Evidence review: How effective are alternatives to plastic tree shelters for establishing new native trees and woodland?

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Abstract

1. In recent decades, plastic tree shelters have been used to great effect to provide protection to individual planted trees in created woodlands. However, at the end of their useful lives (3-5 years), these shelters are difficult to collect, rarely re-usable or recyclable and form a source of plastic pollution in the environment. This review assesses the evidence on the effectiveness of alternative tree protection methods, as well as their potential impact on the biodiversity of created woodlands.
2. Young trees can tolerate low intensity browsing, but few published studies directly compare non-intervention to active protection methods in woodland creation. Similarly, the effectiveness of herbivore culling compared with tree shelters has not been directly established. However, culling (e.g. deer) is not thought to be practical for small-scale woodland creation projects. Fencing can be an effective solution, especially in combination with active deer management, but the cost for widescale usage is prohibitive on large sites.
3. High density planting (HPD) and direct seeding can improve survival rates, cover or vigour of saplings, but their efficacy still depends on a measure of herbivore control via fencing or culling. Woodland creation via natural regeneration can rapidly increase vegetative cover but lacks experimental evidence to date.
4. Alternative-material tree shelters are in their infancy and do not present a realistic solution at this stage. There are small-scale schemes to collect and reuse plastic tree shelters, but this still ultimately presents an end-of-life issue. Anti-herbivore paint needs frequent re-application during establishment and is not practical or cost-effective on a large scale.
5. There is a lack of evidence that plastic tree shelters, or any of the other methods, affects the biodiversity value of created woodlands on a long-term basis. However, preliminary evidence suggests microplastics can impact the woodland soil ecosystem (e.g. earthworm ingestion). It is prudent, therefore, to continue research in alternative tree protection methods, as well as improving the re-use or recycling of existing plastic shelters.
6. Overall, widespread herbivore culling is likely to have the most benefit on a landscape scale, both as a tool for woodland creation and in ongoing management.

1. Introduction

To respond on sufficient scale to the biodiversity and climate crises in the coming years, vast new areas of woodland will need to be created. This intervention must be effective for producing the desired outcomes of large-scale carbon sequestration and biodiversity conservation, without increasing harmful environmental side effects of current tree planting techniques. A major challenge when aiming to establish new trees is the impact of herbivores. Several species of herbivorous mammal cause problems with tree establishment in the UK, including voles, rabbits, hares, deer and livestock (Pepper & Hodge, 1998). Deer are present at especially high population densities in most regions of the UK (Mitchell & Kirby, 1990), as their populations are unchecked by natural predation. Therefore, to successfully establish trees, some form of protective measure is normally necessary (Gill & Morgan, 2010).

In the last few decades, the invention of plastic tree shelters has provided the option of individual tree protection. Their use is recommended in Forestry handbooks and guidance documents (e.g. Hart, 1991; Pepper & Hodge, 1998; Savill, 2000) and they have become an important part of standard practice in woodland creation projects. The use of plastic tree shelters has been very successful, and they are effective for enabling trees to pass through the establishment phase with reduced likelihood of suffering browsing damage (Davies, 1985). Plastic tree shelters increase the rate of tree growth by creating a miniature greenhouse effect around the planted tree in addition to reducing damage by herbivores. They also have many other practical and financial advantages, including protection of the tree itself from exposure to herbicides used for weeding (Pepper & Hodge, 1998) and allowing the use of smaller planting stock, which are cheaper. Most importantly, the use of plastic tree shelters in combination with herbicides has led to greater survival rates for planted trees (Sharkey, personal communication, 2020).

The key to the success of plastic tree shelters is their durability in field conditions. Hart (1991) recommends a life of at least 5 years, so that the tree can grow out of the top and it can continue to give support and protection for the next couple of years. Until recently, forestry guidance did not consider the management of the plastic shelters at the end of their useful life, in fact the same handbook recommends that 'The tree shelter should remain around the tree until it disintegrates which should be between 5 and ten years'. It is now widely known that plastics disintegrate into long-lasting pollution in the environment. Single-use plastics are at the heart of current environmental debate, and tree shelters are a highly visible example of a single-use plastic. They are far from the perfect solution for tree protection that they once appeared. All industries and organisations must look seriously at their use of plastic. Environmental organisations which rely on public support risk damage to reputation through their use, and risk losing public support for tree planting projects if a response isn't found (Yorkshire Dales Millennium Trust, 2019).

Trees without shelters can survive some level of browsing. A classic experiment with oak and sycamore seedlings demonstrated that, although growth was reduced in comparison to those protected with tree shelters, the survival of unprotected trees after 2 years was still 97% for oak and 81% for sycamore (Davies, 1985). These survival percentages are from a sample of 64 unprotected saplings, which received no herbicide application. Furthermore, in a planting experiment using nursery-reared seedlings, Iszkuło et al. (2014) found high sensitivity of yew samplings to light levels, but with a relative tolerance to grazing. However, the level of browsing intensity of this experiment may not reflect conditions in the UK.

Browsing by herbivores reduces tree growth rate. The speed of recovery depends on the severity of the damage, and repeated browsing may never allow trees to grow above browsing height. Increased frequency and severity of damage increases the chance of mortality. Younger trees are more vulnerable than older trees, but the threshold age/size depends on species and site conditions. Trees can show some compensatory growth either within or between individuals in response to browsing, and broadleaved species appear to be relatively resilient to browsing compared to coniferous species due to the distribution of dormant buds which are able to produce new growth after apical shoot loss. The loss of apical stem (leader) causes a multi-stemmed or forked tree due to the loss of apical dominance (Gill, 1992a). Stem forking is considered a negative outcome when the objective of a plantation is timber production, but when the objective of a plantation is for biodiversity conservation, leader browsing and resulting loss of apical dominance needn't necessarily be viewed as a failure. On the contrary, browsing pressure in a tree's early life may even lead to a diversity of growth forms in later life – potentially improving the structural diversity of the resulting woodland (Barkham, 1978; Mitchell & Kirby, 1990). However, when side shoots become dominant, growth is likely to be horizontal rather than vertical, increasing the risk of mortality from prolonged repeated browsing on shoots before they can reach above the browse-line. For this reason, on Woodland Trust woodland creation sites, the aim is currently for leader damage of below 15-20% of trees planted. To achieve this in most areas of the UK requires some form of young tree protection due to the density of herbivore populations (Harrower, personal communication, 2020).

This review discusses the evidence for the effectiveness of alternative methods of young tree protection.

2. Methodology

This review was conducted using Collaboration for Conservation Evidence's recommended guidelines and standards for evidence synthesis (CCE, 2018). Microsoft Academic, Google Scholar, Google, and BASE were searched using a search string with "tree shelter" or other variations of the name of the product, such as "tree guard" and the alternative intervention. Where searches returned results consistently from studies in the tropics, the terms AND "UK" OR "Britain" NOT "tropic*" were added to refine results. Reference lists were checked to identify additional studies and included where relevant. Only papers that referred to newly planted trees of species native to the UK were included for review, and studies from a UK context were preferred. However, to extend the number of suitable studies, those carried out in a non-UK setting were included providing their study tree species was also native to the UK. These were largely restricted to European studies. Where evidence is from outside the UK this is identified in the text. Evidence produced with objectives driven by commercial forestry as well as that applied to conservation/amenity tree planting was included as long as at least some of the study tree species were native to the UK. Diverse evidence sources were included, such as primary experimental studies, literature reviews, grey literature, unpublished field trials etc. Literature was not filtered by date.

To obtain knowledge and expertise from Woodland Trust staff and external contacts, a request for evidence was sent out via email to a list of stakeholders across all four countries of the UK. Notes were taken from informal interviews. Grey literature was searched via Google and BASE, and any form of grey literature was considered for inclusion if relevant.

3. Results

3.1. Herbivore control

An option for reducing grazing pressure on tree establishment is to reduce the local herbivore population. In lowland Britain, seedling density was negatively correlated with deer density, and maintaining a maximum population of ~14 deer/km^2 could help 120,000 larger seedlings survive in the same area (Gill & Morgan, 2010). Although this is less than half the density normally used for intensive timber production (250,000 seedlings/km^2), it may be sufficient to create a relatively open structured woodland for biodiversity and amenity objectives. In the uplands, the estimated threshold for natural regeneration is <4-5 deer/km^2, perhaps due to lower productivity (Putman et al. 2011). Sheep grazing is also a predominant landscape feature in upland regions. In an upland grazing experiment, ~75% of naturally regenerating saplings escaped being browsed with a summer grazing density of 0.6-1.2 sheep/ha (Hester et al. 1996). The same stocking density on winter grazed plots led to around half of saplings suffering browsing damage, with plants being less able to recover (Hester et al. 1996).

There have not been any controlled trials directly comparing the relative effectiveness of deer management with that of plastic tree shelter use on the survival rate of saplings. Deer control is frequently suggested as the most desirable long-term solution in forestry and conservation contexts because the intervention influences the whole ecosystem rather than being limited to the trees themselves (Mountain Woodland Project, n.d.; Savill, 2000). However, there are many practical considerations to consider, and deer culling is most suitable for large woodland creation projects (Harrower, personal communication*,* 2020).

Voles are also a serious threat to tree establishment (Gill, 1992b). There are no legal methods to directly control vole populations with culling (Pepper & Hodge, 1998); therefore, any control of vole populations must involve habitat management. Vole populations thrive in open areas with dense ground vegetation (Gill, 1992b); conditions which describe most woodland creation sites. Usually, vegetation around the base of planted trees is removed using herbicides, which has the benefit of removing cover for voles (Davies & Pepper, 1993; Gill, 1992b), but the use of herbicides is also controversial from an environmental perspective. An alternative method to limit vole damage could involve manipulating the species of ground cover plants at woodland creation sites. For example, a Czech study showed that vole damage to beech and rowan saplings increased with grass cover around the tree but less so with herbs or bramble cover (Heroldová et al., 2012).

Sowing a no-grass herbaceous wildflower seed mix (Glen et al., 2017) could potentially create conditions less conducive to high vole occupancy compared with traditional grass ground cover sowings, but this requires new research. Trial areas of unprotected tree planting on sites with non-grass ground cover would be necessary to test the strength of any protective effect for trees compared with conventional woodland creation sites. The encouragement of vole predators via the installation of raptor perches (Machar et al., 2017) and raptor nest boxes (Paz Luna et al., 2020) has successfully reduced vole abundance in experiments in mainland Europe, but trials demonstrating their effectiveness in UK settings are lacking. Despite this, the practice is already used by UK foresters, but is usually considered a complementary intervention (Harrower, personal communication, 2020; Jacyna, 2017). These measures are aligned with improving the conservation interest of a site.

3.2. Herbivore fencing

Fencing is a traditional method of protection that prevents browsing damage by restricting herbivore access to the planting area. This method has been used extensively on the Woodland Trust estate; including deer, deer and rabbit, and rabbit-only fence designs. The experiences from the Woodland Trust estate show that fencing is not a fail-safe solution. In some cases, small tree shelters are still needed within enclosures to protect against voles or rabbits. Deer and rabbit culling is still necessary for individuals caught within the fenced areas when fences were erected and subsequent break-ins (Sharkey, personal communication, 2020). Fencing is not considered a long-term solution by foresters (Savill, 2000) or conservationists (Harrower, personal communication, 2020), as it fails to deal with the core problem: the overabundance of deer. There are concerns about the impact on local deer populations and their movement, which can increase pressure on the surrounding land. Fencing may simply move the problem rather than deal with it.

There are aesthetic, practical and financial considerations associated with fencing which are discussed in detail in forestry guidance (Mountain Woodland Project, n.d.; Pepper & Hodge, 1998; Trout & Pepper, 2006). Fencing is generally considered a good option for medium sized sites, but is inordinately expensive for small sites, where plastic tree guards would be more economical. According to Pepper and Hodge (1998), fencing becomes more cost effective than individual tree protection at a minimum area of approximately 2ha, assuming 1000 saplings/ha, and the target herbivore species is roe deer. This calculation was based on prices of tree shelters and fencing from over 20 years ago; however, the latest guidance now states 3ha is the minimum advisable area to fence (Forestry Commission, 2020). An important evidence gap concerns the survival rate of trees planted inside fenced areas compared to trees in shelters. Fencing is not able to protect against small mammals such as voles (Pepper & Hodge, 1998), suggesting it would not provide such effective tree protection as tree shelters, which although not 100% vole-proof, do provide a relatively good level of protection (Davies & Pepper, 1993).

Even if the use of fencing reduces (or eliminates) the need for plastic in tree planting, it cannot be assumed that the environmental impact of producing and disposing of fencing is smaller than that for plastic tree shelters. A life-cycle analysis suggests the production of steel fencing has a higher carbon footprint than the production of polypropylene shelters to protect a 10ha plantation (Arnold and Alston, 2012). However, this analysis does not account for the greater possibility of re-use for temporary metal fencing compared with plastic shelters (Trout and Pepper, 2006). In principle, if trees are planted at a set density, there may be a given area at which the carbon footprint of a steel perimeter fence would be exceeded by the carbon footprint of plastic shelters. This threshold area is not presented in the analysis by Arnold and Alston (2012).

3.3. High-density planting

High-density planting (HDP) involves planting more trees than are expected to survive, to compensate for a percentage of losses due to herbivores. The Forestry Commission (2020) advises HDP without any protection in small areas (<3ha) or where herbivore populations are naturally low or being controlled. There is, however, no evidence to suggest what the minimum planting densities are in this situation. HDP without protection is not recommended in areas with high herbivore densities, or areas large enough to warrant investment in fencing (>3ha) (Forestry Commission, 2020). Several studies from abroad have shown increased success of tree recruitment if initial density of seedlings is high: perhaps due to the effects of competition on foliar nutrient content (Gill, 1992a). Note that these studies were conducted under different herbivore communities and densities to those found in the UK. Trials are needed to test whether the option of HDP could reduce reliance on plastic tree shelters, and whether the increased requirement for saplings would cause supply issues. An additional suggestion is to trial a matrix of less palatable species such as birch, with clumps of more palatable trees shielded within the matrix (Harrower, personal communication*,* 2020).

3.4. Direct seeding

Direct seeding is an alternative method of woodland creation which aims to aid the process of natural regeneration by artificially introducing seed to a site. The evidence base for direct seeding in UK woodland establishment is limited compared with what is known about traditional planting. The most comprehensive guidance on direct seeding for broadleaved woodland creation to date is provided in Willoughby et al. (2004a). This guidance reports that direct seeding can be successful in specific contexts and recommends appropriate silvicultural techniques. However, increased competition between seedlings also increases variability (Willoughby et al., 2004a). Oak, ash, sycamore, wild cherry, field maple and birch were confirmed as suitable species by Willoughby et al. (2004a) but this has since extended to rowan, alder, sweet chestnut and a wide variety of native shrub species (Willoughby and Jinks, 2009; Willoughby et al., 2019). A breakdown of the price of direct seeding compared with traditional planting is also provided in Willoughby et al. (2004a). Direct seeding is recommended for creating new broadleaved woodland on good quality, well-drained lowland sites with low populations of seed predators (for example, improved grassland or arable sites, or possibly well-restored brownfield sites). More recent work has also demonstrated success with direct seeding for re-stocking clear-felled upland sites with broadleaves, even with significant numbers of seed predators known to be present (Willoughby et al., 2019).

Early reports (e.g. Watson, 1994) suggested the combined use of arable/wildflower cover crops and direct seeding would be sufficient to overcome the problem of browsing without further intervention. However, more recent experimental evidence fails to find a protective benefit from cover crops or diversionary vegetation (Willoughby et al., 2004b). Consequently, the standard recommendation for protecting sown areas against browsing mammals is to always use at least rabbit fencing, and combined deer/rabbit fencing where deer are present (Willoughby et al., 2004a).

Voles, too, may cause damage; particularly once trees are established. However, given adequate seedling densities (>10,000 seedlings/ha), losses from vole damage are low (Willoughby et al., 2004a). The rapid canopy closure made possible by direct seeding leads to the shading out of ground vegetation within a shorter time frame than with planted trees (Willoughby and Jinks, 2009). This could reduce vole habitat at the crucial stage of tree development, but to date this hypothesis is untested.

So far there is no evidence that the larger number of seedlings produced by direct seeding will mitigate browsing by rabbits and deer, so areas with herbivores must be fenced or herbivores must otherwise be controlled (Willoughby et al., 2004b). Fenced areas have been shown to be more cost effective when combined with direct seeding rather than leaving to naturally regenerate, as woodland established much more quickly and successfully (Willoughby et al., 2019).

Some unpublished case studies of direct seeding on Woodland Trust sites can provide anecdotal insight into the practical application of direct seeding, and the level of success with removing plastic tree shelters from the woodland creation process. At Comfort's Wood, Cranbrook, Kent, an ex-arable area with rabbit fencing was direct seeded in 1991, alongside a conventionally planted area protected with 90cm plastic tubes (Tucker, personal communication, 2020). After 12 years, the directly seeded area had developed into dense woodland dominated by oak with a good shrub understorey. Stocking and form were very good (2-5 trees/m^2 and 5-6m tall), and direct seeding led to a greater degree of canopy closure than the conventional planted area. The successful result at Comfort Wood suggests that direct seeding combined with rabbit fencing can be an effective method of woodland creation at sites without deer pressure.

At Penguin wood, another direct-seeding trial site in Derbyshire, a wildflower mix cover crop was tested in combination with deep-plough soil inversion. Traditional planting in plastic tree shelters took place at the same time on adjacent land, and both areas were protected with rabbit fencing. In contrast with Comfort Wood, the directly seeded area at Penguin wood has developed a diverse open structure after 13 years (Logan, personal communication, 2020). The differing outcomes from the two sites highlights the variability of direct seeding in comparison with traditional planting. Both also provide examples where rabbit fencing was able to successfully replace plastic tree shelters, leading to quality woodland creation for biodiversity (Porter, personal communication, 2020).

Overall, the available evidence suggests direct seeding can be an effective means of creating native woodland in suitable upland and lowland areas, with potential to completely remove plastic tree shelters from the process, providing that appropriate fencing or herbivore control is in place. Currently, a constraint to the use of direct seeding for native woodland creation in the UK is the lack of a substantial, contemporary UK evidence base for its application. However, this is expected to be addressed in the coming years, as more trial sites are established, and improved techniques are developed for sowing and seed treatment (Waterson, personal communication, 2020).

3.5. Natural Regeneration

Natural regeneration is an alternative method of establishing native woodland (here 'natural colonisation' is included in this definition), but naturally regenerating saplings are also subject to herbivore pressure (Gill, 1992a), so protection via fencing or herbivore reduction may be needed to allow natural regeneration. Natural regeneration has been shown to achieve tree densities to those produced by planting (Harmer et al., 2001; Spracklen et al., 2013).

Interestingly, in the Czech Republic, unprotected wild beech and rowan saplings were less prone to vole damage than unprotected nursery saplings. This may reflect the use of fertilisers in nursery production leading to highly palatable and nutritious seedlings compared to those regenerating naturally (Heroldová et al., 2012). This finding invites further investigation in a UK context.

Quercus robur saplings can survive in open areas if protected from large herbivores by association with blackthorn (*Prunus spinosa*) a spiny, thicket forming shrub which acts as a pioneer nurse species (Bakker et al., 2004). This ecological interaction (known as associational resistance) was experimentally demonstrated to be as effective as fences at protecting oak saplings from large herbivores. However, *P. spinosa* shrub cover is probably less effective against smaller herbivores such as rabbits and voles. At high population densities they are likely to eat the young *P. spinosa* before it has developed spines, preventing the shrub from expanding clonally to form the correct structure needed to protect oak saplings from larger herbivores. Nevertheless, there is great potential to use this ecological interaction to deliver woodland creation through natural regeneration with reduced need for artificial tree protection.

Natural regeneration is influenced by a wide range of interacting biotic and abiotic factors, including proximity to seed sources, tree species present and soil and weather conditions (Harmer, 1995). The poor understanding of regeneration in temperate European woods remains an important evidence gap across the whole forestry and conservation sector. However, a recent study of rewilding on ex-agricultural sites at Monks Wood National Reserve, Cambridgeshire, found rapid establishment post-abandonment, and after 60 years new woods approached the maturity and species diversity of nearby ancient semi-natural woodland (Broughton et al., 2021).

3.6. Non-plastic individual tree shelters

Recently, there has been a surge of non-plastic and non-single-use plastic tree shelter products hitting the market. The range of alternative materials includes cardboard, flax and cashew nut oil resin and biodegradable plastics (biopolymers) such as polylactic acid. A few small-scale trials of these products have taken place (Middleton, n.d.; Reforesting Scotland, 2020; Yorkshire Dales Millennium Trust, 2019). More extensive trials are required to assess longevity and the nature of their breakdown in the field, and the current state of evidence does not support non-plastic tree shelters as a realistic solution for the foreseeable future.

3.7. Other approaches

3.7.1. Household plastic-waste shelters

A single site study at a nature reserve in the south of the UK found that reclaimed plastic bottles and single-use plastic containers made from polyethylene (PE) could be effective against vole damage for long enough for trees to become established (4 growth seasons) (Williams & Northcroft, 1994). Additionally, the collection of reclaimed containers acts as a good community engagement exercise (Williams & Northcroft, 1994). This technique could have some use for small-scale community plantings where voles are identified as the main threat or used in combination with deer fencing. Negative public perception of household plastic items as an eyesore/litter in the environment is a potential drawback. In addition, the containers are not designed to split open like commercial tree shelters so must be checked regularly and removed as soon as they are redundant. The containers may not be fit for recycling after 4 years in the field, but this is also the case for commercial plastic tree shelters (Sharkey, personal communication*,* 2020). This method may be useful for small planting areas where community volunteer engagement is high and can be sustained for the duration of the tree establishment phase.

3.7.2. Anti-herbivore paints

In a trial on 3-5-year-old trees, anti-herbivore paint applied to tree stems was successful in deterring sheep damage in an agroforestry setting (Eason et al., 1996). However, in the earlier establishment phase, tree growth was observed to split the paint covering the bark, exposing unprotected areas, and reducing the protection. For the early years of establishment, the paint would need very regular re-application to maintain sufficient protection, making it practically unfeasible on a large scale.

3.7.3. Soil inversion site prep

Soil inversion is a cultivation technique which has been trialled on the Woodland Trust estate and elsewhere in the UK (e.g. Landlife, 2008), but has not undergone rigorous testing. Soil inversion involves deep ploughing (1m depth) to bury fertile topsoil, after which a ground cover wildflower seed mix can be sown. On light soils, Landlife (2008) observed faster tree growth, and higher survival rates with soil inversion than with traditional forestry techniques; this is potentially due to reduced weed competition and enhanced drought tolerance of trees. There is no direct evidence that trees on soil inversion sites would be less vulnerable to browsing, but an increased growth rate has potential to reduce the duration of the vulnerable establishment phase. Further, Landlife (2008) recommend planting fewer trees to compensate for the higher survival rate on inversion sites, but this is based on limited evidence. Since carbon sequestration is a major objective of woodland creation, it is also important to quantify the impact of invasive cultivation technique on soil carbon fluxes.

3.7.4. Reducing, rather than eliminating, plastic use

Harrower (personal communication*,* 2020) suggests using tree shelters on a certain percentage of trees planted and allowing the increased risk of losing unprotected trees. This would ensure at least a minimum density of reliable establishment, avoiding the risk of complete site failure. Another suggestion is to reduce the volume of plastic by using smaller shelters in conjunction with protection measures against larger herbivores such as vole guards within deer/rabbit fenced areas, or plastic rabbit spirals in conjunction with deer culling (Sharkey, personal communication*,* 2020). However, it is important to choose shelters that offer full protection from the herbivore threat present at the site, otherwise there is the risk of wasting the plastic altogether.

3.7.5. Recycling traditional plastic tree shelters

Recycling of shelter tubes is currently very difficult; there can be issues with the condition of the tubes, the ease and cost of collecting, and the logistics required to place the tubes into the recycling market. Any future recycling of tubes is likely to need a co-ordinated and specialist recycling chain (Sharkey, personal communication*,* 2020) with manufacturers of plastic tree shelters responsible for recovering and recycling them, or woodland creation grants covering the recovery and recycling element (Yorkshire Dales Millennium Trust 2019). There is also a need to identify the key criteria in terms of the types of tubes that will best serve the tube manufacturers, tree planters and the end use/recycling sectors. For example, determining whether the goal is for shelters to decompose fully in the field or be truly long-life and fully recyclable, with a way of ensuring collection takes place. In some cases, it has been possible to collect and reuse tree shelters up to 2-3 times. Such schemes are usually small scale and local, but this could reduce the environmental footprint of otherwise single use plastics. However, end of life issues for such tubes still remain (Sharkey, personal communication*,* 2020).

3.8. The impact of tree protection on biodiversity outcomes

As discussed above, plastic tree guards, fencing and herbivore control can all be of use for establishing trees. But do these options of tree protection have equal outcomes with regards to the quality of the resulting woodland for biodiversity?

A potential drawback of plastic tree shelters is the negative impact on biomass allocation to the roots due to lack of wind stimulation. This effect has been demonstrated in a small experiment with sweet cherry (*Prunus avium*) saplings. Unsheltered saplings (n=10) allocated 60% of their biomass to roots after one growing season, compared to 37% in sheltered saplings (n=10; Coutand et al., 2008). However, it is unknown whether this would affect the long-term growth patterns of trees, and what consequences this might have on the biodiversity of planted woodlands.

Although it is well established that soil is a key element of woodland ecosystems (Woodland Trust, 2016), research on the impact of plastic pollution on soil ecosystems is in its infancy. Most studies so far have focussed on earthworms as a model organism for the soil environment, and preliminary findings suggest microplastics are ingested by earthworms, with effects on their biology, and the potential for transfer through the food chain (Chae & An, 2018). Although plastic tree shelters are only one relatively small source of plastic pollution, these findings would suggest that avoiding plastic use in new woodlands, and/or removing it before it enters the soil, will be a positive move for their future ecological health.

Methods of tree protection which involve reducing, rather than eliminating tree loss to herbivores appear the most promising for improving the biodiversity of the site. Low level grazing in some woodlands promotes biodiversity when compared with the absence or surplus of grazing (Mitchell & Kirby, 1990). A moderate level of tree loss could lead to young woodlands which are low density, patchy, with structural complexity in the first few decades (Kirby, personal communication*,* 2020; Broughton et al., 2021). Structural heterogeneity of trees and understorey cover strongly influences the abundance and species richness of some woodland-associated insects – as observed across 78 secondary woodland sites created within the last 160 years (Fuller et al., 2018).

Tree shelters only protect new trees from the impacts of herbivore overabundance, rather than protecting the habitat. In the long term, the aim will be for woodland creation sites to develop a self-sustaining ground flora of high conservation value. As 40% of existing native woodlands in Britain are in unfavourable ecological condition with regards herbivore damage (Forestry Commission, 2020), widespread herbivore control in both establishing and mature woods is likely to have the most biodiversity benefit of all the methods discussed (Mitchell & Kirby, 1990).

A good understanding of herbivore damage (or lack there-of) in newly establishing woods is important for achieving biodiversity objectives but this knowledge is lacking from the literature (Gill, 1992a). Kirby (personal communication*,* 2020) suggests grazed open woodlands will benefit shrub species, tall grasses and herbs, which are likely to attract insects and small mammals and provide feeding areas for bats for several years. On the other hand, dense tree growth in protected situations will rapidly produce a shaded understory; this can lead to loss of shrubs and open ground plants but produce favourable conditions for shade specialist plants such as ferns and cuckoopint. Overall, Kirby (personal communication*,* 2020) suggests differences in ecological outcome due to initial seedling density are short-term and adjust as woodlands mature.

4. Conclusion

Plastic individual tree shelters are effective for establishing trees. Although there is no specific research on the impact of tree shelters, preliminary evidence suggests that plastic pollution can have impacts on the soil ecosystem. The use of tree shelters may also reduce the incentive for effective herbivore management, which could ultimately lead to declines in woodland condition. However, there is no evidence that their use leads directly to wood structures or quality issues.

The widespread awareness of plastic pollution is relatively recent, and due to the heavy reliance on plastic tree shelters over many years, there is currently little empirical evidence quantifying the effectiveness of alternative methods for tree establishment. If the future of woodland creation is to be plastic free, the largely anecdotal evidence which is available suggests sustained deer control at a landscape scale has the greatest potential for achieving long term reduction in browsing pressure. Sites over 3ha in area could benefit from fencing, but this must be in combination with herbivore management and sustained maintenance.

Within fences, alternative methods of woodland creation such as direct seeding and natural regeneration are possible. On small sites, where effective culling is not feasible, and fencing is prohibitively expensive, plastic shelters remain the cheapest and most effective solution. However, the forestry and conservation sector should work closely with manufacturers to decide whether research on biodegradable shelters, or overcoming barriers to the collection, reuse or recycling of traditional plastic shelters, is prioritised. Any new method of tree protection involves risk to the survival of individual trees, and grants/support schemes need to move to a longer-term target of 'woodland created' rather than sapling survival rates to give tree planters the confidence to innovate with new alternatives.

5. Recommendations for future research

Recommendations for future research include:

- Collating unpublished evidence on natural regeneration.
- Expand research into direct seeding in woodland creation schemes, with and without herbivore control.
- Well-replicated and geographically distributed trials to quantify the benefits of herbivore control. For example, comparative plots of trees planted with shelters vs unprotected plots, both in high deer-density areas vs areas where deer/other herbivores are controlled to a known level.
- Surveys of vole abundance on woodland creation sites with wildflower cover crops compared with traditional planting, and trials monitoring the effectiveness of raptor hunting perches and nest boxes on vole populations.
- Furthering the initial research on soil inversion/deep plough techniques. For example, investigating the impact of cultivation on soil C stocks, understanding the role of soil inversion in natural regeneration and quantifying the value of enhanced tree growth in soil inversion sites.
- Feasibility assessment of sapling supply chain to meet demand for HDP on a large scale.
- Trials of alternative-material shelters in UK field conditions.

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Conflict of interest statement

The author declares no conflict of interest

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