Evidence review: What are the effects of active interventions on biodiversity in newly established woodlands?

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Abstract

1. Newly created and young woodlands often lack important attributes that contribute to a well-functioning woodland ecosystem. Active management can accelerate the development of these attributes to attain high conservation-value woodlands more quickly. To achieve the most effective outcomes, it is important to understand the effects of management interventions on biodiversity. A range of intervention approaches are investigated here, through a review of scientific and grey literature and expert experience.
2. *Artificial structures for cavity-dependent species:* Nest boxes can have desirable effects on bird populations and fecundity, especially if well-designed and placed in suitable locations at a range of orientations. The benefits for bats are more equivocal. Boxes for saproxylic invertebrates can provide alternative habitat, but only when placed near existing old hollow trees with source populations.
3. *Veteranisation:* Anecdotal evidence shows that insects, birds and bats utilise chainsaw-carved holes soon after creation. Pollarding and ring-barking accelerate the formation of decaying wood for saproxylic invertebrates or other excavating species such as woodpeckers. These techniques are appropriate for recently planted woodlands as they rapidly create structural diversity and a variety of deadwood.
4. *Species reintroduction, population reinforcement and assisted colonisation:* Species reintroductions can restore ecological functioning and bolster populations of rare species (e.g. black poplar). Assisted colonisation is less widely practiced or well understood but may be used to introduce woodland plants, fungi or lichens to woodlands that are isolated from other woods and/or are established on agricultural land.
5. *Increasing structural complexity:* Young woodlands have a high density of even aged trees. Selective thinning, coppicing and pollarding are ways of introducing heterogeneity to the woodland understory. The conservation objectives must be clear from the outset, as this affects which technique is appropriate and practical. The biodiversity value of a woodland can be further enhanced by creating open small areas through linear rides and glades, and by re-sculpting woodland margins.

6. *Grazing:* Grazing by large herbivores can help maintain open areas in woodlands, create structural complexity and enhance floral diversity. Considerations include forage quantity and quality; densities of wild herbivores and habitat use patterns. The right levels of herbivory will ensure the maintenance of earlier successional stages, but grazing can also hinder the successful recruitment of trees and shrubs and negatively impact other species.
7. *Recommendations for future research:* Evidence gaps were identified where research at present is inconclusive, lacking for the UK, or a major gap exists in the literature.

1 Introduction

This is a review of the literature on the effects of various conservation interventions on the biodiversity of newly established woodlands. The overall aim is to inform guidance on how to create native woodlands with high conservation value. Although approximately half of the UK's woodlands are non-native commercial plantations, and there are ways they can be improved for biodiversity, these are not considered here. The guidance that will result from this review will be for the Woodland Trust's approach to woodland creation, which has at its heart the prioritisation of native woods and trees.

2 Objectives and scope

Within the overarching question '*what are the effects of active interventions on biodiversity in newly established woodlands in the UK?'* five specific interventions were identified:

1. Provision of artificial structures for cavity-dependent species
2. Promoting the formation of deadwood habitats (veteranisation)
3. Species reintroduction, population reinforcement and assisted colonisation
4. Increasing structural complexity
5. Grazing with large herbivores

The studies that have been included describe these interventions, and how they may be implemented, as well as studies that evaluate the effectiveness of interventions for a given target taxa or species. It was not possible to confine the search to studies only on newly established woods, as this would have limited the search results too much and would have excluded useful studies on interventions carried out in more mature woods. Research on production-based silvicultural systems is out of scope for this review. The focus is on interventions to achieve semi-natural woodland of high conservation value.

3. Methodology

This systematic review draws on scientific papers and reports and was performed using Collaboration for Conservation Evidence recommended guidelines for evidence synthesis (CCE, 2018). Google scholar was primarily used to search for academic papers, using a search string with the intervention and 'woodland', and 'biodiversity' or a given species or taxa to help focus on outcomes for conservation. Results were filtered for planted trees of species native to the UK, and studies from a UK context were prioritised. However, to extend the range of suitable evidence for inclusion, non-UK studies were included providing their study tree species was also native to the UK. A range of evidence sources were included, such as primary experimental studies, literature reviews and grey literature. Internal and external experts also provided additional relevant papers or reports in response to a targeted evidence request. Reference lists were checked to identify additional studies and included where relevant. The Conservation Evidence website (www.conservationevidence.com) was searched for UK-relevant syntheses. The full papers cited in these syntheses were then reviewed.

4. Results

4.1. Provision of artificial structures for cavity-dependent species

A range of species across various taxa are dependent on naturally occurring tree cavities, holes and cracks. These cavities may be used for nesting or roosting. Such habitats are limited in many woods as they predominantly occur in older trees, which are severely lacking in UK woods. Indeed, 98% of native woodland stands surveyed for the National Forest Inventory had fewer than 0.05 veteran trees per hectare (Forestry Commission, 2020). Where the availability of natural cavities is limiting populations of dependent species, the provision of boxes is often used as a conservation intervention. Newly established woods will be lacking mature trees with such features. Therefore, provision of boxes could be a simple way to provide these microhabitats in the interim period before natural cavities form, which can take decades to centuries. For example, hollows develop in oak at about 200 years old. It is important, however, to first assess the effectiveness and suitability of artificial structures, and if they can provide the appropriate conditions for the target species.

4.1.1. Birds

Based on studies from across the world, the provision of artificial nesting sites for songbirds, falcons and owls was categorised as ‘beneficial’, due to desirable effects on population density, population growth rates, and productivity (Williams *et al.*, 2019). Studies on nest box design are, however, more equivocal (Williams *et al.*, 2019). As these conclusions were based on a huge range of study systems, some woodland bird specific studies that are most applicable to the UK are reviewed here.

Artificial nest boxes will inevitably differ from natural cavities. From a management point of view, it is important to replicate natural conditions as closely as possible to avoid negative ecological impacts, such as poor development of nestlings, mortality due to sub-optimal conditions and increased prevalence of pests, disease or predation. Microclimate is one aspect of investigation into whether nest-boxes are an appropriate substitute for tree cavities. Nest-boxes provided for marsh tits (*Poecile palustris*) were found to provide significantly poorer thermal insulation and have lower humidity compared to tree cavities (Maziarz *et al*., 2017). Therefore nest-boxes with improved insulation such as wood, or a waterproof concrete/wood compound, should be placed in shaded sites to avoid extremes in both heat and cold. The drier environment within nest boxes provides better conditions for the development of flea larvae, which can increase nestling mortality. Nest material can also build up between breeding seasons, which can be inhabited by overwintering fleas. Therefore, regular cleaning of nest-boxes is essential, but this also adds to the costs of installation and management (Maziarz *et al*., 2017). However, Maziarz *et al*. did not test the effects of the difference in temperature and humidity on survival or reproductive success. Further work should examine the effects on species' populations. *P. palustris* is red listed under UK Birds of Conservation Concern and is very unlikely to breed in new native woodland in Britain; however, the general conclusions about nest boxes are applicable to other species.

Another consideration is nest box orientation, which can influence occupation and breeding success of woodland passerines. Fewer nest boxes oriented south-southwest were occupied by great tits (*Parus major)* than boxes facing other directions, whilst fewer pied flycatcher (*Ficedula hypoleuca*) younglings fledged from S-SW facing boxes. Blue tits (*Cyanistes caeruleus*), however, showed no effect of nest box orientation on either occupancy or breeding success (Goodenough *et al.*, 2008). These findings suggest that siting boxes in an arc from west through north to south will provide the most benefit to pied flycatcher and great tit populations. In nature, there would be variability in cavity orientations allowing the individual to choose the one with the best environmental conditions. This should be replicated with artificial boxes.

Nestlings in boxes may also be vulnerable to predation; box design is an important consideration to reduce risk from predators. For example, covering nest boxes with wire mesh reduces great spotted woodpecker major predation of blue tit (Mainwaring and Hartley, 2008). Advice on building, erecting and monitoring bird boxes is available from Cromack (2018).

4.1.2. Saproxylic invertebrates

Saproxylic invertebrates are another group that inhabit tree hollows (mainly comprising of beetles, dipterans and pseudoscorpions). Many saproxylic species have rare, isolated and declining populations, again largely due to declines in populations of old hollow trees. To inform recommendations on artificial habitat provision by saproxylic invertebrate fauna, the utilisation of boxes was investigated over four years at three sites in Sweden with many hollow oaks (Jansson *et al.*, 2009). The boxes were similar to large bird boxes, with a circular entrance hole, but were 70% filled with potential substrate for saproxylic organisms. Boxes were placed on hollow oaks and younger oaks within a 10-200m radius of a hollow oak. A large proportion of beetles found in hollow oaks (70%), including some red-listed species, were recorded in the boxes, demonstrating that they can provide suitable alternative habitat where tree cavities are limiting. Low-dispersal ability does however play a role, as the number of species associated with tree hollows in oak decreased with distance from sites with hollow oaks. Therefore, artificial boxes are only likely to be effective if placed within fairly close proximity to existing old hollow trees inhabited by saproxylic invertebrates. The authors provide a detailed description of box design, construction and placement that can be used for guidance.

A follow-up study on the same boxes 10 years after initial placement found that species richness was lower at this time, but the abundance of specialised hollow tree species increased (Carlsson *et al.*, 2016). This is attributed to the wood mould in artificial boxes becoming more like real wood mould and shows that wooden boxes can provide habitats for saproxylic species over long periods. Material for forming wood mould, such as saw dust, would need to be added to the boxes to mimic the dynamics in a tree hollow (Carlsson *et al.*, 2016). The authors provide further recommendations for box design, including lining the bottom of the box with plastic to prevent disintegration, and making boxes larger to create a more stable microclimate.

4.1.3. Bats

All UK bat species have been found in or around trees and wooded areas. Whilst some only use woodlands to forage, many are known to roost in trees, with some species also or mainly utilising caves or built structures. Species that utilise roosts in trees include brown long-eared bat, noctule, barbastelle, Bechstein's bat and Natterer's bat. Tree roosting species require cavities, crevices and splits, loose bark and dense ivy in different parts of the tree at different times of the year to provide the conditions they need (Jackson, 2015). In the summer, females gather in maternity roosts in the higher canopy where it is warmer, whereas in the winter both sexes move deeper and lower into the tree to hibernate where it is cooler. Mature and veteran trees provide many natural features for roosts; such as cracks and branch splits, loose bark, old woodpecker holes and hollow trunks. If trees with these features are lacking, bat boxes can be fitted to younger trees to provide artificial roosts. The evidence on the provision of bat boxes for roosting bats has been summarised by Berthinussen *et al*., (2019). On the basis this study, independent experts categorised the overall effectiveness of this intervention as 'unknown' due to limited evidence. The provision of bat boxes is a widely used conservation intervention and there is a lot of literature on the use of these structures by bats. However, the many different designs make it difficult to draw consistent conclusions, as evidence in support of each individual design is lacking (Berthinussen *et al*., 2019).

Despite the lack of conclusive evidence, bats are rare, protected, species and bat boxes are an important tool for their conservation. Bat Conservation Trust provide a guide to bat boxes that includes many considerations - such as box design, orientation and location which can help optimise their suitability (Bat Conservation Trust, 2020). As with bird boxes, it is important to provide bat boxes with a range of microclimates and box aspects, although the evidence on the effect of box height on uptake is inconclusive (Rueegger, 2016). Longer-term studies are needed on population-level responses to provision of bat boxes compared with no provision.

4.2. Promoting the formation of deadwood habitats (aka veteranisation)

The recurrent theme with providing artificial structures to mimic natural cavities is that mature and veteran trees that have these natural features are often lacking; particularly in young, recently established woodlands. There are, however, various techniques for speeding up the process of deadwood habitat formation in trees, which is known as veteranisation. Different techniques can be used depending on the type of habitat and conditions you want to produce for your target species.

4.2.1. Chainsaw-carved cavities

Cutting into a live tree with a chainsaw to create artificial cavities is an alternative to attaching artificial boxes. These cavities may be used by tree-roosting bats, birds or mammals. Trials in Sweden, England and Norway provide anecdotal evidence that insects, birds and bats will utilise chainsaw-carved 'nest boxes' and 'woodpecker holes' soon after creation (Bengtsson, 2019). The techniques are described in Bengtsson *et al.* (2012) & Bengtsson (2015), but full analyses and results are yet to be published.

Empirical data on the effectiveness of chainsaw hollows is limited. However, a study was found from Melbourne, Australia, which experiences a Mediterranean climate (Griffiths *et al.*, 2018). Griffiths *et al*. found that traditional plywood nest boxes did not effectively replicate the thermal conditions within natural tree hollows, whereas chainsaw hollows had thermal profiles that were similar to tree hollows, being consistently warmer than ambient conditions at night, but cooler during the day. Chainsaw hollows, therefore, could provide more suitable conditions for target species than artificial boxes, as they are better insulated and match natural tree hollows more closely. However, the uptake of these by target wildlife species wasn't measured, nor the impacts on survival or reproductive success. A comparison of the thermal conditions in chainsaw hollows compared to natural hollows is required for the UK. Longer-term work is also required to determine the use of these structures by target species, and whether differences in their properties have population consequences due to variation in survival or breeding success.

4.2.2. Coppicing and pollarding

Two techniques that speed up the formation of hollows that have been widely practiced for centuries are coppicing and pollarding. Coppicing involves cutting the tree at the base, whereas pollarding involves the periodic removal of the upper branches of a tree above browsing height (Sebek *et al.*, 2013). Multiple new stems are produced by the cut stump, which are harvested on rotation (usually between 7-25 years). This practice increases the life of the tree and mimics natural processes whereby many tree species naturally regenerate after experiencing damage. The stools themselves can also be important for saproxylic species. Many species are suitable for coppicing, including oak, hazel, maple, sweet chestnut, lime and ash. Pollarding of white willow (*Salix alba*) significantly increased the probability of hollow occurrence compared to non-pollard trees, especially in young trees (Sebek *et al.*, 2013). It is therefore an important tool for restoring saproxylic habitats and conservation of hollow-dependent fauna. Coppicing and pollarding also leads to greater variation in woodland age structure that can be beneficial for biodiversity (discussed further in a later section).

4.2.3. Ringbarking

Ringbarking is another technique used to increase the structural diversity of woodland and volume of deadwood for conservation purposes (Agnew and Rao, 2014). Also known as girdling, ringbarking involves the complete or nearly complete removal of bark from around the circumference of a tree trunk or limb. This disrupts the movement of water and nutrients between the roots and the top growth and leads to dieback or death. The resulting decaying wood can be exploited by saproxylic invertebrates or other excavating species such as woodpeckers. It would not however benefit non-excavating species for example passerines such as great tits, for which creation of artificial hollows as described above would be more suitable. This technique is appropriate for recently planted woodlands that are depauperate in deadwood and have trees of a similar age.

An eight-year study of ring-barked Scot's pine on Mar Lodge Estate, Scotland, demonstrates that ring-barking can rapidly create structural diversity and a variety of deadwood, from course woody debris on the woodland floor to exposed standing deadwood (Agnew and Rao, 2014). Most ring-barked trees had presence of holes created by tunnelling invertebrates, whilst three quarters had woodpecker holes, in comparison to control live trees which were absent of holes. Invertebrate species were dominated by beetles that can bore into hard wood, whereas saproxylic fly species, which are highly associated with deadwood in soft and wet conditions, were largely absent. Recommendations include ring-barking trees in both small and large groups (1-15 trees per group in this study), ring-bark in regular temporal cohorts to maintain continuity of decay stages and consider size of woodland when choosing how many trees to ring-bark.

4.3. Species reintroduction, population reinforcement and assisted colonisation

Species reintroductions and population reinforcements for conservation objectives are increasingly seen as an important way to restore parts of the ecosystem that have been lost. Successful reintroductions require careful planning and execution, and for some species a process of many years of release and monitoring. The International Union for Conservation of Nature (IUCN) guidelines for reintroductions require a full feasibility study of the planned reintroduction. This includes ensuring issues such as the reasons for the original extinction or depletion have gone or been substantially mitigated, that there is sufficient suitable habitat to support a population, there are no critical conflicts with other species or habitats, and that a robust source population exists to provide the animals or plants needed for the reintroduction. Critically, any feasibility study for reintroductions should include a rigorous socio-economic appraisal and engagement with local communities and stakeholders.

Among the spectrum of types of translocations, 'species reintroductions' are the reintroduction of a species within its native range in which it has previously been lost, with the aim of re-establishing a self-sustaining population. Species reintroductions may be of direct importance for the conservation of that species – when there is habitat loss in the current range or where establishment of a second population would increase the genetic resilience of a nearby population. In other cases, it may be a keystone species in the functioning of a wider ecosystem – as a predator important for stabilising prey populations, an important part of the prey population for other animals, or in the way it impacts habitats and other species. ‘Population reinforcements’ also represent a form of reintroduction within the native range of a species, where although some individuals may remain, they are too low in numbers, or genetically too restricted, to sustain a population. In the context of newly established woodlands, it may be necessary to restore other elements of the woodland ecosystem beyond trees. It could take decades for flora, fauna and fungi to colonise these woods naturally, if at all. Assisted colonisation can speed this up – species can be translocated (moved from one site to another) and assisted to establish self-sustaining populations in the new site.

4.3.1. Animals

Species reintroductions and population reinforcements have been used to restore populations of mammalian species in the UK. European beaver (*Castor fiber*) went extinct in Britain in the 16th century, but reintroduction efforts have been underway since 2009 and there are now several controlled field trials across Britain. The restoration of sustainable beaver populations can have a positive effect on the wider ecosystem through the creation of wetland habitats that support greater numbers of invertebrates, amphibians, fish and birds, making them a keystone species (Law *et al.*, 2017).

Pine martens (*Martes martes*) have experienced massive declines, with small populations surviving in remoter areas of the UK. They have been the subject of population reinforcement, with individuals being translocated from their strongholds in Scotland. Pine martens need a well-connected habitat network of arboreal features – woods, well-formed hedges, riparian woodland and tree belts – to find food and denning locations, disperse from natal sites and establish new territories (Vincent Wildlife Trust, 2014). Creating these well-connected wooded landscapes to ensure a thriving pine marten population benefits many other species, including bats and small mammals, invertebrates and plants. Pine martens also play a role in suppressing grey squirrel populations, thereby aiding recovery of native red squirrel (*Sciurus vulgaris*) populations (Sheehy *et al.*, 2018). The red squirrel is a native mammal that is suffering steep declines due to compounding threats. It is an excellent flagship species for raising awareness and garnering support for conservation of woodlands. Red squirrels cannot move far across open ground; thus, translocation is important for establishing populations in suitable woodlands that they would not otherwise colonise naturally, such as the Woodland Trust site Ledmore and Migdale.

Hazel dormice (*Muscardinus avellanarius*) are another rare, legally protected species that has suffered population declines and range contraction, which is due to inappropriate woodland management and woodland fragmentation. Population reinforcement programmes have been running for over 25 years, set up in several locations to aid their recovery; see Bright and Morris (2002) for a protocol for dormice reintroduction based on experimental studies. Based on this accumulated knowledge, dormice reintroductions can be very successful. However, key to their long-term success is ensuring appropriate, active management of the woods, including reviving coppice rotations. Dormice are an important focal species for conservation efforts, as the conditions they require, such as diversity in structure and tree and shrub species, and connectivity between woodlands through hedgerows, benefit many other species (Bright and Morris, 1996).

4.3.2. Flora

Reintroductions and reinforcements have also been used for rare, protected native plant species. Chester Zoo, Cheshire, is involved with several conservation projects for native trees and plants, including black poplar (*Populus nigra* subsp. *betulifolia*) and common barberry (*Berberis vulgaris*), the larval food plant of the barberry carpet moth (*Pareulype berberata*) (Bird *et al.*, 2017). The Woodland Trust has undertaken translocation of the rare twinflower (*Linnaea borealis*), which is at threat from shading, overgrazing, and competition from other plants.

Besides conservation of rare flora in need of population reinforcement, there is also a case for introducing more common species to recently established woods for conservation purposes. Without this 'assisted colonisation' of woodland plants, woodlands that are isolated from other woods, and/or are established on agricultural land, often fail to develop characteristic woodland plant communities (Worrell *et al.*, 2018). These woods can become dominated by grass and agricultural weeds that outcompete woodland ground flora communities. This is clearly demonstrated by a study of two abandoned arable fields within the Rothamsted Experimental Station in Herefordshire that developed into mixed deciduous woodland by natural succession; after 100 years many locally characteristic woodland plants failed to establish populations, with few individuals present that are restricted to the woodland edge (Harmer *et al.*, 2001). Worrell *et al.* (2018) provide best practice guidance on plant introductions aimed at fostering the development of naturalistic and attractive plant communities in situations where this is unlikely to happen naturally. An analysis of understory community composition of 13 recent forest stands in Belgium, aged between 36 and 132 years and contiguous with the Meerdaalwoud ancient forest, found that competitive species and forest edge species dominated forests up to 90 years old, then their cover starts to decrease (Bossuyt and Hermy, 2000). Some forest species with very low colonisation rates still had low cover in recent forest over 105 years old, thus highlighting how assisted colonisation could speed up the development of recent forests to a more natural state that would otherwise take over a century.

4.3.3. Fungi and lichens

Fungi and lichens are extremely important yet overlooked elements of woodland ecosystems. Many are highly sensitive and vulnerable to the same threats as animals and plants. Wood-inhabiting fungi have largely declined due to woodland loss and reduction of deadwood.

One technique for establishing fungi in areas where populations need reintroducing or reinforcing involves transferring cultured mycelial growth to wood plugs of the host tree species. These are inserted into pre-drilled holes in dead trees or logs in the translocation site to introduce the fungi (Abrego *et al.*, 2016). Using this technique, Norway spruce logs in old-forests in Finland were inoculated with seven red-listed wood-inhabiting fungal species. All seven species established as mycelia within three years, and four produced fruit-bodies (Abrego *et al.*, 2016). Control plots showed that these colonisations were greater than would be expected than by background colonisation rate. However, this study was introducing fungal species that were rare or missing from woodlands that had a sufficient volume of deadwood to host these species. Newly established woodlands are lacking in deadwood resource, so this technique would not be available early in the management of a young wood. It would only be possible after some years of interventions to increase the volume of deadwood (see section on veteranisation). This management intervention has not been widely used and tested in the UK, so more research is needed before any recommendations or guidance can be produced on this.

Lichens are important ecological and environmental indicators influenced by climate change, air pollution and woodland management. They are also used for food, shelter and camouflage for many species of woodland fauna. As with other taxa, lichen translocation may be used to conserve rare species, or to introduce this aspect of a woodland ecosystem to newly established woods. There has been a long history of lichen translocation with varying success (Smith, 2014). Epiphytic lichens can be collected by removing some bark from trees upon which the lichen is growing, which is then glued to the trunks of trees that are absent of this lichen (Smith, 2014). There has been some success with transplanting fruticose, foliose and cyanolichens, but crustose and leprose species are difficult to remove. There is no set protocol to follow when designing a lichen translocation, but rather each case requires the development of methods based on a number of considerations as outlined in Smith (2014). As with fungi, this is a research area that requires further development.

4.4. Increasing structural complexity

Woodland management, or absence of management, has important consequences on internal woodland structure, which in turn influences habitat quality and conditions for other flora and fauna. Undermanaging broadleaved woodlands has been identified as a threat to species requiring open habitats (and higher light levels) or complex low vegetation structures. There are various techniques available to increase structural complexity in maturing woods to ensure a variety of niches and conditions are available to support woodland biodiversity.

4.4.1. Harvesting wood

Young woodlands planted (or regenerating) will have a high density of even aged trees. To accelerate the transition to a more diverse structure characteristic of late successional woodlands, selective harvesting techniques can be employed. The products from harvesting wood can be used to generate income.

Thinning is one such technique whereby some trees are removed to adjust density, species composition and age composition (through establishment of new trees in the gaps). This can be used as a conservation management approach to reinstate more natural woodland conditions. Commercial thinning as a timber management practice within forestry plantations is not discussed here. The literature on the effects of thinning on biodiversity is dominated by North America, with relatively fewer studies from European sites (Fuller, 2013). Sensitive thinning in mixed oak woodland in Sweden increased herb species richness by 4-31% after 1-2 years compared to paired undisturbed controls (Götmark *et al.*, 2005). Further work on the same research plots found that the average abundance of mycetophilid species associated with deadwood, wood fungi and saprotrophic fungi increased in thinned plots likely due to the increase of deadwood (Økland *et al*., 2008). Therefore, preserving the tops and branches from removed tree stems *in situ* can increase the biodiversity benefits of wood harvesting.

In a study by Carr *et al*. 2020, bats and their insect prey were sampled in UK Woodland Assurance Standard (UKWAS) managed broadleaved woodlands ('managed woodland', n=27) in England and Wales which were paired with woods that had not received any systematic management for over 20 years ('under-managed woodland', n=27). The managed woods had been systematically thinned in 10 to 15-year rotations, retaining 55-65% canopy cover. Woodland thinning positively influenced bat richness and overall activity likely due to opening up the interior more, providing better foraging conditions for edge and open foraging bats. Woodland thinning, however, reduced the number of tree cavities and dead trees, therefore limiting the availability of roost sites for bats. Consequently, variable effects of thinning were found depending on the species/species group. Common pipistrelle (*P. pipstrellus*) and serotine bat (*E. serotinus*) activity were all significantly positively influenced, with soprano pipstrelle (*P. pygmaeus*) showing a non-significant but positive trend, which was linked to the higher light levels in thinned woods. In contrast, barbastelle bat (*B. barbastellus*) was significantly negatively affected by management and long-eared bats (*Plecotus spp.*) and common noctule (*N. noctula*) showed non-significant negative trends. These are woodland specialist species that mainly dwell in tree cavities. To effectively use thinning to improve the value of woodlands for bats, 'positive selection' should be used whereby trees are removed that are competing with valuable trees that must remain, and an open and heterogenous canopy should result that encourages a species rich understory in a mosaic of open and dense patches. These findings are supported by Jung *et al.* 2012, who found positive effects of woodland structural complexity on the occurrence and activity of bats.

Coppicing and pollarding are other means of harvesting wood that create structural diversity in the form of a patchwork of different aged stands with substantially different amounts of light and woody biomass. These traditional practices have largely been abandoned over the last century since demand for wood fuel declined and agriculture was industrialised. Abandoning coppicing results in loss of understory and a simpler structure. Many species have become dependent on the conditions provided by coppiced woodland (Kirby *et al*., 2017); declines in many species of birds, butterflies and moths for example have been attributed to the cessation of this practice (e.g. Fuller and Henderson, 1992). Targeted conservation through active management, where habitat requirements and species ecology are well understood, can however reverse these declines – as for the heath fritillary butterfly (*Mellicta athalia*) (Warren, 1991). Management involved reinstating coppicing of a substantial area of the Blean Woods NNR, cut in small plots (1-5 ha) on a rotation of 15-20 years, which have been connected by a network of wide rides and permanent glades.

For coppicing to benefit the broadest range of woodland bird species, a mosaic of age structures should be maintained using coppice rotations, and management should consider the requirements of all age-classes at different times of year (Maccoll *et al*., 2014). This requires woodlands large enough to ensure continuity of each successional stage (Fuller, 2013). A full coppice cycle is also important for butterflies and moths to create the conditions and promote the understory species they require (Butterfly Conservation, 2011). Tree species composition is less important for butterflies than moths, as it is the ground flora that supplies their larval foodplants, whereas the larvae of many moth species do feed on shrub and tree species (Butterfly Conservation, 2011). As with birds, larger woodlands were found to offer the best opportunities to increase macro-moth diversity, particularly of common declining species, through active coppice management (Merckx *et al.*, 2012). Dormice are strongly associated with coppice woodland, requiring an unshaded understory with a high diversity of tree and shrub species (Bright and Morris, 1990). Importantly, dormice require small, dispersed patches of coppice, rather than large adjacent blocks, and a long rotation, as they are arboreal and so need continuity of branch connections. This contrasts with larger connected blocks of shorter rotation coppice for butterflies or birds (Fuller and Warren, 1993). Therefore, the conservation objective for coppice management must be clear from the outset – see Fuller and Warren (1993) for further guidance.

Both selective thinning and coppicing were shown to benefit breeding birds within a large working broadleaf woodland in lowland southern Britain (irregular stands and coppiced stands held higher densities of breeding birds than the limited intervention stands) (Alder *et al*., 2018). Heavy and moderate thinning of uneconomical mature trees within lapsed oak coppice-with-standards in the Czech Republic was undertaken to restore understory plant communities. In comparison to unmanaged controls, heavy thinning (removal of c. 70% of trees) led to the greatest increase in floral diversity ten years on, with an increase in both light-demanding oligotrophic species and native ruderal species, while moderate thinning (removal of c. 25% of trees) had mostly insignificant effects (Vild *et al.*, 2013). It is important to note that the evidence base for the biodiversity of coppice woodlands comes from mature woodlands that have a history of coppicing – whether the species and communities found in these would establish and thrive in younger woodlands that are managed as coppice (or whether they would require additional interventions first such as assisted colonisation) requires further investigation.

4.4.2. Rides, glades and woodland margins

Whilst many woodland specialists inhabit a wood's interior, the biodiversity value of a woodland can be enhanced by opening small areas through linear rides and small glades, and by re-sculpturing woodland margins. These techniques increase the amount of woodland edge available to species that depend on this for nesting, feeding and protection. The maintenance of open areas will require active management to prevent the establishment of trees and succession to woodland. This can involve manually removing midstory and ground-level vegetation.

Creation of glades, re-sculpturing the woodland margins, and creating shelter belts at Minsmere RSPB reserve in Suffolk led to an increase in the breeding nightjar (*Caprimulgus europaeus*) population from 8 to 23 churring males (Burgess *et al*., 1990). Rides, glades and woodland edges are important for some species of Lepidoptera – particular considerations and techniques for creating and managing these are given by Butterfly Conservation (2011). For further information on improving woodland habitat for wildlife, including woodland edge and open space see Blakesley and Buckley (2016).

Old oak-hazel woodlands in south-central Sweden that were managed by clearance, mowing and grazing had higher vascular plant and bird species richness than sites managed by mechanical clearing or were unmanaged (Hansson, 2001). Unmanaged (abandoned) woodlands were particularly low in breeding bird richness. Species richness was therefore highest in sites experiencing intermediate levels of disturbance.

4.4.3. Grazing with large domestic herbivores

Grazing by large herbivores can help to maintain open areas in woodlands, create structural complexity and enhance floral diversity. A study of 105 grazed and ungrazed seminatural woodlands across Northern Ireland found that grazed woods had increased botanical diversity and a reduction in cover of dominant species, such as bramble (*Rubus fruticosus* agg.) (McEvoy *et al*., 2006). Sheep grazing has been shown to control rank grass and weeds in plantations of oak and ash woodlands without causing significant damage to the trees, using two 5-day grazing periods 6 months apart (McEvoy and McAdam, 2008).

When including grazing in a woodland management plan, it is important to consider forage quantity and quality (Pollock *et al.*, 2005) as well as densities of wild herbivores (Blakesley and Buckley, 2016) and habitat use patterns (Pratt *et al.*, 1986). The right levels of herbivory will ensure the maintenance of earlier successional stages. However, in some cases, woodland grazing may hinder the successful recruitment of trees and shrubs and negatively impact the populations of other species groups. This is illustrated by exclusion experiments, where vegetation composition is compared between unfenced areas and fenced areas (‘grazing exclosures’). Exclosed areas in a hillside alder woodland at Coedydd Aber in North Wales had high densities of young ash as well as a well-developed field layer 20 years after fences were erected, with significantly higher cover of plant litter, deadwood, bryophytes and woodland species. In contrast, unfenced woodland areas where sheep and ponies had unrestricted access had virtually no tree regeneration and a sparse field layer (Latham and Blackstock, 1998). Similarly, oak was able to successfully regenerate in exclosures protected from sheep grazing (Pigott, 1983).

It has long been recognised that appropriately managed domestic stock grazing can enhance woodland biodiversity. The Forestry Commission provides detailed information on the feeding preferences and behaviour of different domestic species, the consequences of that for woodland habitat (flora, tree regeneration and structure) and the impacts on biodiversity (Mayle, 1999). Stocking levels, breed choice, timing etc. are heavily site-specific and dependent on management objectives. An individual management plan which includes a grazing regime is therefore essential before introducing grazing animals (Blakesley and Buckley, 2016) – see the Woodland Grazing Toolkit (Sumsion and Pollock, 2005). Peer-reviewed literature on the effects of grazing in woodlands on biodiversity is thin, probably because it is so site-specific. There will be a wealth of examples from practitioners implementing grazing regimes on their sites, but these are largely unpublished. But essentially, grazing is simply a tool to create the conditions required for certain species, so if the ecology of the target species is known, the appropriate type and level of grazing can be put in place.

5. Recommendations for future research

Some evidence gaps were highlighted throughout this review, which are summarised below:

- Studies on bird and bat boxes often only measure occupancy by a species, not reproductive success, which is the ultimate determinant of their effectiveness for conservation. Longer-term studies are needed on population-level responses to provision of boxes compared with no provision.
- Studies on bird and bat boxes in young woodlands, as opposed to mature woods, are lacking.
- UK-based research on the use of more pioneering methods of creating deadwood habitats, such as chainsaw hollows and ring barking, for biodiversity conservation is needed.
- Assisted colonisation of flora, fungi and lichens is another management intervention that is underutilised and poorly studied in the UK.
- Evidence for the effects of coppicing and pollarding on biodiversity comes from mature (or even ancient) woodlands that have a long history of coppicing. Studies on recently established woodlands that are managed as coppice are needed to assess whether the same species and communities would establish and thrive there, or whether they would require additional interventions first such as assisted colonisation, for example in the case of ancient woodland indicator species.

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