aspects such as water and air quality as part of woodland restoration. Other impacts such as noise pollution could be impacting on the integrity of woodland soundscapes[198].

2.3.1 Better water

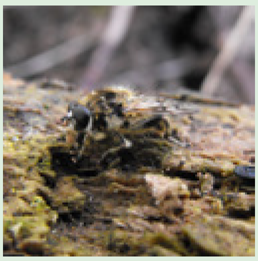
Hydrological processes and the health of aquatic habitats must be restored. This includes restoring moisture levels in wooded ecosystems[82] and rebuilding unique links between wood and water. This helps ensure the full expression of natural habitat mosaics[106], accepting that rewetting may result in changes to vegetation and tree composition[104].

The presence of wood and water together creates unique habitats. Elongated sedge (*Carex elongata*) is a specialist of ancient wet-woodland habitats, and can germinate on submerged or floating water-saturated deadwood. Montgomeryshire, Mid Wales.

IMAGES THIS PAGE: ALASTAIR HOTCHKISS

Practical actions include:

- Consider blocking all drainage ditches. This will increase soil moisture, helping restore abundances and richness of specialist soil-dwelling woodland invertebrates[199]. This may overlap with earlier phases of restoration. But if drainage enables machinery access and extraction, then it may be practicable to avoid significant rewetting until phase two is complete, and the wood is 'secure'. Rewetting can cause mortality in the tree stand, contributing decaying wood and decreasing evapotranspiration, raising the water table further[105]. It can help develop old-growth characteristics, because of reduced human intervention in wet woods with many watercourses[200].
- Do not remove naturally developing woody debris dams in streams and small rivers. These are critical components of naturally functioning watercourses, providing essential physical complexity and habitat[201,202]. This is required by specialist invertebrates[203], fish[204] and white-clawed crayfish[205]. Consider installing or creating new woody debris dams in appropriate locations. Wood in watercourses can be highly mobile. Lengths shorter than 2.5x the channel width are potentially mobile[206]. Eurasian beavers build woody debris dams naturally, so appropriate reintroduction projects could help support restoration *(see 2.5)*.
- For both of the above, it may be necessary to consult relevant authorities, and seek permissions where required. Ordinary watercourse consent may be required from the local authority, under the Flood and Water Management Act 2010, and other legislation such as the Land Drainage Act 1991 may apply.
- Seepages, flushes, mats of golden saxifrage and features like tufa springs in woodlands are important. Their extent can be small, but their contribution is often great, supporting biodiversity not occurring elsewhere. Identify and avoid all damage to these areas from any management or the continuous presence of heavy animals[37].
- Always prioritise opportunities for peatland restoration within or near to ancient woodlands. This restores natural ecotones and functioning carbon storage systems[97,106].



The unique conditions provided by the combination of water and wood-host specialist invertebrates. Woody debris in watercourses can support specialist splinter craneflies (*Lipsothrix* spp.) and caddisflies (*Lype* spp.) which build feeding galleries in submerged wood[201].

The increasing occurrence of specialist log-jam hoverflies (*Chalcosyrphus eunotus*) in parts of Europe is considered directly proportional to an increase in the number of beavers over the last 20 years[203]. The hoverfly larvae use water-saturated decaying wood, particularly in log jams in wooded watercourses.

ALASTAIR HOTCHKISS

Restoring hydrology and water quality at Fingle Woods in Devon – a partnership between the Woodland Trust and National Trust. High fluctuations in water levels, increasing acidity and loss of fish populations within the ancient woodland is largely an impact of the land higher up on Dartmoor. So using fairly low-grade softwood timber extracted during phase two restoration of plantation on ancient woodland sites (PAWS), timber is milled-up within the wood and transported to be installed up on the open moor. Rewetting parts of high Dartmoor will thus benefit water quality in the River Teign through the wood itself. Elsewhere, thinned conifer material has been used to make woody dams, with monitoring showing increases in trout within the streams and passing through the leaky dams. The hydrological monitoring shows reduction in peak flows as water is retained in pools and released into streams more gradually. Fingle Woods, Devon.

- Other factors need to be considered outside the boundary of an existing site. For example, addressing issues with ground and surface-water pollution, such as nitrates and phosphates. Try to buffer ancient woods to reduce or intercept ground and surface-water pollution. Create zones around ancient woodlands where there are no inputs (e.g. no spreading of fertilisers, manure or slurry).
- Impacts from ground water abstraction on the water table have repercussions for the integrity of woodland vegetation[207]. With the predicted increase in future drought events[208,261] may come a lowering of the water table, soil desiccation and reduced humidity, impacting on soil invertebrates[82,209] and fungal decomposition rates[210]. Opening up stands too much can exacerbate risks to soil moisture levels and humidity in some locations, which may have implications for some species, particularly those towards the south or east of their ranges.
- Features such as wooded ravines, spring-lines, gills and other north-facing parts of sites could become important climate-change refuges[211]. In general, the invertebrate fauna of wet woodland sites, especially those in upland situations, or on northerly aspects, require moist, shaded conditions. Hydroelectric power schemes (HEP) divert water from a stream or river, altering flows and humidity regimes. These can be damaging to important bryophytes[211].

SIMON COOTER NATURAL ENGLAND

Ditch-blocking in woodland. Stiperstones, Shropshire.

2.3.2 Better air quality

The ecological integrity of most ancient woodland in the UK has been impacted by the effects of historic and current air pollution. The historic impacts of sulphur dioxide from industrial pollution still persist and atmospheric nitrogen pollution is of significant concern today. Most ancient woodland exceeds the levels of nitrogen deposition at which the ecosystem will deteriorate[212].

Nitrogen deposition has many impacts on ancient woodland ecosystems. It leads to a greater abundance of nitrogen-tolerant plants, with consequences for less tolerant species[213,214]. Air pollutants impact lichens growing on trees[215], woodland mosses[216,217], moths, butterflies and other insects[215,218,219,220,221].

Ectomycorrhizal fungi (associated with tree roots) are highly sensitive to nitrogen deposition. Their decline has knock-on impacts on tree health[222,223]. Links between nitrogen pollution and tree diseases, such as acute oak decline[224], may be related to mycorrhizal fungi declines. The loss of these fungi also results in soil carbon release to the atmosphere[225]. These essential fungi can recover where steps are taken to reduce nitrogen deposition[226]. The deteriorating nutritional health of trees across Europe (e.g. foliar levels of phosphorous, magnesium, calcium) has been linked to nitrogen deposition[227], with consequences for ecosystem functioning and climate change response.

Wood density of some tree species (e.g. beech, sessile oak, Scots pine) has decreased significantly since 1900 due to the changes in climate and nitrogen deposition. As well as impacts on timber quality, lower wood density generally means a higher susceptibility to disturbance events, such as high winds.

Many ancient woodland lichen communities evolved in naturally low levels of atmospheric nitrogen and are highly sensitive to change (e.g. beard lichens *Usnea* spp.). Lichens on trees provide shelter, food, and vital microhabitats for invertebrates, and are considered to contribute to wider ecosystem services, for example in carbon cycling and water retention[270]. Oak canopy rich with beard lichens in Dartmoor, where nitrogen pollution levels are relatively low compared to other parts of the UK.

A high proportion of ancient woods in the UK are devoid of the richness of lichens and other associated organisms because of levels of reactive nitrogen in the air. This has resulted in a shifting baseline. There is a misconception that trees covered in lichens are a phenomenon of the western oceanic woods because of climate. Climate does contribute to key differences, but many western parts of the UK are also the least historically impacted by air pollution. Oak canopy devoid of lichens in a nitrogen-polluted wood in northeast Wales

IMAGES: ALASTAIR HOTCHKISS

Most air pollution issues arise from sources outside the boundary of woods themselves. But a number of actions can be considered:

- Try to buffer ancient woods to reduce, capture or intercept emissions[229]. Create zones around ancient woodlands where there are no inputs (e.g. no spreading of manure, fertiliser). Edge effects of 200m can be detectable in woods adjacent to land uses with high nitrogen deposition levels[230].
- Trees can play a role in the interception and capture of ammonia emissions, and planting of tree belts may protect ancient woodlands from existing sources of pollution[231]. In some areas, consider the risk of exposing the interior of woodlands to greater levels of nitrogen deposition as a result of interventions that open up stands.
- Be aware of new developments in the local area, and mindful of the impacts from air pollutants. New developments should not lead to further degradation of ancient woodland sites due to significant increases in atmospheric nitrogen[231]. This can include nearby developments like intensive agricultural units. Game bird releases can also have significant impacts on localised nitrogen emissions[232].

ALASTAIR HOTCHKISS

A healthy community of lichens growing on trees in the relatively clean air by Loch Sunart, Scotland. The lungworts are among our largest lichens, and include the green leafy-looking *Lobaria pulmonaria* and grey *Lobaria scrobiculata* shown here. These species are now mainly confined to the westernmost extremities of the UK, but this emphasises an important shifting baseline. Their present distribution is not because of climatic factors, but because many woodlands in the far west have been least affected by air pollution historically. Species such as *Lobaria pulmonaria* and *Lobaria scrobiculata* are often portrayed as a flagship for temperate rainforests, yet they occurred throughout most of Western Europe historically, including in much drier climates. This is illustrated by their continued presence in the relatively dry Cairngorms, and from historical records of these species in all parts of the UK, including many parts of the Midlands and South East England.

2.4 Better treescapes – landscape-scale integrity

The ecological integrity of any individual site is reliant on the integrity of the landscape it occurs within. Nature recovery and climate change resilience depend on landscape-scale restoration. Ancient woodlands are a part of wider treescapes, as core elements of wooded habitat networks. But the land use surrounding ancient woodlands must be better integrated with the management of the sites themselves[5].

Phase three is about considering the contribution of the existing landscape to the integrity of individual ancient woods. This includes the role of other woods, scrub and individual trees. It is about considering woodland expansion within landscapes, and the space over which particular natural functions act[264].

ALASTAIR HOTCHKISS

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Top. Expansion of trees and scrub through the natural processes of seed dispersal and the patchy disturbance and herbivory from large animals. Allowing more natural process outside the boundaries of existing woods will support complementary habitat structures at landscape scales. These will provide far wider opportunities for biodiversity and the recovery of woodland species. Denser scrub and thickets outside of ancient woodlands can support breeding birds like garden warbler and nightingale, as well as purple emperor butterflies. Knepp Estate, West Sussex.

Below. Aerial Imagery example – **(far left)**. In this example, two blocks of ancient woodland are fragmented and highly juxtaposed against agricultural land with limited tree cover outside of the ancient woods. **(Middle)** Conventional woodland planting schemes have increased tree cover in these areas, but these are still distinct from adjacent land use, and the dynamism and connectivity across the treescape remains limited. These are used by some species, such as willow warbler and moths associated with native trees. **(Right)** Land management changes and extensive grazing have resulted in complex woodland expansion through natural regeneration and scrub development. The landscape is considerably richer in ecotones, with less distinction between the 'woodland' and 'open agriculture'.

NIALL BENVIE/WTML

Woodland expansion in many upland landscapes requires management of deer populations or domestic sheep grazing. The Woodland Trust's Glen Finglas, Loch Lomond and the Trossachs National Park.

Diagram showing woodland expansion from a small remnant pocket of trees, a ghost wood or relic of ancient woodland which was more widespread and has declined through decades of overgrazing. In many situations, where seed sources and dispersal are not limited, management of herbivore impacts is the priority in order to achieve woodland expansion.

Make wooded ecosystems bigger and more joined up

To make our woodlands bigger and better connected, we must consider 'woodlands' with ill-defined boundaries to include variation in space and time[150]. We can define the 'woodland' by where trees are living now; where trees may have grown in the past; and where few or no trees grow now, but may grow in the future[233]. Woodlands are a continuum of 'groves' (denser, more treed areas), 'ecotones' (less treed areas – *see Box 2 – Ecotones – the essential grey areas,* section 2.2) and 'glades' (scattered or untreed areas).

Outside of ancient woodlands are younger wooded patches, scrub and individual trees. These contribute to species persistence and functions across broader landscapes[124,234]. For many species and processes, it is inappropriate to try and join up woods by densely treed strips connecting one dense grove to another dense grove. But certain features will always sever connectivity, such as roads and other development.

Actions include:

- Consider how the management of individual veteran and ancient trees outside the boundaries of ancient woodlands contribute to that site's ecological integrity. Old-growth characteristics need considering at a landscape-scale in terms of ecological integrity[235] and climate change adaptation[236].
- Individual ancient and veteran trees outside woods should not be in a critical condition, and management should ensure these are secure. The value of younger and smaller trees should not be discounted. These are crucial for the long-term perpetuation of large old trees. Legacy trees within woods must be accompanied by similar approaches to ensure perpetuation of trees outside woods[237].
- Woodland expansion could be a priority phase three action for many woods:

ALASTAIR HOTCHKISS

The flightless wood cricket (*Nemobius sylvestris*) is mainly found in relatively large, mature woodland fragments situated closely to another occupied site. Its occurrence is related to fragment area, isolation, habitat availability and woodland age. It is more likely to be present in woodland fragments with ancient characteristics than in woodlands of secondary origin[268]. For species like wood cricket, better treescapes may be less about creating young dense woodland patches, but more about site-based actions to improve habitat quality and maintain large populations[284].

- For example, those in intensively farmed landscapes where habitat loss and fragmentation have been more severe[238].
- Expansion is also a priority in many upland landscapes where grazing pressure and browsing by deer threatens the existence of the diminishing ancient woodland and prevents natural mobility in the landscape[233]. Dynamism across landscapes is a key facet of adaptation to climate change.
- Prioritise 'ghost' and 'shadow' woods[239], where ancient woodland may now only be represented by patches of ancient woodland plants, scattered individual trees in the uplands, along watercourses or rocky ground, or field trees in lowlands. These trees can maintain important biological continuity[240]. Expansion along watercourses provides many wider ecosystem services[106,241,242].

- Expansion of ancient woodlands through natural regeneration is usually highly achievable and most appropriate for both ecological integrity and carbon storage[243]. Planting trees within or around ancient woodlands risks eroding the historical, ecological and genetic integrity of ancient woodlands, and risks devaluing the biogeography of certain species[113], such as small-leaved lime, microspecies of elm, or the genetic diversity of birches. In specific instances, planting or seeding of tree species within or around ancient woodlands may be appropriate (see 2.5, and Module 4 of this series).
- Scrub and shrubs have always formed a transition between more open habitats and denser groves[244]. Naturalistic grazing *(see 2.2.2)* can benefit woodland expansion, and natural scrub ecotones. Climax scrub can occur on exposed and windswept situations, e.g. on coastal sites and oceanic hazel scrub[196]. The expansion and restoration of montane scrub woodland is an important part of the ecological integrity of wooded ecosystems in mountainous regions, home to numerous willow species, dwarf birch and juniper. Montane scrub would be self-sustaining through natural regeneration; but planting and protection is often required because natural regeneration is often not possible due to absence of seed sources, poor viability and high herbivore pressures[245].
- Existing younger and small woods within fragmented agricultural landscapes can deliver high ecosystem service provision[246]. While younger secondary woodlands can be colonised by species associated with older wooded habitats, they would often benefit from actions to improve the habitat quality and structure[247]. Many phase three restoration actions should be considered in these younger wooded ecosystems. Equally, restoring the ecological integrity of nearby ancient woodland will provide stronger sources to populate these younger woods.

2.5 More reintroductions and translocations

In many cases, re-establishing natural processes and functions will require intervention, including the reintroduction of species[89].

Reintroductions occur where species were known to have existed, usually within recent history and supported with evidence.

Translocations are different in that species are moved from one location to another, with limited evidence to suggest the species definitely occurred there. They are likely to be well adapted to the site and the ecological integrity of the ancient woodland will not be reduced. Mitigation translocations because of habitat loss due to human actions are always an absolute last resort[248].

Reinforcements involve bolstering species by adding individuals to the existing population of the same species, which is usually threatened.

Actions include:

- Support reintroduction, reinforcement or translocation projects involving species which represent keystone, functional roles, or other target species. These should be seen as the restoration of missing processes, or where they contribute to the conservation of a target species.
- Always follow the guidelines set out by the *International Union for Conservation of Nature (IUCN)* on conservation translocations. Always be aware of the place of your organism in the ecosystem, including functional roles. These include pollination, seed dispersal, predation (including seed predation), host parasite relationships, facilitation, and providing resources (e.g. as prey). This will often require involving specialist ecologists. Detailed monitoring and dissemination of results is needed[249].
- Any reintroduction needs to take full consideration of the legitimate concerns of stakeholders and local communities who might be affected[89]. A thorough assessment of potential ecological, social and economic impacts, both direct and indirect, positive and negative, should be carried out. The extent and condition of sufficient suitable habitat must exist to ensure the wellbeing of viable populations. Where there is high risk, or uncertainty of risk, reintroductions or translocations should not proceed[248].

Flora

There can be a need to translocate or reintroduce plants. For example, adding native seed and creating suitable germination sites can be required after removing dense invasive plants[250,251,252,278] where dense shading conifer plantations have occurred for a long time[253], or after rewetting of wet woodlands[150].

The seed bank or dispersal may be limited. This should not be about attempting to recreate any specific vegetation composition, but prioritising identified missing functional roles. Approaches can be small scale and low cost. Genetically appropriate sources of seed and plants must be used. Seed and plants must be collected as locally as possible, from populations with environmental conditions similar to those at the receptor sites[254]. If seed is bought from a supplier, the source must be within the same region as the planting site[253]. Local partnerships with plant recorders associated with the Botanical Society of Britain and Ireland (BSBI) will help ensure the appropriateness of projects.

ALASTAIR HOTCHKISS

Some species represent functional reintroductions. Common cow-wheat (*Melampyrum pratense*) ecology involves complex interactions with other species and processes. Seeds are dispersed by ants, including red wood ants (*Formica* spp.) which are often not present. They are also hemiparasitic and derive some of their nutrition from the roots of other plants, affecting vegetation structure. Some species can be difficult to introduce, where they have complex interactions with fungi and other taxa[283].

Translocation of trees or seed may be necessary in specific circumstances, for example: site native tree species lost due to past management, or to support the recovery of woods from tree disease[124]. For instance, aspen has limited ability to disperse naturally by seed, but it may be a useful species to support species associated with ash as it has comparable bark, decay, canopy-lightness and drought-tolerance characteristics. Consideration to the introduction of trees is covered in Module 4. Ultimately, allowing natural processes to determine species and genetic responses to change will always be most appropriate. Attempting to artificially increase species diversity will not ensure ecological resilience[97,255].

Fauna

Against the backdrop of a biodiversity crisis there has been wildlife recovery across Europe[256]. Unlike mainland Europe, where animals move across a

ALASTAIR HOTCHKISS

A project at the Woodland Trust's Ledmore & Migdale site on the Dornoch Firth in northeast Scotland has involved translocation of twinflower (*Linnaea borealis*). Translocating this characteristic native pinewood specialist involves a novel method of dragging a log around an existing donor site to acquire seed. The log is moved and dragged around the receptor site, dispersing the seed and creating the ecological disturbance to support germination and establishment.

large land mass, the return of many extinct animals to the UK must be a conscious decision. Many are significant keystone species and ecosystem engineers. The role of domestic cattle and horses as surrogates for extinct wild animals has been

ANNE-MARIE KALUS/WTML

Pine martens have been released in Mid Wales as part of a population reinforcement project. A small, low density population was considered to exist in the area, based on infrequent observations and genetic testing of scat. As well as a species conservation intervention, animals like pine marten represent wider functional reintroductions. For example, their role in the predation and stress of non-native grey squirrels.

considered *(see 2.2.2)*. They are a functional reintroduction. But wider species reintroductions and translocations of animal species are increasing, for example, involving pine marten and Eurasian beaver *(see 2.3)*.

All should be considered for the role they might play in restoring important missing natural processes. The restoration of missing process associated with animal herbivory, carnivory and scavenging can shape more self-regulating ecosystems[256], performing key roles in maintaining ecosystem functioning.

Fungi

Many fungal species have declined because of woodland loss, fragmentation, and decreases in decaying wood habitats. They can colonise new habitat by spores, and while some fungi fail to travel beyond a few metres from the fruit bodies, others may travel significant distances[68,257]. Some lichens do not produce spores because of various factors (including climate and air pollution), and can be quite limited in their dispersal, while others are very mobile. Consider translocations of lichens where critically low populations occur on fallen trees, or on ash which are dying or dead. Seek advice, as this will require expert involvement.

Some wood-decay fungi can move with insects like wood-decay beetles[258]. Keystone heartwood-decay fungi, such as beefsteak fungus and chicken-of-the-woods, are crucial in the process of developing old-growth characteristics[259]. Management like veteranisation techniques can result in other more natural colonisation by decay-fungi. Reintroductions of fungi should always be preceded by a risk assessment of the species to be reintroduced, involving expert mycologists. They should be considered complementary to the primary target of increasing the volume of their habitat.

Fungal inoculation can be an effective method for reintroducing threatened wood-inhabiting fungi[260]. But these should be seen as species conservation interventions primarily. It is not appropriate to use commercially available preparations of any fungi, including mycorrhizal fungi, within ancient woodland. These often include species that are not native to an area[72].

EMMA GILMARTIN

Tooth fungi (*Hericium* spp.) are rare conservation priorities in the UK, associated with woods rich in old-growth characteristics. They can be introduced through wood inoculation techniques, but these are primarily species conservation interventions. Commercially available preparations of fungi are not appropriate for ancient woodland.

3 There is no end....

Monitor progress

For sites that have progressed through earlier restoration phases, phase three requires a switch from using an ancient woodland restoration (AWR) assessment (Module 2), to a more general woodland condition assessment. The AWR assessment process is essential to phase one and phase two management, informing the urgent recovery of critical and threatened ancient woodland sites. But for 'secure' zones or compartments, the assessment must switch to a condition assessment which is less about addressing impacts, and more about informing how to achieve the phase three vision. This should trigger concern if something desired is not happening, or not likely to happen in the medium term through natural processes, for example.

Regular observation must be continued by surveying on the ground. Information will guide decisions about a site, and a condition assessment will usually be carried out in advance of a management plan review. The results need to be considered alongside all the other factors that influence the management of woods, including public access, cultural features, and practical considerations.

Integrity is more difficult to quantify than simpler concepts such as richness and diversity[160]. Therefore, measuring its increase can be problematic. Some phase three objectives can be measured within an area (e.g. decaying wood volumes), while others may require more intuition across a wider woodland or landscape (e.g. appropriate dynamism and space). Observation is always important, and long-term monitoring can be highly revealing and informative[27,262,265].

Studying the unexpected can track the development and mortality of individual trees and wider ecological change, while also holding the potential to detect changes from other future impacts. Being species aware as part of monitoring is important. Only by understanding species can we be sure that structural and habitat qualities are being provided and processes are functioning[266].

Set the trajectory

The timescales for many woodlands to achieve maximum ecological integrity is beyond the lifetime of humans. But we must set the trajectory and mind-set of what ancient woodlands can be. Ecological time-lags will mean we must be patient for success[294], and this must complement or counterbalance the urgency to intervene. But we can always remain optimistic: restoration works.

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> *'A thing is right when it tends to preserve integrity, stability and beauty of the biotic community'*
> (Aldo Leopold, 1949)

> *'The world as we have created it, is a process of our thinking. It cannot be changed without changing our thinking.'*
> (Albert Einstein)

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