Forest Research

Woodland Establishment Costs in England: A Review

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Executive Summary:

With 14.5% forest cover, England ranks among the least forested countries of Europe. In line with its carbon net-zero ambitions, the government aims to increase both woodland cover and trees outside woodland in England to 16.5% by 2050. However, the lack of data on woodland establishment costs is a significant obstacle to encouraging landowners to plant more woodlands. This review addresses this gap by providing guidance and costs estimates derived from unpublished field data, academic literature, and publicly available datasets. The costs are categorised across five major expenditure areas, ranked from most to least expensive: wildlife management, infrastructure, planting, vegetation control, and ground preparation. Whilst care has been taken to ensure the figures in this report accurately represent the costs of woodland establishment and individual items, actual costs may vary due to factors such as woodland types, suppliers, contractors, and regional wage disparities. The figures provided are intended as a guide and cannot replace calculations based on specific project conditions.

To better test the impact of individual item costs, illustrate the influence of various variables on woodland establishment costs, and offer realistic estimates, eight case studies were produced. These case studies were derived from sixty England Woodland Creation Offer (EWCO) cases provided by the Forestry Commission. The eight case studies are split into two categories: average and specific. The average case studies (see table 2 and appendix 1) provide average establishment cost estimates for broadleaved and for coniferous woodlands in England, for the range of projects applying for EWCO grants within these categories, providing a useful reference for costs to adopt for these in wider analyses. The specific case studies (see table 3, 4, and appendix 1) illustrate how factors like fencing types, stock

densities and slopes, affect woodland creation costs. The average case studies suggest that in England:

- Establishing and maintaining a one-hectare broadleaved woodland costs between £17,000 to £19,000 (mean £17,800) over a 100-year period, which is roughly the duration of a single rotation for productive broadleaved woodlands. A one-hectare coniferous woodland costs between £12,700 and £14,200 (mean £13,400) over a 50-year period (one rotation period for conifers). Differences partly reflect the costs in the first year being around 50% higher for broadleaves than for conifers, and there being less concern, or need for, protection of coniferous woodlands against wildlife, with fewer tree guards and fences tending to be used.
- Larger woodlands generally have much lower establishment costs per hectare compared to smaller ones due to economies of scale (savings from buying in bulk). Notably, fencing costs per hectare decrease as the size of a woodland increases. Economies of scale also apply to purchasing tree guards and mulch mats, with prices reduced by up to 15% when buying in bulk, depending on suppliers.
- The estimates in Table 2 below (see also: Appendix 1), illustrate the impact of these economies of scale on woodland creation costs: the cost per hectare decreases by over 22% between one and two hectares and again by over 10% between two and three hectares. Economies of scale are less marked beyond 7 hectares, with a decrease in establishment costs of approximately 1%-2% per hectare as the size of the woodland created rises by an additional hectare.

The specific case studies indicate that:

- Wildlife management, which involves protecting trees from damage by species like deer and grey squirrels through protection or population control, accounts for a significant portion of woodland creation costs in England. For broadleaved woodlands in the case studies examined in this review (see Appendix 1), wildlife

management accounted for 54% to 64% of the initial establishment costs and for 34% to 49% of all costs over a 100-year period, excluding maintenance costs (see Case Studies A, B). These costs, though accounting for a lower share of the total, are also significant for coniferous woodlands, ranging from 10% to 26% of total costs over fifty years (see Case Studies C, D).

- Infrastructure costs vary significantly depending on woodland size and management objectives. Small and non-commercial woodlands can generally avoid costs of building roads and instead build "All Terrain Vehicle" (ATV) tracks (£5 per metre, with maintenance costs of £5 per metre every twenty years). Large commercial woodlands on the other hand may require the construction of roads suitable for timber haulage (c.a., £100 per metre, with maintenance costs of £10 per metre every twenty years).

- Planting, whilst more costly than direct seeding and natural regeneration, is the most reliable method for woodland establishment. The review found the average planting cost for a mixed woodland of broadleaves and conifers with 1800 trees per hectare ranges from £1.63 and £1.96 per tree, including both supply and labour. Labour costs for planting increase by over 25% on sloped and difficult to access sites (see Case Studies E and F). Less costly alternatives like direct seeding and natural regeneration can be cost-effective on suitable sites, but they require commitment to specific silvicultural practices and are less predictable. Preliminary findings suggest that hybrid methods combining planting and natural regeneration could balance the benefits and drawbacks of both approaches.

- Weeding is essential for protecting young seedlings and saplings. Spot spraying herbicides (£0.06-£0.10 per tree) is cost effective but is not invariably applicable due to environmental concerns. Our case studies indicate that spot spraying accounts for a small percentage of total costs (5% to 6%) for small coniferous and broadleaved woodlands (see Case Study A and C). However, the cost of spot spraying rises drastically as tree density and woodland size

increase, accounting for over 17% of total costs (£1176 per hectare) in one of the case studies produced for this review (see Case Study D). Mowing, though less cost-effective, poses fewer pollution risks and is recommended near water bodies. Although less easy to implement and less cost-effective for larger woodlands, manual weeding can be appropriate for sites under one hectare where landowners can manage weeds themselves. Organic mulches are effective and environmentally friendly, but relatively expensive (£1.18-£1.36 per mat including pegs).

- Ground preparation costs vary based on soil conditions, the terrain, method used and objectives (e.g., using ground preparation as a weeding method).
- Topography contributes to a noticeable, albeit moderate increase in woodland establishment costs. Fences and infrastructure are more difficult to build on sloped, irregular, and difficult to access terrains. Similarly, tree guards on sloped areas need to be taller, and thus are more expensive.
- Comprehensive regional labour cost data for the post-Brexit period are not currently available. As might be expected, the available evidence indicates that wages for loggers and forest workers are higher in London and the South-East, with lower wages in the West Midlands and the North of England. In some areas of the country, limited availability of contracted personnel may also make it more difficult to find appropriately trained workers.

Table 1: Woodland Establishment Costs: Average and Ranges per Item (2023 prices, each cost is explained below)

ITEM	UNIT	COST (AVG)	COST (RANGE)
GROUND PREPARATION & PLANTING			
Polythene Mulch Mats w. 5 Pegs	Each	£ 0.74	£0.71 - £0.79
Biodegradable Mulch Mats w. 5 Pegs	Each	£ 1.26	£1.18 - £1.36
Spot Spraying (1600 - 2200 trees/ha)	Per hectare	N/A	£132 - £220
Tree Cost (Avg. Broadleaf 100+)	Per tree	£ 0.58	£0.52 - £0.64
Tree Cost (Avg. Broadleaf 1000+)	Per tree	£ 0.43	£0.39 - £0.47
Tree Cost (Avg. Conifer 100+)	Per tree	£ 0.50	£0.45 - £0.54
Tree Cost (Avg. Conifer 1000+)	Per tree	£ 0.42	£0.38 - £0.46
Planting (Broadleaf Tree Only)	Per tree	£ 0.40	N/A
Planting (Conifer Tree Only)	Per tree	£ 0.25	N/A
Planting (w. Guard and/or Mulch Mat)	Per tree	£ 1.10	£1 - £1.19
WILDLIFE MANAGEMENT			
Vole Guards (Plastic)	Each	£ 0.28	£0.25 - £0.31
Vole Guards (Biodegradable)	Each	£ 0.50	£0.45 - £0.54
Spiral Guards (Plastic)	Each	£ 0.46	£0.41 - £0.52
Spiral Guards (Biodegradable)	Each	£ 1.30	£1.21 - £1.38
60cm Shelters w. Stake (Plastic)	Each	£ 1.90	£1.72 - £2.15
75cm Shelters w. Stake (Plastic)	Each	£ 2.46	£2.16 - £2.76
75cm Shelters w. Stake (Biodegradable)	Each	£ 2.66	£1.99 - £3.28
1.2m Shelters w. Stake (Plastic)	Each	£ 3.11	£2.78 - £3.46
1.2m Shelters w. Stake (Biodegradable)	Each	£ 3.98	£3.32 - £4.62
1.8m Shelters w. Stake (Plastic)	Each	£ 5.10	£4.67 - £5.52
Post & Wire Fencing	Per metre	£ 9.10	£8.52 - £9.70
Rabbit Netting Supplement	Per metre	£ 5.11	£4.34 - £5.85
Sheep Netting	Per metre	£ 11.20	£9.9 - £12.7
Deer Fencing	Per metre	£ 15.88	£14.26 - £17.50
Top Wiring Stone Wall	Per metre	£ 6.81	£5.15 - £9.1
Squirrels Control	Per hectare/year	£ 52.40	£39.2 - £66.25

Table 2: Establishment Cost Estimates – Average Case Studies (2023 prices, over 100 years for broadleaves and over 50 years for conifers. Click for full tables)

	Woodland Size (ha)	Average Cost	Average Cost per ha
Broadleaves	1	£ 17,883	£ 17,883
	2	£ 27,747	£ 13,874
	3	£ 37,379	£ 12,460
	4	£ 46,804	£ 11,701
	5	£ 56,185	£ 11,237
	6	£ 65,184	£ 10,864
	7	£ 74,183	£ 10,598
	8	£ 83,273	£ 10,409
	9	£ 91,756	£ 10,195
	10	£ 100,901	£ 10,090
Conifers	1	£ 13,386	£ 13,386
	2	£ 20,874	£ 10,437
	3	£ 27,928	£ 9,309
	4	£ 34,631	£ 8,658
	5	£ 41,521	£ 8,304
	6	£ 48,398	£ 8,066
	7	£ 55,161	£ 7,880
	8	£ 61,938	£ 7,742
	9	£ 68,731	£ 7,637
	10	£ 75,666	£ 7,567

Based on the evidence collected, findings suggest:

- EWCO payment rates for certain items do not meet average establishment costs. Currently, at 2023 prices, our estimates indicate that the average cost per linear metre of post and wire fencing is 14.9% above EWCO rates, that of sheep netting 19.9% above EWCO rates, that of deer fencing 54.6% above EWCO rates, and that of tree guards 28% above EWCO rates (see Table 1). The current payment rates for rabbit netting supplements and dry-stone wall netting are adequate, being around actual costs.
- Conducting research in an English context to assess the cost-effectiveness of various wildlife management approaches aimed at limiting tree damage caused by species such as deer and grey squirrels. Fences and tree guards are not only expensive but can adversely affect other wildlife and soil health. While wider

factors such as social acceptability can be very important too, studies conducted outside of the UK suggest that culling can be as effective as fencing, while incurring a fraction of the typical costs.

- Further exploring the costs and benefits of hybrid methods that combine planting with natural regeneration (e.g., "applied nucleation"). The evidence reviewed in this study suggests that these methods have the potential to help foster resilient and biodiverse woodlands while reducing sapling and planting costs by over 25%. Combining hybrid planting methods with more integrated wildlife management methods potentially could help create woodlands at a fraction of the usual costs.

1 Introduction

The capacity of woodlands to sequester substantial amounts of carbon and offer an effective means to help mitigate ongoing climate change is widely recognised. Woodland creation has been identified as an integral part of the England net zero strategy, with the government aiming to reach 16.5% tree and woodland cover by 2050 (Forestry Commission, 2023). Likewise, woodlands play a vital role in supporting biodiversity, providing a rich and diverse habitat for a variety of plants and animal species. Whilst woodland creation may seem straightforward, successful woodland establishment is not merely a matter of planting saplings or seeds, but a complex process that necessitates following a series of steps. These encompass, among others, design, ground preparation, protection against wildlife, and often also a detailed economic appraisal. Much has been published about planting methods (Willoughby et al., 2019), silvicultural systems (Macmillan et al., 1998), ground preparation (Paterson and Mason, 1999), wildlife management (Gill, 1999; Spake et al., 2020), and their associated costs. Yet, comprehensive information covering the most important aspects of woodland establishment, and their costs is still lacking. This report sets out to address this evidence gap. It explores the various phases of woodland establishment, examining corresponding expenses, and how costs can vary, including due to location-specific factors.

1.1 Methodology

A literature search was undertaken to identify relevant studies using Web of Science, Google Scholar, Jstor, and other academic databases and aggregators. Keywords such as "Woodland Establishment Costs UK" were used initially to identify relevant articles and reports, and to compile an extensive bibliography that reflects the current state of research in the field. This bibliography was subsequently used to identify significant research gaps, key woodland establishment phases and their costs, and formulate a series of precise research questions. The second phase of the literature

search focused upon specific keywords including "ground preparation forestry," "direct seeding," and "wildlife management" to help address the research questions formulated previously.

After noting the most significant stages of woodland establishment, this report proceeds to examine the various costs associated with each of these. Whenever feasible, these costs are based on field data collected by Forest Research and/or generously provided by partner organisations such as the Woodland Trust (Northern Forest Team), the National Trust, and Forestry England. Ranges were computed from this field data using the bootstrap method, a resampling technique that improves robustness by iteratively drawing samples with replacement from the observed data distribution. The resulting ranges represent 95% confidence intervals and should be useful to provide some measure of uncertainty. In practice, this means that we are 95% confident that the true cost falls within the ranges provided for each item.

In cases where recent field data on actual costs were not available, data were compiled from other sources including: 1) relevant academic literature, 2) government reports, 3) discussions with experts, practitioners, and contractors, and 4) standard costs data provided by the Forestry Commission[1]. Road building costs were calculated using the *Woodland Improvement Cost Calculator* model developed by the Forestry Commission Wales between 2009-2011 and the *Forest Roads and Tracks Regulations Operations Note* 25 published by the Forestry Commission England in 2011. To ensure accurate comparisons across time, all reported numbers have been inflation adjusted as of June 2023 using the HM Treasury GDP deflator.[2] Guidance pertaining to survey procedures is provided in appendix 2 for easy reference and detailed information. An extensive thematic bibliography that details the sources used in this report is given at the end.

[1] Available at, EWCO Grant Manual v3.3 issued 12.07.2023.pdf (publishing.service.gov.uk)
[2] Available at, GDP deflators at market prices, and money GDP March 2023 (Spring Budget) - GOV.UK (www.gov.uk)

1.2 Methodology: Case Studies

Eight case studies were developed to supplement and test the figures produced for this report. Detailed in Appendix 1, these case studies were analysed using Monte Carlo experiments, a computational technique that uses repeated random sampling to model a range of possible future outcomes based on past data. For each study, 10,000 simulations were run using scenario-specific assumptions and the cost ranges specified in *Table 1: Woodland Establishment Costs*. The results of these simulations were aggregated and averaged to provide mean costs for each scenario. Additionally, 95% confidence intervals for total and per hectare costs were calculated to better capture the variability and uncertainty inherent in woodland creation projects.

The timeframes adopted for the eight case studies are year one and year one hundred for broadleaved woodlands and year one and year fifty for coniferous ones, providing both short-term and long-term perspectives. Average cost data for years 15, 30, 50, and 75 are also provided to better understand how costs evolve over time. Unless stated otherwise, all costs have been discounted annually at a rate of 3.5%.

The eight case studies are divided into two subsections. The "average case studies" include two scenarios created using Forestry Commission field data, averaged to produce typical scenarios for broadleaved and coniferous woodlands. These average case studies aim to provide a general idea of typical woodland creation scenarios in England, give realistic estimates applicable to a wide variety of projects, and serve as a reference point when analysing woodland creation costs.

In addition to the average case studies, Appendix 1 includes simulations for six "specific case studies". These specific case studies, also based on Forestry Commission field data, were carefully selected to illustrate the impact of factors such as different types of fencing, stock densities, slopes, and haulage roads on woodland creation costs. Unlike the broadly applicable average case studies, the specific case studies offer a more comprehensive view of the potential challenges and costs unique

to different woodland creation scenarios in order to help stakeholders better understand and anticipate the specific needs of their woodland creation projects.

Considerable care has been taken to ensure that the figures presented throughout the report and in Appendix 1 are up-to-date, reliable, and accurately representative of the actual costs involved in woodland establishment. Nonetheless, limitations inherent to such an exercise should be noted. Actual costs may differ from the numbers provided in this report depending on factors such as woodland types, suppliers, contractors, and regional wage disparities, among others. As such, the figures presented here do not purport to account for every scenario and should be taken as realistic estimates providing a general idea of costs, rather than an exact science. Despite such caveats, the data presented herein should, while not offering exact figures applicable to every scenario, offer a good overview of the cost structure associated with woodland establishment in England.

2 Ground Preparation and Planting Costs

2.1 Cultivation

Ground preparation usually involves some form of cultivation and in forestry refers to the practice of altering the soil to facilitate the establishment and healthy growth of trees (FAS, 2018). Ground preparation is carried out before planting, either manually or with machines such as scarifiers and mounders. Cultivation can mitigate factors that impede tree growth such as soil compaction, and erosion (NRC, 2019). In less fertile upland conifer plantations, cultivation may also serve as an effective weed control method (Willoughby et al., 2009). Cultivation is not always necessary and should be avoided on sites that are already fertile, but also on bogs, skeletal soils, calcareous soils over chalk or limestones and littoral soils (Scottish Forestry, 2021). Likewise, mechanical ground preparation is not suitable for dry, nutrient poor, naturally regenerated, and very steep sites (Von der Gönna, 1992).

Ploughing consists of turning over and loosening soils to enhance soil aeration, drainage, and rooting conditions for young trees in order to promote shoot growth and yields (Thompson, 1984). The cost of ploughing depends on the method used and the type of terrain. Furrow ploughing involves turning the soil over a single time before planting and costs between £120 and £157 per hectare (FAS, 2018). Double mouldboard ploughing, a more extensive method that involves two passes of the plough to invert and bury more soil, costs between £265 and £314 per hectare (FAS, 2018). On steep terrain, the cost of ploughing is significantly higher, sometimes twice as expensive as on flat ground (Nix, 2022).

Continuous mounding is used to create raised beds for planting seedlings or saplings and costs between £290 to £338 per hectare. Hinge mounding uses a similar process, but forms isolated individual mounds separated by a trench and costs between £423 and £785 per hectare (FAS, 2018).

Scarifying consists in disturbing the forest floor to expose mineral soils, reduce competition from vegetation and encourage natural regeneration. Scarifying costs between £122 and £348 per hectare with an average cost of £146 per hectare and screefing of £266 to £604 per hectare (FAS, 2018). Detailed explanations regarding when and how to use specific methods can be found in Paterson and Mason (1999), and Scottish Forestry (2021).

2.2 Planting

Following ground preparation, woodlands are usually established using one of three methods: planting, direct seeding, or natural colonisation (Hotchkiss et al., 2022). The advantages, disadvantages, and costs of each of these methods need to be carefully considered to ensure cost-effective woodland creation.

Planting, the most frequently used method for woodland establishment, involves physically inserting young trees into the soil. Planting is characterised by its predictability, speed, and flexibility, as landowners are free to pick specific and/or better adapted species tailored to the desired type of woodland (Hotchkiss et al., 2022). It also generally has high survival rates and predictable growth patterns (Bavin, 2020).

Although predictable and adaptable, planting can be expensive due to the time needed to grow seedlings/saplings — two to four years on average, — and the costs of transporting them to the chosen site. As a general guideline, the average wholesale cost of seedlings ranges from £400-500 per 1000 trees for conifers and £400-650 per 1000 trees for broadleaves (Nix, 2022). Nurseries based in England currently indicate costs for 100+ units of 20-40 centimetres seedlings as follows: Beech (£0.55), Birch (£0.52), Douglas Fir (£0.51), Hazel (£0.65), Oak (£0.42), Sitka Spruce (£0.43), Scots Pine (£0.49), Sycamore (£0.50) (FR Field Data, 2023). In general, broadleaves tend to be more expensive than conifers, but prices can vary significantly

depending on suppliers, size of order, tree size, and annual fluctuations influenced by weather conditions (Noisette, 1987).

Field data collected by Forest Research indicate that labour costs of tree planting range from £1 per tree (£1000 per 1000 trees) to £1.19 per tree (£1119 per 1000 trees) with an average cost of £1.10 per tree (£1110 per 1000 trees) (FR Field Data, 2023). This includes the cost of installing a tree guard with its stake. When tree guards or mulch mats are not needed, planting trees is less expensive, with costs ranging from £0.25 to £0.40 per tree (WCC, 2022). Planting in remote and difficult to access areas, such as slopes exceeding 25%, incurs an increase of 25-50% in labour and transportation costs. Furthermore, several studies note a direct correlation between inadequate planting practices and high tree mortality rates. The Institute of Chartered Foresters (ICF), among others, notes that subpar planting methods are responsible for approximately 30% of newly planted trees perishing within the first few years (ICF, 2021). This situation might result in a marked increase in replacement costs, commonly referred to as "beating up." The labour expenses associated with beating up are estimated at £115-£210 per hectare whilst the cost of obtaining replacement plant supply can range from £95 to £160 per hectare of dead trees, depending on the chosen species (Nix, 2022).

In the six specific case studies produced for this report, planting costs, including saplings and labour costs, accounted for 15% to 48% of total costs at year one. This broad variation can be explained by the specific characteristics of each woodland. Planting is significantly more expensive as a percentage of total costs for case study D (102 hectares, 2000 trees per hectare) where the sheer number of saplings needed account for nearly 23% of the total costs. Planting costs are relatively high for case study A despite the relatively small size of the woodland and the low stocking density (2 hectares, 1600 trees per hectare). In this case, the need for fitting tree guards with stakes when planting the saplings drives the cost up to a total of £1700 per hectare. Conversely, planting costs are at their lowest (approximately 15% of total costs at year one) in case study C (1.30 hectares, 2200 trees per hectare). Despite

the high stocking density, the small size of the woodland and the absence of trees guards keep planting costs relatively low compared to other case studies. Regardless of the higher initial costs, planting is the most reliable and thus preferred method for woodland establishment thanks to the relatively high survival rates of seedlings/saplings and the lower maintenance costs over time.

Table 3: Seedling/Sapling Costs (Broadleaves, 2023 prices, FR Field Data, Averaged from English Nurseries)

Seedling/Sapling Costs (Broadleaves)		
Tree Type	Cost (per unit 100+)	Cost (per unit 1000+)
Beech	£ 0.55	N/A
Birch	£ 0.52	£ 0.45
Blackthorn	£ 0.50	£ 0.36
Buckthorn	£ 0.60	£ 0.45
Crab Apple	£ 0.53	£ 0.38
Dogwood	£ 0.48	£ 0.40
Field Maple	£ 0.40	£ 0.30
Hawthorn	£ 0.65	£ 0.36
Hazel	£ 0.65	£ 0.55
Hornbeam	£ 0.58	£ 0.49
Large Leaved Lime	£ 0.95	N/A
Oak	£ 0.42	£ 0.35
Rowan	£ 0.55	£ 0.48
Sessile Oak	£ 0.60	£ 0.53
Small Leaved Lime	£ 0.72	£ 0.55
Sycamore	£ 0.50	£ 0.40
Average Broadleaf	£ 0.58	£ 0.43

Table 4: Seedling/Sapling Costs (Conifers, 2023 prices, FR Field Data, Averaged from English Nurseries)

Seedling/Sapling Costs (Conifers)		
Tree Type	Cost (per unit 100+)	Cost (per unit 1000+)
Douglas Fir	£ 0.51	£ 0.43
European Larch	£ 0.40	N/A
Grand Fir	£ 0.50	£ 0.45
Norway Spruce	£ 0.53	£ 0.40
Scots Pine	£ 0.49	£ 0.40
Serbian Spruce	£ 0.61	£ 0.50
Sitka Spruce	£ 0.43	£ 0.34
Average Conifer	£ 0.50	£ 0.42

2.3 Direct Seeding

As its name suggests, direct seeding involves placing seed directly into the prepared ground. This method yields trees that are more effectively adapted to site conditions than planted trees and produces high-quality timber. Furthermore, direct seeding is cheaper than more conventional methods as it sidesteps the substantial nursery and transportation costs associated with planting (Grossnickle and Ivetic, 2017). Another, often underestimated, advantage of direct seeding, is its similarity to crop planting processes. These similarities can be appealing to farmers seeking to grow trees without having to grapple with the intricate and labour-intensive procedures associated with planting saplings (Willoughby et al., 2004).

Recent cost estimates for England are provided by Willoughby et al., who give a range of £236 to £887 per hectare (£200-£750 in 2019) depending on species, plus labour costs of £59 per hectare (£50 in 2019) (Willoughby et al., 2019). A review by Grossnickle and Ivetic indicates that, on average, the cost of direct seeding per hectare is 60 to 70% cheaper than planting seedlings (Grossnickle and Ivetic, 2017).

Whilst direct seeding is easy to understand and cheap, its predictability lags behind that of planting. The number of seeds planted depends on assumptions of survival determined by foresters or land managers at the time of sowing (Ezell and Kushla, 2019). Wildlife such as birds, insects, and mammals may consume many of the seeds, reducing the chances of germination and, consequently, hindering successful woodland establishment (Hotchkiss et al., 2022). Likewise, on sloped terrains, seeds may be washed downhill by rainstorms, resulting in a very uneven distribution (Ezell and Kushla, 2019). In other cases, an excessive number of seeds may survive and lead to situations where expensive pre-commercial thinning is needed to protect the desired trees from too much competition (Ezell and Kushla, 2019). In addition, the efficacy of direct seeding hinges on good weather and favourable soil conditions. Frost, droughts, but also poorly drained, waterlogged, compacted, or improperly

prepared soils can hamper seedling development and prove fatal to newly germinated seedlings (Willoughby et al., 2019; Lula et al., 2021).

Though viable under suitable conditions, and cheaper than planting, the unreliability of direct seeding can be a significant barrier for landowners to adopt the silvicultural practices necessary to ensure its success (Willoughby et al., 2019). Nevertheless, research underscores the potential of direct seeding in well-drained upland regions with limited fertility (Willoughby et al., 2019).

2.4 Natural Colonisation

Natural colonisation, also sometimes referred to as a type of natural regeneration[3], is a woodland management approach reliant on the natural dispersion of seeds by agents like wind or wildlife to foster expansion or renewal of forests with minimal or no human intervention. This method is often lauded for its potential to enhance biodiversity, mimic natural forest ecosystems and, due to selection pressure, yield trees that are generally well adapted to their soil conditions, more resilient to environmental challenges and capable of producing higher timber quality compared to traditional planting (Hotchkiss et al., 2002; Lula et al., 2021). Like direct seeding, the straightforwardness of natural colonisation may appeal to small landowners who wish to invest in woodland establishment without needing to master planting methods that are often perceived as complicated (Nguyen-The and Lafont, 2001).

Modelling the costs associated with natural colonisation is challenging due to numerous uncertainties. Predicting tree sprouting times, the number of trees growing and determining the duration for which naturally regenerating trees need protection from wildlife all contribute to the complexity of this task (Hosius et al., 2016). In light of these considerations, a significant economic advantage of natural colonisation is

[3] For the difference between natural regeneration and natural colonisation as defined by Forest Research, see natural colonisation as a strategy for woodland creation and expansion - Forest Research.

its ability to circumvent the high expenses associated with seedling procurement (£400-500 per 1000 trees for conifers and £400-650 per 1000 trees for broadleaves), transportations, and sowing costs (£1 - £1.19 per tree) associated with conventional planting, and to a lesser extent, direct seeding (Macmillan et al., 1998). Depending on existing vegetation, ground preparation such as scarifying (£122 and £348 per hectare) may also be needed to prepare a suitable seed bed (FAS, 2018).

A recent analysis comparing the costs of planting with those of natural colonisation in oak stands found that the absence of seedling and planting costs along with reduced weeding expenses resulted in establishment costs over five times lower when employing natural colonisation (Kaliszewski, 2017). Likewise, another study, focusing on the financial outcomes of planting versus natural colonisation in oak and pine forests in the southern USA and Poland notes that the financial returns for natural colonisation are comparable and, in some instances, superior to planting, particularly when commercially desirable species are produced (Chudy et al., 2022). However, Kaliszewski, 2017 points out that expenses related to pre-commercial thinning and wildlife control were respectively 12% and 50% higher when opting for natural colonisation (Kaliszewski, 2017).

Despite its appealing simplicity and the advantage of low establishment costs, a key trade-off should be noted between reduced costs of establishment and the inherent unpredictability and lack of control associated with natural colonisation (Forestry Commission, 2021). Such drawbacks may be partially mitigated by adopting a hybrid approach that combines natural colonisation with some planting. This method, also described by Rey Benayas et al. (2008) as "woodland islets", and by Corbin and Holl (2011) as "applied nucleation", involves strategically planting patches of tree in areas lacking native vegetation to initiate natural colonisation. In 2011, a case study conducted in a tropical area of Costa Rica achieved successful woodland establishment while reducing planting and maintenance costs by 27% (Holl et al., 2011). Whilst further research is needed to adequately understand the costs and benefits of applied nucleation in an English context, such methods may provide a

compromise balancing the high initial costs of active planting and the unpredictable yet ecologically and economically beneficial nature of natural colonisation.

3 Weeding Methods and Costs

Grasses, bracken, brambles, and other vegetation compete for light, moisture, and nutrients, and can impede the growth of young trees. Hence ensuring successful afforestation requires adequate weeding and initial site preparation (Duan and Abduwali, 2021). Weeding methods may include, among others, manual, mechanical or chemical approaches - all of which need to be implemented immediately before planting and at regular intervals over the subsequent three to five years. Just as with the different planting techniques examined before, each method has its own advantages, disadvantages and costs that necessitate careful consideration when selecting the most suitable approach for individual sites.

3.1 Manual Weeding

Manual weeding is a straightforward technique involving the use of common tools such as hoes, spades, sickles, and scythes to eliminate surrounding weeds from a seedling's vicinity. The simplicity of manual weeding allows virtually anyone to carry it out, regardless of training (Hart, 1998). Equally noteworthy is its versatility, making it useable on both flat terrains and steep slopes. As a result, on very small plots, where landowners can personally undertake weed removal without the need for additional, more expensive, labour, manual weeding can prove cost-effective.

However, in the long run, the effectiveness of manual weeding is poor by comparison with mechanical and chemical alternatives. A key problem lies in the difficulty of manually eradicating roots, which often survive, and rapidly facilitate weed regrowth, once again encroaching upon the site (Fitzgerald, 1998). In medium and large woodlands, the need to hire extra workers makes manual weeding excessively labour intensive, inconvenient, time consuming and costly. Data on manual weeding are scarce given the lack of contractors offering this service. Archival data from Forest Research indicate that, accounting for inflation, manual weeding costs approximately

£600 per hectare for two weedings per year (Wittering, 1974). Comparison with the agricultural sector, where manual weeding is more common, gives costs ranging from £500 per hectare to £2500 per hectare, depending on the type of weeds, and the crops being planted (Cook et al., 2019). These broad ranges can be explained by the fact that, depending on circumstances, hundreds of hours may be necessary to manually clear a field of weeds and even with an hourly rate set at the minimum wage of £11.44 (April 2024), the total cost per hectare per year for complete control may often exceed £1000 — a relatively high cost compared to alternative methods. As such, manual weeding remains a practical option for very small sites where its user-friendly nature and limited associated expenses might present a more financially sensible choice for landowners, and in locations where the application of chemicals is restricted due to high pollution risks such as riparian areas.

3.2 Mechanical Weeding

The principles underpinning mechanical weeding, closely resemble those of manual weeding, with the key distinction being the replacement of hand labour by machines such as mowers. The various techniques employed include, among others, cutting weeds with rotating blades or crushing them with rollers. Mechanical weeding is less labour intensive than manual weeding and can be carried out using dedicated equipment or tractor mounted accessories. It is also effective at reducing cover for wildlife that may pose a threat to woodland establishment such as voles (Atchison and Ricke, 1996). However, the effectiveness of mechanical weeding is limited on sites dominated by grasses as grasses can regrow almost immediately after being cut (Willoughby et al., 2004). When tractors and other heavy machinery are used, mechanical weeding may also contribute to soil compaction, which can promote the growth and spread of potentially fatal fungal infections. Additionally, it is not suitable and can be hazardous on slopes exceeding 35% (Simard et al., 2003).

Flail mowing costs between £43 and £48 per hectare, with a mean of £45 per hectare and needs to be done two to three times per year for the first three to five years (FR Field Data, 2023). Inter-row mowing, a more precise, small-scale method that focuses on clearing unwanted vegetation between lines of trees incurs costs ranging from £80 to £225 per hectare (Nix, 2022). Cutting bracken with mechanical methods is associated with similar costs, estimated at around £230 per hectare (FR Field Data, 2023). Finally, the cost of ride mowing, a method used to create or maintain open spaces within a woodland is estimated at £535 per kilometre (National Forest Company, 2022). Mowing on slopes incurs higher costs, but determining the exact increase is challenging as it may vary based on soil type and level of precipitation. Based on studies conducted outside the UK, adding an extra 10% to the aforementioned costs may be a reasonable, albeit conservative assumption for mowing on slopes. Mechanical weeding costs could be expected to increase further in periods of rising fuel costs (Lowery and Gjerstad 1991).

As a consequence of its limited effectiveness and high cost, mechanical weeding is typically not cost-effective. However, it is preferred over other methods such as chemical weeding in areas near water as it is less likely to contaminate water bodies. Technological advancement, the emergence of herbicide-resistant weeds, and growing public opposition to certain herbicides may, in the near future, contribute to making mechanical weeding a more common weed control method.

3.3 Chemical Weeding

Chemical weeding is currently the most common weeding method employed by foresters and landowners in England (Willoughby et al., 2009). In forestry, chemical weeding usually consists in applying an approved herbicide in a circular pattern around each tree using a backpack sprayer. This process is commonly referred to as "spot spraying." Herbicides are cheap, involve low labour costs, and can be used on most terrains, including slopes, without difficulties. Likewise, when applied at the

right time, herbicides are more effective and have longer lasting results compared to other weed control methods (Simard et al., 2003).

The cost of spot spraying ranges from £0.06 to £0.10 per tree including labour costs assuming two applications per year during the first two to four years (National Forest Company, 2022). Bracken can be controlled with herbicides for £271 per hectare (EWCO, 2023). Spot spraying costs increase proportionally with stocking density. However, in some cases, higher tree densities can result in fewer years of spot spraying, as canopy closure is achieved more quickly. Case study A with a stocking density of 1600 trees per hectare has the lowest spot spraying costs per hectare of all our simulations (£940 per hectare, with two sprayings per year for four years, accounting for 5.54% of total costs). In contrast, for case study C, with a stocking density of 2200 trees per hectare, spot spraying costs £1293 per hectare with two sprayings per year for four years.

Herbicides such as glyphosate are commonly employed to control *Rhododendron Ponticum*, an invasive species introduced to the United Kingdom in the 18th century. *Rhododendron Ponticum* poses a significant threat to woodland establishment as it can smother young trees and spread harmful pathogens such as *Phytophthora ramorum* to various species, including larch (Forest Research, 2006). Several methods for controlling *Rhododendron Ponticum* exist, with the direct application of glyphosate on the foliage or inside the plant, through a hole cut into the stem, among the most effective ones (Ninaber, 2009).

As observed by Parrott and MacKenzie, the cost of controlling *Rhododendron Ponticum* is challenging to assess and varies depending on site conditions and bush density (Parrott and MacKenzie, 2013). Ninaber, who reviewed multiple studies provides estimates ranging from £1400 (£1000, 2009) per hectare to £7000 per (£5000, 2009) hectare for larger bushes (Ninaber, 2009). The cost of controlling *Rhododendron Ponticum* is generally higher on steep slopes and difficult sites, and often ranges from £7000 to £10000 per hectare. However, costs can be far higher

on the most inaccessible sites - as exemplified by a case study that evaluated them at approximately £21000 (£13000, 2002) per hectare (Wong et all., 2002).

Whilst considered cost-effective, herbicides have faced increased scrutiny in recent decades with concerns about their environmental impact raised by scholars, practitioners, and the public. Criticisms focus on the potential adverse effects of herbicides on non-target species and pollinators (Zilnik et al., 2023; Weidenmüller et al., 2022), their impacts on soils and water sources (Syafrudin et al., 2021), potential implications for human health (Syafrudin et al., 2021) and the links between overuse of herbicides and the development of herbicide resistant weeds (Varah et al., 2020).

3.4 Mulching

Mulching consists in applying a layer of materials onto soil surfaces to smother weeds or hinder their access to sunlight. Mulches can be made of synthetic elements such as plastic and polypropylenes as well as organic materials including but not limited to leaves and wood chips (Bavin, 2020). Studies show that when used properly mulches can be as effective as herbicides at controlling competing vegetation (Mc Carthy et al., 2007). Organic mulches are more environmentally friendly but less effective than plastic ones (Mc Carthy and Mc Carthy, 2005). The installation of mulches requires no specialised training and is particularly suited for fragile sites and ecosystems where chemical weeding is ill-advised. Nonetheless, experts have raised concerns regarding the use of plastic-based mulches as their improper disposal can lead to residual microplastics in soils (Khalid et. al. 2023).

The cost of purchasing 60x60 plastic mulch mats with five pegs ranges from £0.71 to £0.79 per mat. In contrast, the more environmentally friendly biodegradable mulch mats come at a higher price than their plastic counterparts. The cost of a 50x50 biodegradable mulch mat with five pegs ranges from £1.18 to £1.36 per mat with an average of £1.26 per mat with pegs (FR Field Data, 2023). Just as with other planting and weeding methods, installing mulch mats on sloped terrains significantly raises

labour costs, compared to flat areas. On average, a 2007 study found that mulch mats are approximately seven times more expensive to use than chemical weeding, even when factoring in ongoing management costs of repeated herbicide applications (Mc Carthy et al., 2007). On very small sites, repurposing household materials such as old carpets as mulches can significantly reduce costs (Willoughby et al., 2004).

While mulching is generally less cost-effective than chemical weeding, like manual weeding, mulches can be cost-effective for small sites, roadsides, and urban forestry. However, their application is not recommended for poorly drained sites unless drained beforehand (Willoughby et al., 2004), for locations with numerous mice and voles, as they can burrow underneath, or for larger areas due to high costs (FR Field Data, 2023).

4 Wildlife and Pest Management Costs

Competing vegetation is not the only threat to tree growth and woodland establishment. Wildlife, including deer, squirrels, rabbits, voles, hares and occasionally horses and boars, but also insects such as large pine weevil (*Hylobius abietis*), pose a substantial threat by consuming seedlings, browsing on young tree foliage, and causing damage to bark (MacMillan and Philipp, 2008).

4.1 Damage Types

Woodlands need protection from browsing by herbivores such as deer, wild boars, and horses. These animals consume shoots, twigs, and leaves, which can delay tree growth, cause the development of multiple stems, and reduce the quality of timber. While browsing rarely kills trees, it significantly impacts their health and economic value (Ward et al., 2004; Gill et al., 2000). Using field data from Scotland, Gill et al. (2000) concluded that deer browsing on Sitka spruce causes an average growth delay of one year, leading to revenue losses of 3.4%. Longer growth delays of two and four

years, caused by deer browsing, can lead to larger losses of approximately 7.2% and 16%, respectively, in timber yield for yield class 12 Sitka spruce over a rotation period of 45 years.

Bark stripping and fraying also poses a significant threat to the economic viability of woodlands as the damage inflicted to a tree's outer layer often results in irregularities in harvested timber. This diminishes the timber's market value and may adversely affect the overall financial viability of forestry operations. Additionally, bark serves as a natural defence against fungal infections and its removal makes trees more susceptible to fungi such as *Sarea difformis* (Arhipova et al., 2015). The discoloration caused by *Sarea difformis* and other fungi frequently leads to a downgrade in wood quality and value (Gill et al., 2000). In severe cases, structural damage induced by fungal infections can be lethal, incurring additional costs for replacement trees, or lead to afforestation failure (Arhipova et al., 2015). Generally speaking, broadleaves are more vulnerable to bark stripping than conifers (Nichols et al., 2016).

A recent study commissioned by the European Squirrel Initiative (hereafter ESI) assessed the cost of damage, including reductions in yield and timber quality, caused by squirrel bark stripping for various tree species, and how it varies depending on yield and quality class. Oak and sweet chestnut trees were identified as the most vulnerable to bark stripping, with annual losses estimated at £44 to £394 per hectare and £56 to £329 per hectare depending on yield class, quality class, and rotation length. The table below summarises the main findings of the ESI report. Another recent study provides average estimates of a similar order of magnitude, evaluating the damage caused by grey squirrels at approximately £100 per hectare per year for broadleaved woodlands, or around £8,000 over an 80+ year rotation period (Glynn and Watson, 2021).

Table 5: Impact of Grey Squirrel Damage on Stand Valuation at Maturity (adapted from ESI, 2019)

Species	Quality Class	Yield Class	Net Loss (£/ha/y)
Oak	High	6	£ 394
	Medium	4	£ 206
	Low	4	£ 44
Beech	High	6	£ 36
	Low	4	£ 30
Sweet Chestnut	High	8	£ 329
	Low	4	£ 56
	Coppice	10	£ 31
Sycamore	High	8	£ 79
	Low	4	£ 41
Birch	Medium	6	£ 31

4.2 Fencing

Fencing is a common way to protect trees from large mammals. Post and wire fencing offers adequate protection against cattle and horses (Trout and Brunt, 2014). As of 2023, the cost of post and wire fencing ranges between £8.52 and £9.70 per metre with an average of £9.10 per metre (FR Field Data 2023). Likewise, the cost of sheep netting ranges between £9.9 and £12.7 per metre with an average of £11.20 per metre (FR Field Data 2023). However, fencing costs can increase significantly when deer and/or rabbit density exceeds a certain threshold. Deer proof fencing typically costs between £14.26 and £17.50 per metre with an average of £15.88 per metre (FR Field Data, 2023). A 60cm rabbit proof extension may be added to an existing fence for an additional cost of £4.34-£5.95 per metre with an average of £5.11 per metre (FR Field Data, 2023). Fencing is more difficult and thus generally more

expensive on sloped, difficult-to-access, and large irregularly shaped sites (EWCO, 2023).

Fences have a lifespan ranging from 10- to 25-years, contingent on their type and manufacturer. Consequently, they must be replaced or repaired every 10 to 25 years. The WCC estimates the costs of repairing a fence at £4.10 per linear meter every twenty years (WCC, 2022). This timeframe is also adopted by the simulations in Appendix 1. When fences reach the end of their serviceable life, the cost for their removal is approximately £1.25-£1.78 per metre with an average of £1.50 per metre (FR Field Data, 2023; Woodland Trust, 2022; National Forest Company, 2022). Additional disposal costs may apply if treated timber was used in the original construction, as it would be classified as "hazardous waste" (Forestry England, personal communication).

Whilst erecting a brand-new dry-stone wall can be expensive, with labour costs ranging between £45.5 and £65.5 per metre, fencing costs can be lower on properties already enclosed by dry stone walls, allowing for the installation of deer proof fencing at an approximate cost of £5.15-£9.10 per metre with an average of £6.81 per metre (FR Field Data, 2023). Dry stone walls are prevalent in the Pennines, the Northwest and the Lake District and may contribute to lower fencing costs in these regions. Aside from being more cost-effective, fences on top of stone walls topped may also contribute to better to preserving England's historic landscape.

Gates can be placed at any location along a fence to provide access to managers, landowners and the public where access rights exist. Public access kissing gates cost between £295 and £377 per gate, wooden field gates between £410 and £545 per gate, and metal field gates approximately £340 per gate (FR Field Data, 2023; EWCO, 2023). In general, metal gates tend to be less expensive than wooden ones (FR Field Data 2023). Special gates are needed to also facilitate movement of wildlife in some cases. Badger gates must be installed when a fence goes through a badger run to allow badgers to use the run without tearing a hole in the fence (Trout and Pepper,

2006). Installing a badger gate in a fence, costs between £71 and £83 with an average of £76.80 per gate (FR Field Data, 2023). Deer gates (designed not to compromise the effectiveness of the fences put up to keep deer out) can also be installed in a deer fence for around £480 per gate (Woodland Trust, 2022).

Despite its manifold advantages, fencing has significant drawbacks. Installation costs are high and thus often not cost-effective for areas smaller than 2-5 hectares (Hart, 1998; Gill, 1999). Case study C highlights how expensive fencing can be for small woodlands, accounting for nearly 70% of total costs at year 1 and over 25% at year 50 (£6,549 per hectare). Fencing often only becomes the most cost-effective option for parcels over 5 hectares. Economies of scale reportedly on average tend to reduce the cost of fencing per metre by around 25% compared to smaller ones (Hart, 1998; Trout and Brunt, 2014). Average case studies 1 and 2, whilst not focusing exclusively on fencing show the effect of economies of scale on woodland establishment. Total establishment cost per hectare decreases by over 22% when increasing from one to two hectares, by over 10% from two to three hectares, and by over 6% when increasing from three to four hectares.

In addition, whilst earlier studies considered fencing a costly but effective solution (Kula, 1988), more recent research has noted the need for regular inspection, with ongoing maintenance costs estimated at £4.10 per metre every twenty years (WCC, 2022), while potential for breaches can limit its efficiency and cost-effectiveness (Hart, 1998).

The impact of fencing on wildlife and biodiversity is also a focus of some wider concerns. According to experts such as Gill (1999), excessive fencing merely displaces deer to adjacent areas, negatively affecting neighbours and society more widely. Fences have also contributed to the decline of species such as black grouse and have driven the population of western capercaillie to near extinction in Scotland (Trout and Kortland, 2012). To prevent collisions and protect bird populations better, fences should be marked with orange meshes, softwood droppers or strike markers

(£0.93 per metre) and removed as soon as they are no longer needed (Trout and Kortland, 2012; EWCO, 2023).

4.3 Tree Shelters

Tree shelters, sometimes also referred to as tree guards, are commonly employed as an alternative to fencing for protecting young trees. Tree shelters are compact tubes forming a physical barrier around saplings, which provide protection against browsing animals. Tree shelters are typically made of plastic, although biodegradable alternatives have become available in recent years (Chau et al., 2021). Besides protecting young trees, tree shelters facilitate CO2 accumulation within the tube, promoting tree growth (Gilbert and Anderson, 1998). Tree shelters are ineffective against robust wild mammals capable of breaking the tube, such as boars and horses (Trout and Brunt, 2014).

Spiral tree guards are cheap, costing approximately £0.41 to £0.52 per guard and effective against small animals such as voles and rabbits, although lacking the sturdiness required to deter large wildlife such as deer. The cost of 60cm shelters with a stake range between £1.72 and £2.15 with a mean of £1.90 per shelter. Likewise, 75cm tall shelters with a stake cost between £2.16 and £2.76 with a mean of £2.46 per shelter and 1.2m high shelters with a stake between £2.78 and £3.46 with a mean of £3.11 per shelter (FR Field Data, 2023).

It is important to note that costs can vary depending on the location and the wildlife present at the site. For instance, Fallow, red, and sika deer require taller (1.8m) and consequently more expensive (£5.10/unit with stake) tree shelters, whilst rabbits, roe, muntjac and Chinese water deer require smaller (1.2m) and cheaper (£3.11/unit) tree shelters (Trout and Brunt, 2014). On slopes and mountainous terrain taller tree shelters are often required to provide protection from high winds and heavy rain, and this tends to increase the cost of the tree guards. As with fencing, economies of scale apply, as buying more shelters typically lowers the price per unit.

In certain situations, and for landowners seeking cost-reducing measures, repurposed plastic containers such as washing up liquid containers may be as effective as commercial grade plastic tree guards against field voles - as demonstrated by a study conducted in Fryent Country Park (London) in the mid-1990s (Williams and Northcroft, 1994). This method is reported to be commonly used by amateur foresters and gardening enthusiasts. Whilst it may not be recommended for medium and large sized woodland creation projects, very small woodland creation projects relying on volunteer labour may find this method helps lower tree protection costs (Williams and Northcroft, 1994).

Despite their affordability and user-friendly nature, it is crucial to acknowledge concerns raised by researchers regarding the release of microplastics from degrading tree shelters into the environment and its potential adverse effects on soils and biodiversity (Chau et al., 2021; Hanif et al., 2024). To mitigate such risks, it is advisable to collect and recycle used tree shelters. As of 2023, a partnership service managed by Tubex, and the Yorkshire Dales Millennium Trust offers to recycle polypropylene, and polyethylene based 1.2m tall shelters for £46.80 per 350-400 units (YDMT, 2021). This partnership also provides a free drop off service at designated locations in Yorkshire, the East, and the Southwest (YDMT, 2021).

Alternatively, cardboard based, or biodegradable shelters may be used instead of plastic ones. These alternatives are pricier than their plastic counterparts. Costs range from £0.50 per unit for vole guards, £1.30 for spiral guards, £2.66 for 75cm shelters with stakes to £3.98 for 1.2m shelters with a stake (FR Field Data, 2023; Woodland Trust, 2022). Prices may further vary depending on suppliers, brands, and number of shelters ordered.

It must be noted, however, that the current generation of biodegradable tree shelters has some drawbacks. Concerns regarding the durability and carbon emissions generated by biodegradable tree shelters have been raised by scholars and organisations such as the Woodland Trust (Chau et al., 2021; Woodland Trust, 2021).

More reliable environmentally friendly options may become available in the near future. The Woodland Trust notably reports promising preliminary results for models made of British wool and cashew oil extracted from nut shells. Nonetheless, several more years of testing are needed until comprehensive efficacy studies are available and the pricing of this new generation of biodegradable tree shelters is presently unknown.

4.4 Deer and Squirrels Culling

On larger estates, deer culling, alone, or in combination with fencing and/or tree shelters is often deemed a safe, cost-effective, practical, and environmentally friendly approach to wildlife management (Beaudesson et al., 2015). A study conducted in the Rhineland-Palatinate region of Germany from 1990 to 2007, indicates that culling enough deer on 600 hectares is approximately 45% cheaper than fencing the entire property, whilst being significantly more beneficial to biodiversity (Beaudesson et al., 2015). Culling can be carried out by the owners, or by professional stalkers, and gamekeepers. The cost of deer culling by professional agents is relatively high, at around £136 per deer (BASC, personal communication). Culling can be facilitated by the installation of deer high seats at £249-£278 per seat and shooting mounds for £250 each (FR Field Data, 2023; EWCO, 2023). As of 2024, the British Association for Shooting Conservation (BASC) maintains a register of competent deer stalkers can be contacted at deer@basc.org.uk.

The cost of installing seats, mounds, and hiring agents can be partially offset by revenues generated from venison sales (Gill, 1999). The production and popularity of venison-based products has grown steadily in the UK over the past decade. In 2020, the sale of 1.221 tons of venison marked a 20.1% increase from 2019 with a market value of £14.4 million, a 10.9% increase from 2019 (Scottish Venison, 2020). However, it is important to note that assessing the potential income from venison can be challenging due to several factors. New regulations, market dynamics, and yearly fluctuations in prices can significantly impact revenue projections. These variables introduce a level of uncertainty that must be considered when evaluating the financial viability of offsetting deer culling costs with venison sales (Gill, personal communication). Nonetheless, the growing appeal of venison-based jerkies, sausages and cured meats in British cuisine and supermarkets may, in the future, present a more attractive potential income stream for landowners interested in woodland creation.

Grey squirrels also constitute a major threat to woodland establishment, due to their bark stripping behaviour, necessitating control measures for successful woodland establishment. Control methods include shooting, and traps (Dutton, 2016). In the 1940s and 1950s, shooting was incentivised in the UK through free shotgun cartridges and bounty schemes. However, NGOs deemed these financial incentives both inefficient and inhumane. The government subsequently abandoned these schemes in 1958. Whilst the effectiveness of shooting as the primary culling method remains a topic of debate (Hart, 1998), the prevailing consensus among academics and professionals favours its use in conjunction with traps (Gill et al., 2019).

Numerous squirrel traps are available on the market though the cost effectiveness of individual models remains uncertain in the absence of large-scale comparative studies. A recent analysis by the National Forest Company suggests that traps costs range from £10 each to approximately £160 each (National Forest Company, 2022). Live cage traps are relatively low cost (£35), but not always effective, and time-consuming as they need to be inspected daily. However, the need for inspections ensures that no other animals are trapped (Dutton, 2016). Lethal traps such as the A18 Goodnature® are expensive (£159.99) but easy to operate as they do not require daily inspections. Yet, lethal traps indiscriminately kill every animal caught within and, as such, cannot be used in regions where red squirrels or pine martens may be present.

Raptor perches can also effectively complement traps and shooting. These perches are inexpensive, costing around £20 each, and can attract raptors to planting sites. Raptors typically prey on small rodents like voles, rats, and grey squirrels. A limited number of studies conducted in England and in the USA have shown that raptors such as goshawks can help reduce grey squirrel populations (Witmer et al., 2008; Field, 2023). Whilst not entirely reliable on its own, promoting the presence of raptors in woodlands may be a valuable component of an integrated control strategy (Dutton, 2016).

Determining the exact expenditure required for squirrel culling to ensure damages are at an "acceptable" level remains a subject of debate, with a limited number of case studies. According to Rushton and Lurz (2002) squirrel culling may entail a cost of approximately £99 (£59, 2002) per hectare including expenses for traps, labour, bait, and capital depreciation for a nine-month season. More recent estimates by Glynn and Watson (2021) provide a range from £20 to £50 per hectare per year. Our field data suggest similar costs range, hovering between £39 and £66 per hectare per year, with an average of £52 (FR Field Data, 2023). Over a project's lifetime, our case studies indicate that squirrel control costs account for 4.16% of total costs for a 2 hectares broadleaf woodland, 8.07% of total costs for a 96 hectares broadleaf woodland, and up to 10.40% of total costs for a medium sized (48ha) mixed woodland (FR field data, 2023). Although these may seem like large sums, they are relatively low by comparison with the potential income losses associated with a lack of grey squirrel management (see, supra-4.1). In addition, grants of £60 per hectare per year are made by the Rural Payment Agency and Natural England to help cover squirrel control costs.

4.5 Large Pine Weevil

The Large Pine Weevil (Hylobius abietis) is a beetle commonly found across nearly all of Eurasia. As in the rest of Europe, Hylobius poses a threat to woodland establishment in England – especially pine and spruce forests. Hylobius feeds on the bark, cambium, and phloem of a tree year-round, with peak damage occurring during the spring and late summer. When left untreated, Hylobius can lead, on average, to the death of 50% to 100% of young, planted trees. The overall economic impact of Hylobius on the UK forestry industry is a matter of debate with estimates ranging

from £5 to £7 million per year.[4] The threat posed to woodlands by Hylobius has long been recognised (Barbey, 1923) and methods to manage this threat have been investigated by studies in the UK (Williams et al., 2013; Willoughby et al., 2020), Ireland (Fedderwitz et al., 2022), and France (Conord, 2006), among others.

In the UK, experts advocate for an integrated management approach before resorting to insecticides (Willoughby et al., 2020). This approach includes using alternative silvicultural systems such as continuous cover forestry (hereafter CCF), or strategies involving leaving ground fallow for a period. In some cases, the use of tall tree shelters and mulches (see supra, 4-3) have proven somewhat effective in combination with other methods. When the use of insecticides is deemed necessary, synthetic neonicotinoids have been recommended rather than synthetic pyrethroids such as cypermethrin and alpha-cypermethrin (Willoughby et al., 2020). Cypermethrin and alpha-cypermethrin based insecticides, although highly effective against Hylobius, are extremely toxic to aquatic organisms and are subject to recent restrictions imposed by the Forest Stewardship Council.

Concerns have also been raised regarding neonicotinoids and their potential effects on the decline of essential pollinators (Martelli et al., 2022). The use of neonicotinoid pesticides has been linked to adverse effects on pollinator populations, including disruptions in their foraging behaviours. These concerns have prompted regulatory actions in some European countries, highlighting the need for further research and responsible pesticide management in forestry and other sectors such as agriculture.

As of 2024, the insecticides allowed for controlling the Large Pine Weevil cost between £60 and £187 per hectare, depending on the chemical selected (Martin Price, personal communication).

[4] See Hylobius Research Fund and Large Pine Weevil: The small pest causing a big problem for restocking | Helping farmers in Scotland | Farm Advisory Service. Last accessed 11/12/2024.

5 Infrastructure Costs

In 1957, E. R. Huggard, a lecturer in surveying and forest engineering at the University of Bangor, noted that "the amount of profit, or loss, to the owner will depend largely on the existence and efficiency of a road system within the forest" (Huggard, 1957). Huggard later added that road building costs must be properly evaluated well ahead of time to ensure a successful and profitable woodland creation. Sixty-six years later, this remains true, as road construction is still one of the most costly and challenging aspects of establishing a woodland (Papa et al., 2023).

5.1 Roads and Tracks

Vehicular access is essential for commercial woodlands. To ensure efficient timber extraction, a well-placed, durable road is necessary. Poorly designed or placed roads can suffer structural damages, degrade soils, and cause compaction, leading to high maintenance costs (Jaafari et al., 2021). Adequate design also minimises environmental impact, preserve biodiversity and prevents sediment release that could harm aquatic wildlife (Kramer, 2001).

The building of a forest road involves a number of essential consecutive steps such as design, clearing, earthwork, drainage, surface treatment and signage. The cost of each of these steps can vary depending on geographical, geological, and topographic factors (Akay, 2006; Ryan, 2005). The total costs of building a road includes not only construction costs but also maintenance costs., which can similarly vary depending upon topographic, geological, and weather-related variables. Building a road on a slope or in a difficult to access site is significantly more expensive than on level ground. Longer roads cost more to construct, not only because of their length and higher maintenance costs, but also due to the need for more ditches and culverts (Jaafari et al., 2021). To avoid unnecessary maintenance costs, nowadays it is

considered best practice to build a road before the first thinning - e.g. at around 15 years after the initial tree planting (Kula, 1988).

Commercial grade haulage roads entail significant costs, typically around £100 per metre (WCC, 2023). The cost of such roads can vary significantly depending on location and proximity to suitable stone supplies, with anecdotal evidence suggesting costs as low as £50 per metre and as high as £300 per metre. (National Trust, personal communication; Forestry England, personal communication). In case study D (96 hectares coniferous woodland), haulage road construction costs accounted for 25.19% (£1742 per hectare) of total costs at year fifty, excluding maintenance costs. The quality of surface needed tends to be lower and hence less expensive for small woodland owners, who usually do not need haulage grade roads but are able to use lower grade tracks suitable for a tractor and forwarder (Forestry Commission, 2011). Expert judgement suggests that all-terrain vehicles (ATV) tracks cost around £5 per metre, access tracks between £15 and £26 per metre, skidder tracks between £18 and £40 per metre, and forwarder tracks between £25 and £50 per metre (FR Field Data, 2023). Case studies A, B, C, E, and F show how relatively unexpensive ATV tracks are, accounting for only 1.37% to 2.65% of total costs, excluding maintenance. Tracks and roads generally require maintenance work every twenty years at a cost of approximately £5 per metre for tracks and £10 per metre for roads (WCC, 2022). The above cost estimates for roads and tracks exclude additional features such as loading bays (£8.30/m), turning areas (£8.30/m), and bell-mouth junctions, (£41/m) (FAS, 2016)

5.2 Drainage

Proper drainage is crucial in road construction and maintenance (Jaafari et al., 2021). Inadequate drainage systems can lead to water or snowmelt accumulation on the road surface causing waterlogging and erosion and resulting in higher maintenance costs (Akay and Sessions, 2004). Poor road drainage can also increase harvesting

and extraction costs as trucks may struggle to manoeuvre and require more time to transport harvested timber. Culvert pipes typically cost between £300 and £400 per culvert, excluding labour costs. Upland sites often require larger (600mm) and more expensive (£380) culverts, whereas lowland areas can use smaller (400mm) and less costly ones (£320). One culvert is generally recommended per 10 hectares of total site size (National Trust, personal communication).

5.3 Bridges

In some cases, bridges may be necessary for the road to pass over a wetland or a river. Data for the UK on the cost of building bridges for forest roads are limited. The cost of bridges is difficult to estimate because of the variability in design and materials used. A case study from Forest Research (1999), evaluates the cost of building a 4m stream crossing in six hours at £213 (£121, 1999), and a 2.5m one completed in 25 minutes at around £180 (£102, 1999). The note concludes that the presence of stone and hardcore near the harvest tracks radically reduces the costs of building a bridge. A study conducted in the Appalachians (USA) illustrates how the type of materials used influences costs, with concrete bridges being found to be significantly more expensive than log stringer and wooden panel bridges (Visser et al., 2003).

6 Labour Costs

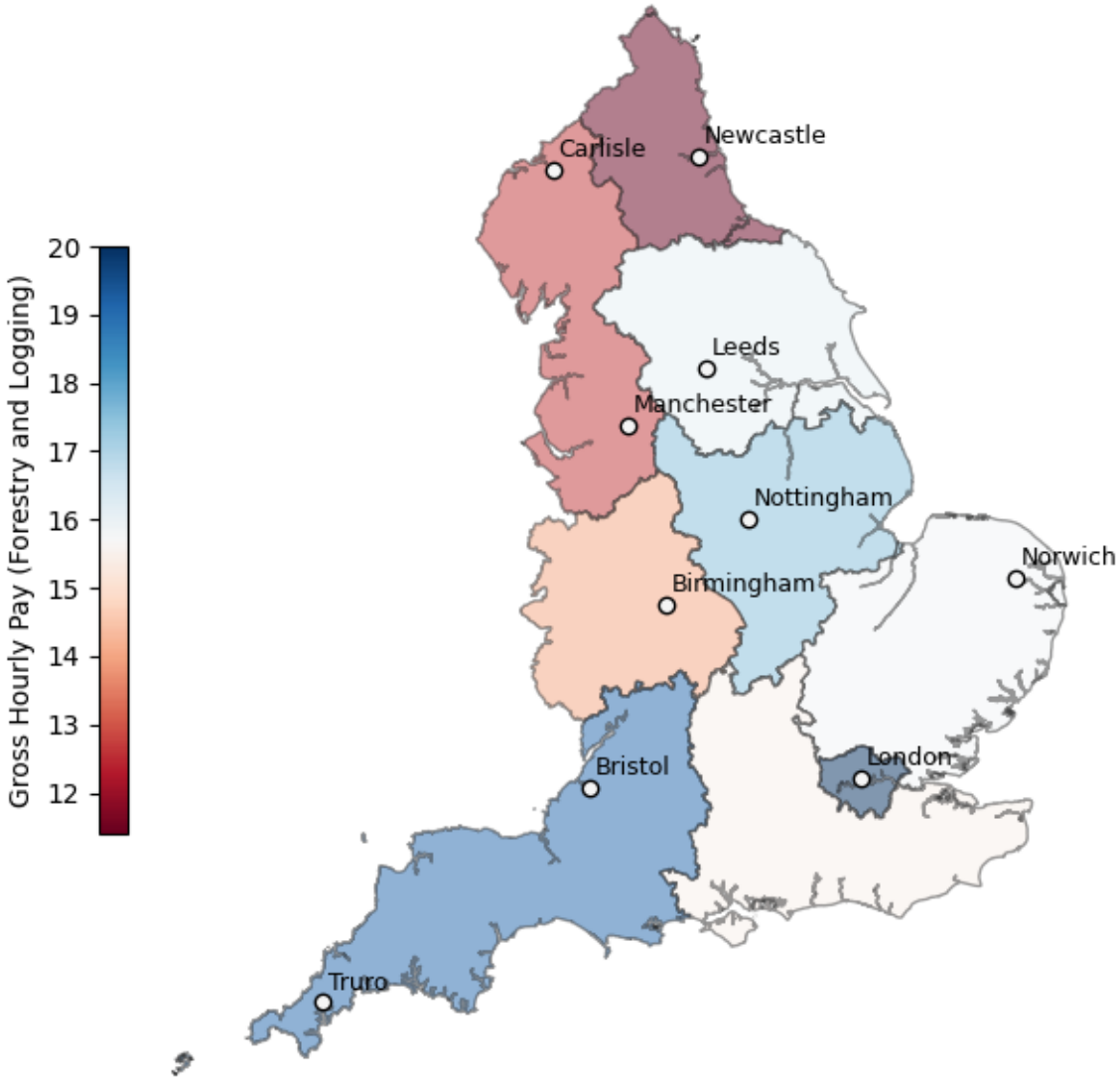
Labour costs are linked with various other expenses discussed in the preceding subsections of this report - including planting, wildlife management, and infrastructure building costs. Labour related matters might impact woodland creation costs on multiple levels.

6.1 Regional Trends

It should be noted that labour costs vary regionally. In contrast to comparable Western European countries such as Germany and France, the UK exhibits a much greater degree of regional variability in terms of wage rates. For example, income per hour worked is approximately 33% and 8% higher than the national average in London and the South-East respectively, whereas it is 15% below the national average in Yorkshire and the Humber (Zymek and Jones, 2020).

According to the Office for National Statistics, gross hourly wage rates for 'forest workers and loggers' are higher in the South-West and the East-Midlands (£19.11, and £17.52, respectively) with the North-West (£12.63), and the West-Midlands (£14) having the lowest gross hourly wage rates (ONS, 2018, 2021, 2022, 2023). Yorkshire and the Humber, the East, and the South-East fall close to the national median hourly wage (£15.88 in 2023) at £16.06, £15.79, and £15.49 respectively (ONS, 2021, 2022). Whilst reliable data could not be found for London and for the North-East, the available evidence suggests that London has the highest gross hourly wages in the country, while that in the North-East is among the lowest. These disparities affect woodland establishment at all levels since, as mentioned above, nearly every activity entails significant labour costs. Although no two sites are ever the same, were other factors equal, woodland establishment would likely be less costly in regions where wages are lower.

Table 8: Wages by Region (Forest Workers and Loggers)



6.2 Labour Shortages

In recent decades, the number of foresters, arborists, and general forestry workers in England has declined. The Institute of Chartered Foresters (ICF) recently

documented this downward trend, emphasising the potentially disastrous consequences such a shortage could have on woodland creation projects (ICF, 2021). According to the ICF, England and Wales will both require an increase of 63% to 86% in the number of forestry workers in order to meet with the UK's goal of planting 30.000 hectares of trees annually. The ICF also notes that labour shortages are expected to worsen between 2020 and 2030 due to the retirement of around 20% of the current workforce (ICF, 2021), as this is unlikely to be offset by a sufficient supply of younger workers (FSF, 2021). The departure of the United Kingdom from the European Union in 2020 has further exacerbated labour shortages in the sector. The limited evidence that is available suggests that European workers - who, until recently, constituted a significant part of the workforce in nurseries, planting, and fencing, have yet to be replaced (ICF, 2021).

Road building and harvesting costs are also likely to be impacted by shortages in labour and specialised skills. A research report by the Forestry Skills Forum group (hereafter FSF) points out that constructing a forest road could take twice as long and consume twice as much fuel when undertaken by insufficiently trained workers (FSF, 2021). Although the FSF report does not explicitly delve into the impact on maintenance expenses, it is likely that poorly constructed roads will incur higher maintenance outlays over time.

Without significant investments in outreach, education, and improved salaries, labour shortages are unlikely to be resolved soon and may even worsen, driving up the costs of woodland establishment. Forest-related subjects are rarely taught at the secondary school level, and many technical colleges and universities have closed their forestry departments over the last few years due to lack of student interest. Poor salaries, combined with the challenging nature of the jobs are often cited as major barriers to recruiting forest workers (FSF, 2021). Such jobs are often considered too difficult and potentially dangerous with financial rewards that may not justify the moral, physical and time investments required. Increasing the attractiveness of

forestry jobs remains a challenge and potentially needs to be considered when designing woodland establishment projects.

7 Conclusions

This report identified five major categories of expenditure in woodland establishment: 1) ground preparation, 2) planting, 3) vegetation control, 4) wildlife management, and 5) infrastructure. Among these, wildlife management is the most expensive, followed by infrastructure, planting, ground management, and vegetation control. Costs vary based on factors such as topography and regional wages. Fencing costs, notably, increase by approximately 25% on sloped areas. Similarly, taller, and more expensive tree guards are often needed on slopes to protect seedlings/saplings from wildlife and wind. Infrastructure costs are also higher in sloped areas due to the need for more time, labour, and additional culverts for drainage.

Wage disparities across regions also impact woodland establishment costs. Reflecting the broader wages variations in England, wages are higher in and around London and lower in the North. The South-West also has some of the highest wages for forest workers and loggers in England, possibly due to high demand in large, forested areas such as Exmoor, Dartmoor, and the New Forest and a limited supply of workers nationwide. The lack of workers is likely to impact woodland establishment costs in the near future. Before 2021, EU workers provided seasonal labour, but the UK departure from the European Union and recent immigration law changes have partially curtailed this source. Without substantial investments in education and training, supply issues are likely to persist across England and the United Kingdom at large.

However, economies of scale significantly reduce establishment costs per hectare in larger woodlands as fixed costs are spread over a larger area. Likewise, fencing costs per hectare decrease for larger woodlands as fewer meters of fencing are needed to enclose larger areas. Additionally, bulk purchasing of materials like tree guards and mulch mats becomes more cost-effective, further lowering per hectare expenses. Adopting alternative establishment methods such as direct seeding and natural regeneration that avoid the need to purchase seedlings/saplings and associated

transportation costs, in some cases can further reduce woodland establishment costs. However, the unpredictability of these methods makes implementation challenging, requiring a willingness to adopt specific silvicultural practices that may not appeal to many landowners. Costs can also be reduced for small woodlands (one hectare and below) in cases where landowners undertake planting and weeding themselves. However, this approach is time consuming and not advised for larger woodlands.

Potential avenues for further research to address existing evidence gaps include:

- Exploring the costs and benefits of hybrid planting-natural colonisation methods such as "applied nucleation" compared to traditional planting, direct seeding, or natural regeneration.
- Investigating the costs and benefits (economic and ecological) of alternative silvicultural methods such as continuous cover forestry.
- Quantifying the benefits provided by species such as pine martens to UK forestry management of "pests" (notably grey squirrels) and what impact their re-introduction has on woodland establishment costs.

Table 6: Woodland Establishment Costs Estimates per Item (2023 prices)

ITEM	UNIT	COST (AVG)	COST (RANGES)
PRE PLANTING			
Insurance	Per site/year	N/A	£170 - * (scales with size and location)
GROUND PREPARATION & PLANTING			
Furrow Ploughing	Per hectare	N/A	£120 - £157
Hinge Mounding	Per hectare	N/A	£423 - £785
Continuous Mounding	Per hectare	£ 320.00	£290 - £338
Scarification	Per hectare	£ 146.00	£122 - £348
Drainage	Per hectare	N/A	£98 - £125
Polythene Mulch Mats w. 5 Pegs	Each	£ 0.74	£0.71 - £0.79
Biodegradable Mulch Mats w. 5 Pegs	Each	£ 1.26	£1.18 - £1.36
Spot Spraying (1600 - 2200 trees/ha)	Per hectare	N/A	£132 - £220
Mowing	Per hectare	£ 45.00	£43 - £48
Inter Row Mowing	Per hectare	N/A	£80 - £225
Direct Seeding	Per hectare	£ 936.00	N/A
Tree Cost (Avg. Broadleaf 100+)	Per tree	£ 0.58	£0.52 - £0.64
Tree Cost (Avg. Broadleaf 1000+)	Per tree	£ 0.43	£0.39 - £0.47
Tree Cost (Avg. Conifer 100+)	Per tree	£ 0.50	£0.45 - £0.54
Tree Cost (Avg. Conifer 1000+)	Per tree	£ 0.42	£0.38 - £0.46
Planting (Broadleaf Tree Only)	Per tree	£ 0.40	N/A
Planting (Conifer Tree Only)	Per tree	£ 0.25	N/A
Planting (w. Guard and/or Mulch Mat)	Per tree	£ 1.10	£1 - £1.19
WILDLIFE MANAGEMENT			
Vole Guards (Plastic)	Each	£ 0.28	£0.25 - £0.31
Vole Guards (Biodegradable)	Each	£ 0.50	£0.45 - £0.54
Spiral Guards (Plastic)	Each	£ 0.46	£0.41 - £0.52
Spiral Guards (Biodegradable)	Each	£ 1.30	£1.21 - £1.38
60cm Shelters w. Stake (Plastic)	Each	£ 1.90	£1.72 - £2.15
75cm Shelters w. Stake (Plastic)	Each	£ 2.46	£2.16 - £2.76
75cm Shelters w. Stake (Biodegradable)	Each	£ 2.66	£1.99 - £3.28
1.2m Shelters w. Stake (Plastic)	Each	£ 3.11	£2.78 - £3.46
1.2m Shelters w. Stake (Biodegradable)	Each	£ 3.98	£3.32 - £4.62
1.8m Shelters w. Stake (Plastic)	Each	£ 5.10	£4.67 - £5.52
Post & Wire Fencing	Per metre	£ 9.10	£8.52 - £9.70
Rabbit Netting Supplement	Per metre	£ 5.11	£4.34 - £5.85
Sheep Netting	Per metre	£ 11.20	£9.9 - £12.7
Deer Fencing	Per metre	£ 15.88	£14.26 - £17.50
Wooden Post and Rail Fencing	Per metre	£ 23.95	£18.52 - £32.19
Dry Stone Wall (New)	Per metre	£ 55.10	£45.5 - £65.5
Dry Stone Wall (Repair)	Per metre	£ 39.00	N/A
Top Wiring Stone Wall	Per metre	£ 6.81	£5.15 - £9.1
Weevil Spraying	Per hectare	£ 124.00	N/A
Deer High Seat	Each	£ 264.32	£249.38 - £278.38
Badger Gate	Each	£ 76.80	£71 - £83
Badger Tube	Each	£ 66.12	£61 - £71.8

Squirrels Control	Per hectare/year	£ 52.40	£39.2 - £66.25
ACCESS			
Wooden Field Gate	Each	£ 470.63	£410.17 - 544.73
Metal Field Gate	Each	£ 340.00	N/A
Kissing Gate	Each	£ 336.20	£294.74 - £377.14
Pedestrian Deer Gate	Each	£ 480.28	N/A
Vehicle Deer Gate	Each	£ 749.63	N/A
Water Gate	Each	£ 428.40	N/A
ROAD/TRACKS INFRASTRUCTURES			
ATV Track	Per metre	£ 5.00	N/A
Haulage Road	Per metre	N/A	£50 - £100
Access Track	Per metre	N/A	£15 - £26
Skidder Track	Per metre	N/A	£18 - £40
Forwarder Track	Per metre	N/A	£25 - £50
Culvert Pipe 600mm	Each	£ 380.00	N/A
Culvert Pipe 400mm	Each	£ 320.00	N/A
MAINTENANCE			
Drains Maintenance	Per hectare	£ 75.00	N/A
Fence Maintenance	Per metre	£ 4.10	N/A
Fence Removal	Per metre	£ 1.50	£1.25 - £1.78
Road Maintenance	Per metre	£ 10.00	N/A
Track Maintenance	Per metre	£ 5.00	N/A
Vehicle Access Gate Maintenance	Each	£ 140.75	N/A
Pedestrian Gate Maintenance	Each	£ 94.00	N/A
Staff/Contractor Welfare On-Site	Per project	£ 300.00	N/A

Appendix 1: Case Studies

Average Case Studies

The following two examples are based on average values derived from sixty EWCO case studies (30 for each type). The case studies were combined and averaged to form an "average case study" whose assumptions are outlined in the "base assumptions column". The average case study and all its components were subsequently scaled down to 1 hectare and then proportionally scaled up in increments of 1 hectare up to 100 hectares using the Monte Carlo method outlined in the introduction.

Each of the case studies includes costs for insurance, beating up, maintenance, management, and ATV tracks costs, in addition to the EWCO specifications outlined below. Case studies for broadleaves also include squirrel management costs. The timeframe is 100 years for broadleaves and 50 years (one rotation) for conifers. All costs are discounted at 3.5% per year. Prices are adjusted for 2023. The ranges are 95% confidence intervals. These case studies do not purport to be as precise or accurate as the more specific ones introduced above. Nonetheless, these provide guidance with regards to the effects of economies of scale and elevation on average costs whilst allowing to understand when it may be more cost effective to fence a woodland or use tree guards. The specifications are as follows:

Broadleaves:

BROADLEAVES	BASE ASSUMPTIONS	1ha ASSUMPTIONS
Net Area (ha)	7.33	1.00
Stock Density (units)	1729.92	1729.92
Broadleaves (%)	0.85	0.85
Conifers (%)	0.10	0.10
Tree Shelters (units)	4540	619.28
Mulch Mats (units)	1160.71	158.33
Stone Wall Netting (m)	8.13	1.11
Post & Wire Fencing (m)	146.19	19.94
Sheep Netting (m)	340.87	46.50

Deer Fencing (m)	902.35	123.09
Rabbit Netting (m)	694.45	94.73
Difficult Site (m)	30.80	4.20
Badger Gates (units)	1.61	0.22
Metal Gates (units)	1.97	0.27
Wooden Gates (units)	0.74	0.10
Vehicle Deer Gates (units)	1.65	0.22
Pedestrian Gates (units)	0.39	0.05
Pedestrian Deer Gates (units)	1.23	0.17
Water Gates (units)	0.03	0.00
High Seat (units)	0.29	0.04
Bracken Chem (ha)	0.13	0.02
Bracken Mech (ha)	0.13	0.02
Bracken Sup (ha)	0.13	0.018
Small Dam (units)	0.10	0.013
Large Dam (units)	0.06	0.009

Conifers:

CONIFERS	BASE ASSUMPTIONS	1ha ASSUMPTIONS
Net Area (ha)	22.57	1.00
Stock Density (units)	1934.40	1934.40
Broadleaves (%)	0.24	0.24
Conifers (%)	0.74	0.74
Tree Shelters (units)	6650	294.68
Mulch Mats (units)	329.14	14.59
Stone Wall Netting (m)	75.11	3.33
Post & Wire Fencing (m)	22.14	0.98
Sheep Netting (m)	359.54	15.93
Deer Fencing (m)	1893.11	83.89
Rabbit Netting (m)	1765.11	78.22
Difficult Site (m)	143.86	6.37
Badger Gates (units)	1.93	0.09
Metal Gates (units)	0.89	0.04
Wooden Gates (units)	0.86	0.04
Vehicle Deer Gates (units)	2.11	0.09
Pedestrian Gates (units)	0.50	0.02

Pedestrian Deer Gates (units)	**1.36**	**0.06**
Water Gates (units)	**0.75**	**0.03**
High Seat (units)	**1.35**	**0.06**

Table 7: Establishment Cost Estimates – Average Case Studies Broadleaves (2023 prices, over 100 years for broadleaves)

Woodland Size	Range	Range per ha	Range (Year 1)	Difference per ha	Difference per ha
1	£16,969-£19,069	£16,969-£19,069	£7,614-£9,693		
2	£26,251-£29,581	£13,126-£14,790	£12,974-£16,209	-£4,009	-22.42%
3	£35,401-£39,838	£11,800-£13,279	£18,289-£22,617	-£1,414	-10.19%
4	£44,255-£49,896	£11,064-£12,474	£23,370-£28,828	-£759	-6.09%
5	£53,230-£59,847	£10,646-£11,969	£28,452-£34,867	-£464	-3.97%
6	£61,757-£69,469	£10,293-£11,578	£33,379-£40,807	-£373	-3.32%
7	£70,222-£78,987	£10,032-£11,284	£38,120-£46,528	-£266	-2.45%
8	£78,766-£88,452	£9,846-£11,056	£42,945-£52,245	-£189	-1.78%
9	£86,883-£97,769	£9,654-£10,863	£47,353-£57,843	-£214	-2.06%
10	£95,422-£107,500	£9,542-£10,750	£52,358-£63,853	-£105	-1.03%
20	£166,668-£189,179	£8,333-£9,459	£98,268-£119,510	-£57	-0.64%
30	£238,758-£271,316	£7,959-£9,044	£143,612-£174,577	-£35	-0.41%
40	£308,971-£351,632	£7,724-£8,791	£188,426-£229,449	-£17	-0.21%
50	£379,176-£433,271	£7,584-£8,665	£234,048-£284,258	£22	0.27%
60	£447,172-£511,294	£7,453-£8,522	£277,670-£338,308	-£17	-0.21%
70	£515,802-£590,851	£7,369-£8,441	£321,763-£392,711	-£8	-0.10%
80	£585,263-£669,558	£7,316-£8,369	£367,022-£446,444	-£16	-0.21%
90	£655,189-£750,600	£7,280-£8,340	£409,954-£500,620	-£5	-0.06%
100	£720,967-£828,164	£7,210-£8,282	£453,432-£554,979	£9	0.12%

Table 8: Establishment Cost Estimates – Average Case Studies Conifers (2023 prices, over 50 years for conifers)

Woodland Size (ha)	Range	Range per ha	Range (Year 1)	Difference per ha (£)	Difference per ha (%)
1	£12,726-£14,204	£12,726-£14,204	£5,123-£6,538		
2	£19,805-£22,211	£9,902-£11,106	£8,930-£11,183	-£2,949	-22.03%
3	£26,496-£29,643	£8,832-£9,881	£12,416-£15,360	-£1,128	-10.81%
4	£32,808-£36,788	£8,202-£9,197	£15,613-£19,199	-£651	-6.99%
5	£39,313-£44,069	£7,863-£8,814	£18,945-£23,250	-£354	-4.09%
6	£45,808-£51,360	£7,635-£8,560	£22,269-£27,292	-£238	-2.87%
7	£52,270-£58,568	£7,467-£8,367	£25,589-£31,258	-£186	-2.31%
8	£58,737-£65,703	£7,342-£8,213	£28,951-£35,220	-£138	-1.75%
9	£65,165-£72,947	£7,241-£8,105	£32,140-£39,190	-£105	-1.36%
10	£71,619-£80,182	£7,162-£8,018	£35,653-£43,265	-£70	-0.92%
20	£125,000-£141,140	£6,250-£7,057	£67,086-£81,096	-£21	-0.32%
30	£179,028-£202,747	£5,968-£6,758	£98,164-£118,637	-£6	-0.09%
40	£230,528-£261,952	£5,763-£6,549	£128,221-£155,416	-£12	-0.20%
50	£281,838-£320,756	£5,637-£6,415	£158,528-£192,084	-£14	-0.23%
60	£333,856-£379,529	£5,564-£6,325	£188,797-£228,456	-£2	-0.03%
70	£386,055-£439,492	£5,515-£6,278	£219,111-£265,704	£3	0.05%
80	£437,304-£499,409	£5,466-£6,243	£248,896-£301,936	-£7	-0.12%
90	£489,336-£558,462	£5,437-£6,205	£279,014-£338,194	-£2	-0.03%
100	£540,930 - £618,187	£5,409 - £6,182	£308,564 - £375,195	£1	0.02%

Specific Case Studies

Each of the six woodlands include insurance, beating up, spot spraying, maintenance, management, ATV (case studies A, B, C, E, and F), and haulage road (case study D). All costs are discounted at 3.5% per year. Prices are adjusted for 2023.

Case Study A. Native Broadleaves (small): 2 hectares, 1600 trees per hectare, 100% broadleaves, 3200 1.2m tree shelters, 300m of sheep netting, 1 metal access gate.

Case Study B. Productive Broadleaves (large): 96 hectares, 2042 trees per hectare, 80% broadleaves, 15% conifers, 5% open space, 950 1.2m tall tree shelters, 13720m deer fencing with 13720m rabbit netting supplement, 39 badger gates, 23 vehicle deer gates, 26 pedestrian deer gates.

Case Study C. Productive Conifers (small): 1.27 hectares, 2200 trees per hectare, 95% conifers, 5% broadleaves, 620m of post and wire fencing with 620m rabbit netting supplement, 1 metal access gate.

Case Study D. Productive Conifers (large): 102 hectares, 2000 trees per hectare, 85% conifers, 10% broadleaves, 5% open space, 680m sheep netting, 2809m of deer fencing, 4335m of rabbit netting, 2 vehicle deer gates, 6 pedestrian deer gates, 4 water gates.

Case Study E. Mixed (no slope): 48 hectares, 2168 trees per hectare, 74% conifers, 25% broadleaves, 1% open space, 1216 1.2m tall tree shelters, 3192m deer fencing with 3192m rabbit netting supplement, 1216 biodegradable mulch mats, 1 vehicle deer gate, 1 pedestrian gate, 2 pedestrian deer gates, 9 water gates.

Case Study F. Mixed (sloped): Same as above with a 25% - 30% slope.

Table 9: Case Studies - Whole Woodland Costs (over 100 years for broadleaves and mixed, 50 years for conifers)

Discounted (3.5% at 2023 prices) Whole Woodland						
Woodland Type	Total Cost		Range	Establishment Costs (Year One)		Establishment Costs (Range Year One)
Broadleaves (2 ha)	£	33,978	£32,055 - £36,323	£	19,054	£17,158 - £21,409
Broadleaves (96 ha)	£	841,244	£747,669 - £964,244	£	524,477	£429,428 - £643,401
Conifers (1.27 ha)	£	22,962	£20,227 - £26,272	£	12,222	£9,495 - £15,553
Conifers (102 ha)	£	616,786	£577,909 - £658,183	£	263,764	£227,602 - £301,641
Mixed (48 ha, no slope)	£	326,669	£299,085 - £360,504	£	187,694	£160,790 - £219,476
Mixed (48 ha, 25% slope)	£	353,560	£320,486 - £395,281	£	214,863	£181,985 - £253,927

Table 10: Case Studies - Per Hectare Costs (over 100 years for broadleaves and mixed, 50 years for conifers)

Discounted (3.5% at 2023 prices) Per Hectare			
Woodland Type	Total Cost (Range)		Cost Year One (Average)
Broadleaves (2 ha)	£16,027 - £18,162	£	9,527
Broadleaves (96 ha)	£7,788 - £10,044	£	5,463
Conifers (1.27 ha)	£16,427 - £21,165	£	9,546
Conifers (102 ha)	£5,665 - £6,453	£	2,586
Mixed (48 ha, no slope)	£6,230 - £7,510	£	3,910
Mixed (48 ha, 25% slope)	£6,676 - £8,235	£	4,476

Costs Breakdown (Specific Case Studies)

Table 11: Case Study A - % Total Breakdown

Item	Costs Y1 Discounted (%)	Costs Y100 Discounted (%)
Tree Guards	46.85%	35.61%
Insurance	0.90%	14.51%
Labour (Planting)	17.84%	10.02%
Fencing (Sheep)	17.27%	9.70%
Management	0.51%	8.15%
Weeding (Spot Spraying)	2.59%	5.54%
Maintenance	N/A	4.43%
Squirrels Control	N/A	4.16%
Saplings (BL)	6.99%	3.92%
Road/Tracks	2.79%	1.57%
Beating Up	2.37%	1.33%
Gates (All)	1.90%	1.06%

Table 12: Case Study A - £ Breakdown per Hectare

Item	Costs Y100 per Ha Discounted(£)
Tree Guards	£6,042
Insurance	£2,461
Labour (Planting)	£1,700
Fencing (Sheep)	£1,645
Management	£1,383
Weeding (Spot Spraying)	£940
Maintenance	£751
Squirrels Control	£705
Saplings (BL)	£666
Road/Tracks	£266
Beating Up	£226
Gates (All)	£181

Table 13: Case Study A - Costs at Specific Years

Year	Accumulated Non-Discounted Cost (£)	Accumulated Discounted Cost (£)
15	£29,536	£26,946
30	£36,886	£30,385
50	£45,092	£32,507
75	£53,631	£33,529

Table 14: Case Study B - % Total Breakdown

Item	Costs Y1 Discounted (%)	Costs Y100 Discounted (%)
Fencing (Deer)	40.47%	25.19%
Maintenance	N/A	14.43%
Weeding (Spot Spraying)	5.79%	13.73%
Fencing (Rabbit)	13.07%	8.14%
Squirrels Control	N/A	8.07%
Saplings (BL)	12.49%	7.78%
Labour (Planting)	11.92%	7.42%
Management	0.25%	4.47%
Gates (All)	5.68%	3.54%
Beating Up	5.03%	3.13%
Road/Tracks	2.77%	1.73%
Saplings (CON)	1.95%	1.21%
Insurance	0.04%	0.72%
Tree Guards	0.55%	0.45%

Table 15: Case Study B - £ Breakdown per Hectare

Item	Costs Y100 per Ha Discounted(£)
Fencing (Deer)	£2,202
Maintenance	£1,261
Weeding (Spot Spraying)	£1,200
Fencing (Rabbit)	£711
Squirrels Control	£705
Saplings (BL)	£680
Labour (Planting)	£648
Management	£390
Gates (All)	£309
Beating Up	£273
Road/Tracks	£151
Saplings (CON)	£106
Insurance	£63
Tree Guards	£39

Table 16: Case Study B - Costs at Specific Years

Year	Accumulated Non-Discounted Cost (£)	Accumulated Discounted Cost (£)
15	£688,426	£644,705
30	£916,422	£754,874
50	£1,126,660	£810,213
75	£1,294,059	£831,111

Table 17: Case Study C - % Total Breakdown

Item	Costs Y1 Discounted (%)	Costs Y50 Discounted (%)
Insurance	1.41%	25.54%
Maintenance	N/A	24.69%
Fencing (Stock)	44.58%	16.66%
Fencing (Rabbit)	25.07%	9.37%
Management	0.51%	9.32%
Weeding (Spot Spraying)	3.62%	5.14%
Saplings (CON)	7.70%	2.88%
Labour (Planting)	6.56%	2.45%
Road/Tracks	3.66%	1.37%
Beating Up	3.29%	1.23%
Gates (All)	2.96%	1.11%
Saplings (BL)	0.64%	0.24%

Table 18: Case Study C - £ Breakdown per Hectare

Item	Costs Y50 per Ha Discounted(£)
Insurance	£6,423
Maintenance	£6,209
Fencing (Stock)	£4,192
Fencing (Rabbit)	£2,357
Management	£2,345
Weeding (Spot Spraying)	£1,293
Saplings (CON)	£724
Labour (Planting)	£617
Road/Tracks	£344
Beating Up	£310
Gates (All)	£278
Saplings (BL)	£60

Table 19: Case Study C - Costs at Specific Years

Year	Accumulated Non-Discounted Cost (£)	Accumulated Discounted Cost (£)
15	£17,425	£16,025
30	£26,415	£20,382
50	£36,620	£22,962

Table 20: Case Study D - % Total Breakdown

Item	Costs Y1 Discounted (%)	Costs Y50 Discounted (%)
Road/Tracks	N/A	25.19%
Weeding (Spot Spraying)	11.96%	17.01%
Maintenance	N/A	14.23%
Management	0.52%	9.41%
Saplings (CON)	22.70%	8.49%
Labour (Planting)	21.77%	8.14%
Fencing (Deer)	16.35%	6.11%
Beating Up	10.30%	3.85%
Fencing (Rabbit)	8.15%	3.05%
Insurance	0.08%	1.46%
Saplings (BL)	3.21%	1.20%
Fencing (Sheep)	2.83%	1.06%
Gates (All)	2.14%	0.80%

Table 21: Case Study D - £ Breakdown per Hectare

Item	Costs Y50 per Ha Discounted(£)
Road/Tracks	£1,742
Weeding (Spot Spraying)	£1,176
Maintenance	£984
Management	£651
Saplings (CON)	£587
Labour (Planting)	£563
Fencing (Deer)	£423
Beating Up	£266
Fencing (Rabbit)	£211
Insurance	£101
Saplings (BL)	£83
Fencing (Sheep)	£73
Gates (All)	£55

Table 22: Case Study D - Costs at Specific Years

Year	Accumulated Non-Discounted Cost (£)	Accumulated Discounted Cost (£)
15	£691,520	£547,106
30	£782,480	£591,735
50	£881,587	£616,786

Table 23: Case Study E - % Total Breakdown

Item	Costs Y1 Discounted (%)	Costs Y100 Discounted (%)
Weeding (Spot Spraying)	8.61%	18.63%
Fencing (Deer)	26.24%	15.04%
Labour (Planting)	18.49%	10.60%
Squirrels Control	N/A	10.40%
Maintenance	N/A	9.27%
Saplings (CON)	14.27%	8.18%
Management	0.45%	7.43%
Fencing (Rabbit)	8.44%	4.84%
Beating Up	7.74%	4.44%
Saplings (BL)	5.79%	3.32%
Road/Tracks	3.89%	2.23%
Gates (All)	3.49%	2.00%
Insurance	0.11%	1.86%
Tree Guards	1.77%	1.37%
Weeding (Mulches)	0.71%	0.41%

Table 24: Case Study E - £ Breakdown per Hectare

Item	Costs Y100 per Ha Discounted(£)
Weeding (Spot Spraying)	£1,263
Fencing (Deer)	£1,020
Labour (Planting)	£719
Squirrels Control	£705
Maintenance	£629
Saplings (CON)	£555
Management	£504
Fencing (Rabbit)	£328
Beating Up	£301
Saplings (BL)	£225
Road/Tracks	£151
Gates (All)	£136
Insurance	£126
Tree Guards	£93
Weeding (Mulches)	£28

Table 25: Case Study E - Costs at Specific Years

Year	Accumulated Non-Discounted Cost (£)	Accumulated Discounted Cost (£)
15	£274,485	£253,816
30	£360,973	£294,870
50	£440,133	£315,988
75	£499,401	£323,268

Table 26: Case Study F - % Total Breakdown

Item	Costs Y1 Discounted (%)	Costs Y100 Discounted (%)
Fencing (Deer)	28.67%	17.36%
Weeding (Spot Spraying)	7.53%	17.21%
Labour (Planting)	20.20%	12.24%
Squirrels Control	N/A	9.60%
Maintenance	N/A	8.56%
Saplings (CON)	12.47%	7.55%
Management	0.40%	6.87%
Fencing (Rabbit)	9.22%	5.58%
Beating Up	6.77%	4.10%
Saplings (BL)	5.06%	3.06%
Road/Tracks	4.38%	2.65%
Gates (All)	3.05%	1.85%
Insurance	0.10%	1.72%
Tree Guards	1.55%	1.27%
Weeding (Mulches)	0.62%	0.38%

Table 27: Case Study F - £ Breakdown per Hectare

Item	Costs Y100 per Ha Discounted(£)
Fencing (Deer)	£1,275
Weeding (Spot Spraying)	£1,263
Labour (Planting)	£898
Squirrels Control	£705
Maintenance	£629
Saplings (CON)	£555
Management	£504
Fencing (Rabbit)	£410
Beating Up	£301
Saplings (BL)	£225
Road/Tracks	£195
Gates (All)	£136
Insurance	£126
Tree Guards	£93
Weeding (Mulches)	£28

Table 28: Case Study F - Costs at Specific Years

Year	Accumulated Non-Discounted Cost (£)	Accumulated Discounted Cost (£)
15	£302,317	£280,707
30	£388,805	£321,761
50	£467,965	£342,879
75	£527,233	£350,158

Appendix 2: Surveys

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Surveys play a fundamental role within the woodland creation process. While some may be undertaken after establishment of trees, most surveys are undertaken before tree planting takes place in order to help generate a sound understanding of the intended woodland creation site before any other activity takes place (Woodland Trust, 2022). This allows woodlands to be appropriately designed with potential negative impacts avoided and mitigated, and opportunities for enhancing the site taken into account (Forestry Commission, 2021). They are also important determining robust baselines to facilitate future monitoring of site conditions (Woodland Trust, 2022), enabling adherence to sustainable forest management requirements and guidelines as set out in the UK Forestry Standard (UKFS). As a result, surveys can arguably be seen as the foundation of woodland creation.

The next two sections cover some details on pre- and post-planting surveys. This is followed by a section highlighting existing cost estimates for specific types of survey.

Pre-planting Surveys

Pre-planting surveys involve compiling a wide array of information on the planting site. This information broadly includes the landscape context, physical site characteristics, features, as well as vulnerabilities and constraints of the site (Woodland Trust, 2022, chap. 3); but it can also be classified into seven core categories (Forestry Commission, 2021, p. 69 & 70) as illustrated in Table 1 below.

The information needed is usually collected initially by drawing upon existing databases and personal knowledge of the site. Once information from this initial stage has been reviewed, site surveys are then conducted where necessary to collect additional information to verify and/or supplement the data collected initially (Forestry Commission, 2021, p. 22; Woodland Trust, 2022). Specialist surveys may

be required in some cases for collection of in-depth site-specific information (e.g. archaeological and habitat surveys), both within the boundaries of the site and adjacent to it.

Table 1: Seven Categories of information required for woodland creation surveys.

Information Category	Examples of Information Required
Legal	Ownership boundaries, Legal access points and routes
Biodiversity	RAMSAR Sites, Special Protection Areas (SPAs), Sites of Special Scientific Interest (SSSIs), National Nature Reserves (NNRs), Priority habitats and species
Landscape & Visual	Landscape Character Area (LCA), with spatial plan and information including visual context, landscape designations, and viewpoints
Historic Environment	Designated (e.g. Listed Buildings, World Heritage Sites, Conservation Areas) and non-designated (e.g. historic features) heritage assets
Water	Flood risk, water quality, water availability
Soil, species selection, and silviculture	Soil type and conditions, presence of peaty soils and deep peat, vulnerability to impacts of climate change
People	Existing Public Rights of Way, Common Land

Source: Adapted and summarised from Forestry Commission (2021, p. 69 & 70)

Note: The list of examples provided of information required for surveys is non-exhaustive. For further information on the woodland creation survey process, please consult the source document.

The above process can be iterative, with the information feeding into stakeholder engagement activities that inform the need for any follow-up surveys. All the information collected can then feed into a woodland creation design plan, which is mandatory in applying for woodland grant funding, as well as for an Environmental Impact Assessment. These steps occur before woodland creation takes place (Forestry Commission, 2021, p. 6). Figure 1 below provides an overview of different woodland creation surveys.

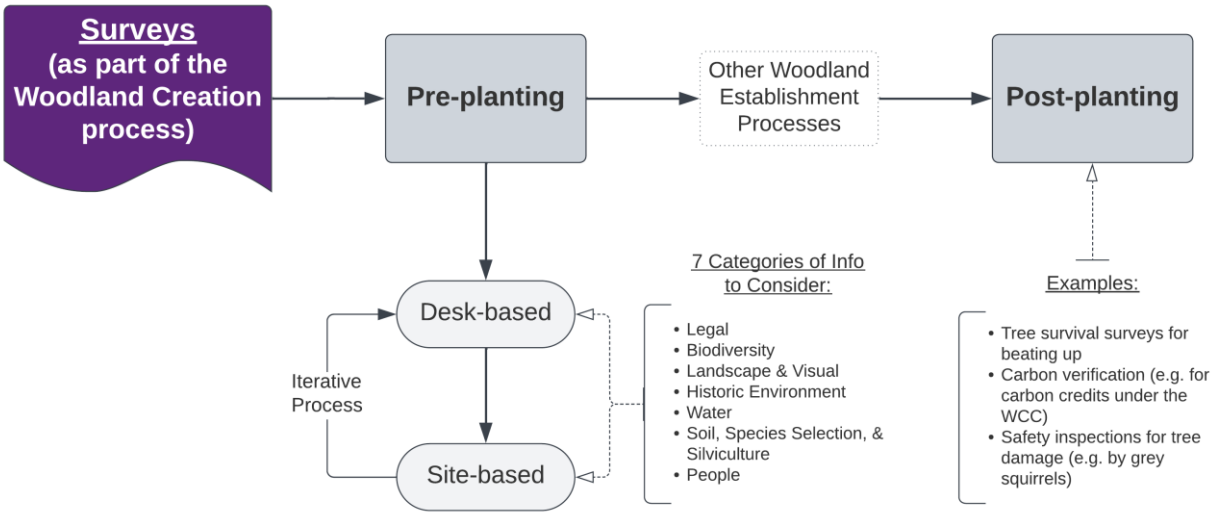

Table 29: Surveys Used in Woodland Creation.

Post-planting Surveys

While arguably of less significance than pre-planting surveys, post-planting surveys can still be important components of woodland creation. They can include surveys of tree survival to inform beating up (see Section 2.2 on Planting Costs), surveys to verify carbon sequestered required under credit or offset schemes (e.g. the WCC), and surveys of any damage to the surviving trees (e.g. by grey squirrels).

Costs of Surveys

The costs of surveys generally vary according to site characteristics (e.g. the total area covered), the approach used and the extent to which known special features (e.g. areas of particular archaeological interest) are present. Due to being a multi-faceted process involving different categories of information being collected, no generic overall cost estimate can be provided for all surveys needed. This review found relatively sparse reliable data and evidence on the costs of different types of surveys and factors affecting them. Nevertheless, Table 2 below provides some estimates for a limited range of survey types.

Table 2: Costs of different types of surveys

Survey Activities	Unit	Per unit Cost
Habitat Survey	Hectare	£312
Peat Depth Survey	Hectare	£246
Breeding Bird Survey	Hectare	£271
Archaeological Survey	Day	£3,829
Beat Up Survey	Hectare	£237
Safety Inspections	Hectare	£200
WCC Verification Survey – Yr 5 or 15+	Project	• £107 ('Small woods' – i.e. <5ha) • £536 (up to 50ha) • £1071 (>50ha)
Note: The list of survey activities above are non-exhaustive. Costs are only indicative.		

It is worth noting that the cost estimates for habitat, peat depth, breeding bird, and archaeological surveys are averages derived from only a very limited number of cases from data provided by the Woodland Trust. As a result, they are likely not as generalisable as the estimates for the other processes presented in the main sections of the report. The limited information found on archaeological surveys implies that their cost depends on the method used – e.g. whether they are desk-based, a walk-over, remote sensing, or trial excavations (Crow, 2003).

References for Surveys

Crow, P. (2003) *Managing the historic environment in woodland: the vital role of research*. Available at: https://cdn.forestresearch.gov.uk/2022/02/frhistoricenviron0203-3.pdf.

Forestry Commission (2021) *A guide to planning new woodland in England*. Available at: https://assets.publishing.service.gov.uk/media/618e79658fa8f503764ed2cf/A_Guide_to_Planning_New_Woodland_in_England_V1.0_Nov2021.pdf.

Woodland Trust (2022) *Woodland Creation Guide*. Available at: https://www.woodlandtrust.org.uk/publications/2022/02/woodland-creation-guide/.

Appendix 3: Glossary

Forestry Terms

Beating up: process that involves replacing trees have died with new transplants, typically done one or two years after the initial planting.

Mulches: layers applied to soil surfaces to smother weeds or hinder their access to sunlight. Can be made of synthetic or organic materials.

Public Rights of Way: legally protected paths that the public can use to travel across private lands.

Ride: open space providing access for forestry operations and walking. Its purpose may vary based on management objectives.

Woodland Establishment: the process of creating or regenerating a wooded area. It typically involves planting, direct seeding, or natural regeneration. Woodland establishment aims to develop a sustainable forest ecosystem, or an area managed for timber production, environmental conservation, recreational use, and other purposes.

Woodland Maintenance: the ongoing management and care of an already established woodland to ensure its health is maintained and its objectives are achieved. This involves long-term activities such as vegetation control, thinning/pruning, and protection from pests and diseases.

Roads and Tracks

The following definitions are partially adapted from: Forestry Commission (2011) *Forest roads and tracks Grants & Regulations Operations Note 25*. Forestry Commission England.

ATV Tracks: light tracks used on sensitive sites or when small volumes of timber are being harvested. Allows for the circulation of all-terrain (light) vehicles and horses.

Skidder Tracks: sturdy tracks built on small woodlands or steep sites where skidding is cost effective. Skidding consists in dragging felled trees or logs from the harvesting side to a landing area or directly into a truck.

Forwarder Tracks: heavy duty tracks used on larger woodlands to transport logs from the cutting site to a landing area or directly into a truck. Allow for the extraction of large volume of timbers using forwarder. Wider than skidder tracks.

Haulage Road/Forest Roads: type of road designed for the transportation of logs by heavy lorries. Used on large commercial woodlands when bringing lorries to into the woodland is cheaper than extracting timber to existing roads.

References:

Textbooks and research tools:

Gilbert OL, Anderson P (1998) *Habitat Creation and Repair*. Oxford University Press, Oxford.

Hart CR (1998) *Practical forestry for the agent and surveyor*, 3rd ed., repr. with amendments. Sutton, Stroud.

Haw R (2017) *Assessing the investment returns from timber and carbon in woodland creation projects*. Forestry Commission, Edinburgh.

Hotchkiss A, Herbert S, Reid C, Hornigold K (2022) *Woodland Creation Guide*. Woodland Trust, Grantham.

Kula E (1988) *The Economics of Forestry*. Springer Netherlands, Dordrecht.

Nix J (2022) *John Nix Farm Management Pocketbook*. Agro Business Consultants Ltd, Melton Mowbray.

Openshaw K (1980) *Cost and financial accounting in forestry: A practical manual*. Pergamon Press, Oxford.

Wagner JE (2012) *Forestry economics: a managerial approach*. Routledge, London.

Publicly Available Datasets:

EWCO Grant Manual Appendix 1 (2023-2024): Standard Cost Items. Available at https://assets.publishing.service.gov.uk/media/65f2dd37af6c1a001af6579c/EWCO_Grant_Manual_-_Appendix_1_-_Standard_cost_items_v3.7_issued_18.03.2024.pdf

National Forest Company (2022) Menu of Standard Costs. Available at www.nationalforest.org%2Fsites%2Fdefault%2Ffiles%2Fcomponents%2Fdownloads%2Ffiles%2FR14%2520CLS%2520Menu%2520of%2520Standard%2520costs%2520202122.xlsx&usg=AOvVaw3cGjuKm9UHqqgjgTzzhYH3&opi=89978449

Office for National Statistics (2018 – 2023) *Earnings and hours worked, UK region by industry*. Office for National Statistics, London. Available at

https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/regionbyindustry2digitsicashetable5

Woodland Carbon Code (2022) Cashflow Spreadsheet 2.2.1 Nov. 2022. Available at https://woodlandcarboncode.org.uk/images/Spreadsheets/WCC_Cashflow_Spreadsheet_V2.2.1_November_2022.xlsx

Cultural Barriers to Woodland Establishment:

Duesberg S, O'Connor D, Dhubháin ÁN (2013) To plant or not to plant—Irish farmers' goals and values with regard to afforestation. *Land Use Policy* 32:155–164.

Felton M, Jones P, Tranter R, et al (2023) Farmers' attitudes towards, and intentions to adopt, agroforestry on farms in lowland South-East and East England. *Land Use Policy* 131:1-15.

FitzGerald O, Collins C, Potter C (2021) Woodland Expansion in Upland National Parks: An Analysis of Stakeholder Views and Understanding in the Dartmoor National Park, UK. *Land* 10:270.

Iversen SV (2018) *Impacts and Perspectives of Woodland Creation in Upland Cumbria UK*. PhD Thesis, University of Lancaster, Lancaster.

Iversen SV, Naomi van der V, Convery I, et al (2022) Why understanding stakeholder perspectives and emotions is important in upland woodland creation – A case study from Cumbria, UK. *Land Use Policy* 114:105929.

Lawrence A, Dandy N (2014) Private landowners' approaches to planting and managing forests in the UK: What's the evidence? *Land Use Policy* 36:351–360.

P Staddon JU J Mills, A Goodenough, J Powell, M Vigani, P Simmonds, E Rowe (2021) *Encouraging woodland creation, regeneration and tree planting on agricultural land: A literature review.* NEER020. Countryside and Community Research Institute report to Natural England. Natural England, UK.

Schirmer J, Bull L (2014) Assessing the likelihood of widespread landholder adoption of afforestation and reforestation projects. *Global Environmental Change* 24:306–320.

Urquhart J, Courtney P, Slee B (2012) Private woodland owners' perspectives on multifunctionality in English woodlands. *Journal of Rural Studies* 28:95–106.

Watkins C (1996) Constraints on farm woodland planting in England: a study of Nottinghamshire farmers. *Forestry* 69:167–176.

Pests and Pathogens Management:

Barbey A (1923) La Forêt européenne et sa résistance aux attaques des Insectes ravageurs. *jatba* 3:593–604.

Conord C (2006) *Ecologie, génétique et symbiose bactérienne chez le grand charançon du pin, Hylobius abietis: adaptation d'un insecte ravageur à son environnement forestie*r. PhD Thesis. Université Joseph Fourier, Grenoble.

Fedderwitz F, Griffin C, McNamara L (2022) *Integrated Pest Management of the Large Pine Weevil Hylobius Abietis*: Review and perspectives for Ireland. Maynooth University, Kildare.

Hardy C, Sayyed I, Leslie AD, Dittrich ADK (2020) Effectiveness of insecticides, physical barriers and size of planting stock against damage by the pine weevil (Hylobius abietis). *Crop Protection* 137:105307.

Lemperiere G, Julien J (2003) Protection contre l'Hylobe du Pin : efficacité d'un insecticide systémique à base de Carbosulfan. *Rev For Fr* 55:129-140.

Martelli F, Hernandes NH, Zuo Z, et al (2022) Low doses of the organic insecticide spinosad trigger lysosomal defects, elevated ROS, lipid dysregulation, and neurodegeneration in flies. *eLife* 11:e73812.

Weidenmüller A, Meltzer A, Neupert S, et al (2022) Glyphosate impairs collective thermoregulation in bumblebees. *Science* 376:1122–1126.

Williams CD, Dillon AB, Harvey CD, et al (2013) Control of a major pest of forestry, Hylobius abietis, with entomopathogenic nematodes and fungi using eradicant and prophylactic strategies. *Forest Ecology and Management* 305:212–222.

Willoughby I, Moore R, Moffat AJ, et al (2020a) Are there viable chemical and non-chemical alternatives to the use of conventional insecticides for the protection of young trees from damage by the large pine weevil Hylobius abietis L. in UK forestry? *Forestry: An International Journal of Forest Research* 93:694–712.

Zaller JG, Brühl CA (2019) Editorial: Non-target Effects of Pesticides on Organisms Inhabiting Agroecosystems. *Front Environ Sci* 7:75.

Planting, Direct Seeding, Natural Regeneration:

Adam Kaliszewski (2017) Analiza kosztów sztucznego i naturalnego odnowienia dębu w wybranych nadleśnictwach Cost analysis of artificial and natural oak regeneration in selected forest districts. *Forest Research Papers* 78:315–321.

Bauld J, Guy M, Hughes S, et al (2023) Assessing the use of natural colonization to create new forests within temperate agriculturally dominated landscapes. *Restoration Ecology* 31:e14004.

Benayas JMR, Bullock JM, Newton AC (2008) Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. *Frontiers in Ecology and the Environment* 6:329–336.

Chudy R, Cubbage F, Siry J, Chudy J (2022) The profitability of artificial and natural regeneration: A forest investment comparison of Poland and the U.S. South. *Journal of Forest Business Research* 1:1–20.

Collet C, Bilot N, Boulanger V, et al (2020) *Dernières innovations sur la plantation forestière. Contribution de la R&D pour accompagner les évolutions attendues dans les pratiques*. INRAE.

Corbin JD, Holl KD (2011) Applied Nucleation as a Forest Restoration Strategy. *Forest Ecology and Management* 265: 37-46.

Corr K (2003) *Revegetation techniques: a guide for establishing native vegetation in Victoria*. Greening Australia Victoria, Heidelberg, Victoria.

Forestry Commission (2021) *Using Natural Colonisation for the Creation of New Woodland.* Forestry Commission.

Grossnickle S, Ivetić V (2017) Direct Seeding in Reforestation – A Field Performance Review. *REFOR* 4:94–142.

Hosius B, Bergmann F, Leinemann L (2016) Natürlich verjüngen oder pflanzen? *AFZ-Der Wald* 14: 24–28.

Johansson U (1998) Timber quality and volume growth in naturally regenerated and planted Scots pine stands in SW. Sweden. *Studia Forestalia Suecica* 204:3–17.

Ezell A W, Kushla J (2019) *Direct Seeding: A Forest Regeneration Alternative*. North Mississippi Research and Extension Center, Starkville, Mississippi.

Holl KD, Zahawi RA, Cole RJ, Ostertag R, Cordell S (2011) Planting Seedlings in Tree Islands Versus Plantations as a Large-Scale Tropical Forest Restoration Strategy. *Restoration Ecology* 19/4: 470–79.

Lamb D (2014) *Large-scale Forest Restoration.* Routledge, London.

Lula M, Trubins R, Ekö PM, et al (2021) Modelling effects of regeneration method on the growth and profitability of Scots pine stands. *Scandinavian Journal of Forest Research* 36:263–274.

Macmillan DC, Harley D, Morrison R (1998) Cost-effectiveness analysis of woodland ecosystem restoration. *Ecological Economics* 27:313–324.

Nguyen-The N, Lafont JP (2001) Quelle stratégie de renouvellement pour le pin sylvestre de Lozère ? Les possibilités de régénération naturelle. *Forêt Méditerranéenne* 22:81-84.

Noisette A (1987) Le coût du reboisement. *Rev For Fr* 39:43-48.

Singh G, Singh B, Tomar UK, Sharma S (2017) *A manual for dryland afforestation and management*. Arid Forest Research Institute by Scientific Publishers (India), Jodhpur.

Wiggins GG (1999) *Proceedings of the Cedar Symposium: growing western redcedar and yellow-cypress on the Queen Charlotte Islands/Haida Gwaii*. British Columbia, Ministry of Forests, Victoria.

Williams H (2004) *Create a farm woodland: a toolkit to help you plan and plant: from experiences in The National Forest*. The National Forest Company, Moira.

Willoughby I, Jinks RL, Forster J (2019) Direct seeding of birch, rowan and alder can be a viable technique for the restoration of upland native woodland in the UK. *Forestry: An International Journal of Forest Research* 92:324–338.

Willoughby I, Jinks R, Gosling P, Kerr G (2004) Creating New Broadleaved Woodland by Direct Seeding. Forestry Commission, Farnham.

Ressources Naturelles Canada (2019) *Gestion de la végétation pour la régénération de la couverture forestière sur des sites pétroliers et gaziers*. Ressources Naturelles Canada.

Weeding and Ground Preparation:

Atchison, RL, Ricke LB (1996). *Weed control options in tree plantings*. Kansas State University Agricultural Experiment Station & Cooperative Extension Service MF-2216, Manhattan (KS).

Bavin S (2020) *Weed management and woodland creation – an evidence review of herbicide alternatives and impacts on biodiversity*. Woodland Trust, Grantham.

Bochet E, García-Fayos P (2004) Factors Controlling Vegetation Establishment and Water Erosion on Motorway Slopes in Valencia, Spain. *Restoration Ecology* 12:166–174.

Bolte A, Löf M (2010) Root spatial distribution and biomass partitioning in Quercus robur L. seedlings: the effects of mounding site preparation in oak plantations. *Eur J Forest Res* 129:603–612.

Cook SK, Davis LR, Pickering F, et al (2019) *Weed control options and future opportunities for UK crops*. Research Review No. CP 182 / 1807258.

Duan J, Abduwali D (2021) Basic Theory and Methods of Afforestation. In Gonçalves AC (Ed.) *Silviculture*. IntechOpen, London.

Farm Advisory Service (2018) *Ground Preparation Practice Guide*, FAS, United Kingdom.

Fitzgerald SA (1998) *Site Preparation: An Introduction for the Woodland Owner*. Oregon State University Extension Service, Oregon.

Foot K, Sinnett D (2014) *Do you Need to Cultivate before Woodland Establishment*? Forest Research, Farnham.

Forestry Commission (2017*) The UK Forestry Standard: The governments' approach to sustainable forestry*. Forestry Commission, Edinburgh.

Hanif MN, Aijaz N, Azam K, et al (2024) Impact of microplastics on soil (physical and chemical) properties, soil biological properties/soil biota, and response of plants to it: a review. *Int. J. Environ. Sci. Techno*.

Hawkins CB, Steele TW, Letchford T (2006) The economics of site preparation and the impacts of current forest policy: evidence from central British Columbia. *Can J For Res* 36:482–494.

Khalid N, Muhammad A, Ali N, Zarrin FR (2003) Impact of Plastic Mulching as a Major Source of Microplastics in Agroecosystems. *Journal of Hazardous Materials* 445: 130455.

Lowery RF, Gjerstad DH (1991) Chemical and Mechanical Site Preparation. In: Duryea ML, Dougherty PM (eds) *Forest Regeneration Manual*. Springer Netherlands, Dordrecht, pp 251–261.

Marshall EJ (2001) Biodiversity, herbicides, and non-target plants. *BCPC Conference Weeds*:855-862.

McCarthy N, MacCarthy C, O Rathaille M (2007) *Mulch mats: their potential in establishing forest and other tree crops*. COFORD, Dublin.

McCarthy N, McCarthy C (2005) Herbicides and forest vegetation management: A review of possible alternatives. *Irish Forestry* 62:44–53.

Minogue PJ, Cantrell RL, Griswold HC (1991) Vegetation Management after Plantation Establishment. In: Duryea ML, Dougherty PM (eds) *Forest Regeneration Manual*. Springer Netherlands, Dordrecht, pp 335–358.

Morris LA, Lowery RF (1988) Influence of Site Preparation on Soil Conditions Affecting Stand Establishment and Tree Growth. *Southern Journal of Applied Forestry* 12:170–178.

Naylor REL, British Crop Protection Council (eds) (2002) *Weed management handbook*, 9th ed. Published for the British Crop Protection Council by Blackwell Science, Oxford; Malden, MA.

Natural Resources Canada (2019) *Gestion de la végétation pour la régénération de la couverture forestière sur des sites pétroliers et gaziers*. NRC, Canada.

Ninaber D (2009) *Improved control of rhododendron ponticum for environmental management*. PhD Thesis, Bangor University, Bangor.

Parrott J, MacKenzie N (2013) *A critical review of work undertaken to control invasive rhododendron in Scotland*. Forestry Commission, Edinburgh.

Paterson DB, Mason WL (1999) *Cultivation of soils for forestry*. Forestry Commission, Edinburgh.

Qi Y, Li J, Guan X, et al (2020) Effects of herbicides on non-target plant species diversity and the community composition of fallow fields in northern China. *Sci Rep* 10:9967.

Ressources Naturelles Canada (2019) *Préparation du terrain pour la régénération de la couverture forestière sur des sites pétroliers et gaziers*. Ressources Naturelles Canada.

Scottish Forestry (2021) *Cultivation for Upland Productive Woodland Creation* sites. Scottish Forestry, Edinburgh.

Simard SW, Jones MD, Durall DM, et al (2003) Chemical and mechanical site preparation: effects on Pinus contorta growth, physiology, and microsite quality on grassy, steep forest sites in British Columbia. *Can J For Res* 33:1495–1515.

Sinnett D (2014) *Complete Cultivation*. Forest Research, Farnham.

Sinnett D, Poole J, Hutchings TR (2006) The efficacy of three techniques to alleviate soil compaction at a restored sand and gravel quarry. *Soil Use and Management* 22:362–371.

Syafrudin M, Kristanti RA, Yuniarto A, et al (2021) Pesticides in Drinking Water—A Review. *IJERPH* 18:468.

Thompson DA (1984) *Ploughing of Forest Soils*. Forestry Commission, Naver Forest.

Varah, A., Ahodo, K., Coutts, S. R., Hicks, H. L., Comont, D., Crook, L., Hull, R., Neve, P., Childs, D. Z., Freckleton, R. P., & Norris, K. (2020) The costs of human-induced evolution in an agricultural system. *Nature sustainability*, 3(1), 63–71.

Von der Gönna, MA (1992) *Fundamentals of Mechanical Site Preparation*. FRDA Report 178. Forestry Canada, Victoria, B.C.

Willoughby I, Harmer R, Seier M (2009) United Kingdom. Willoughby I, Balandier P, Bentsen NS, et al (Ed.) *Forest vegetation management in Europe*. COST Office, Brussels.

Willoughby I (1999) Vegetation management in farm forestry: a comparison of alternative methods of inter-row management. *Forestry* 72:109–122.

Willoughby I (ed) (2004) *Reducing pesticide use in forestry*. Forestry Commission, Edinburgh.

Wittering WO (1974) *Weeding in the forest: a Work Study Approach*. HMSO, London.

Wong J, Youde E, Dickinson B, Hale M (2002) *Report of the rhododendron feasibility study*. University of Wales, Bangor.

Zilnik G, Bergeron PE, Chuang A, et al (2023) Meta-Analysis of Herbicide Non-Target Effects on Pest Natural Enemies. *Insects* 14:787.

Wildlife Management:

Arhipova N, Jansons A, Zaluma A, et al (2015) Bark stripping of Pinus contorta caused by moose and deer: wounding patterns, discoloration of wood, and associated fungi. *Can J For Res* 45:1434–1438.

Beaudesson PP, Brossier P, Apert A (2015) Prélèvements intensifs et soutenus pour la maîtrise des populations de cervidés dans des forêts allemandes. *Forêt-entreprise* 225:12-14.

Chau C, Paulillo A, Lu N, et al (2021) The environmental performance of protecting seedlings with plastic tree shelters for afforestation in temperate oceanic regions: A UK case study. *Science of the Total Environment* 791:148239.

Croft S, Massei G (2023) Modelling the management of an invasive species at landscape scale: are oral contraceptives the missing ingredient for success? *Wildl Res Special Issue*.

Dolman P, Fuller R, Gill R, et al (2010) Escalating ecological impacts of deer in lowland woodland. *British Wildlife:* 242–254

Downing G (2008) *The deer stalking handbook*. Quiller, Shrewsbury.

Dutton CJ (2016) *Grey Squirrel Management and control handbook*. European Squirrel Initiative, Woodbridge.

The European Squirrel Initiative (2019) "The Economic Damage caused by Grey Squirrels". *Squirrel* 37: 7-8.

Field A (2023) Goshawk as predators of grey squirrel in Gloucestershire. *Quarterly Journal of Forestry* 117: 92-97.

Gill R (1992) A review of damage by mammals in north temperate forests. 3. Impact on trees and forests. *Forestry* 65: 363–388.

Gill R (1999) Deer management to protect forest vegetation – a British perspective. Wiggins G. (Ed) *Proceedings of the Cedar Symposium, Haida Gwaii, Queen Charlotte Islands, 28-30 May 1996.* Ministry of Forests, British Columbia: 59-68.

Gill R (2000) *The impact of deer on woodland biodiversity*. Forestry Commission. Edinburgh.

Gill R, Webber J, Peace A (2000) *The Economic Implications of Deer Damage: A review of current evidence*. Final Report for The Deer Commission for Scotland, Wrecclesham.

Gill R, Morgan G (2010) The effects of varying deer density on natural regeneration in woodlands in lowland Britain. *Forestry* 83:53-63.

Gill R (2019) *Controlling grey squirrels in forests and woodlands in the UK*. UK Forestry Standard Technical Note December 2019. Wrecclesham

Gill R, Massei G, Pinkham R, Beatham S, Whitelaw B, McNicol C (2022) Grey squirrel control research – what new approaches may we anticipate for the future? *Quarterly Journal of Forestry* 116:54–61.

Glynn M, Watson P (2021) *An Analysis of the Cost of Grey Squirrel Damage to Woodland.* Prepared by RDA associates for the Royal Forestry Society. RDI Associates Ltd.

Huxley L (2003) *The Grey Squirrel Review. Profile of an invasive alien species. Grey squirrel (Sciurus carolinensis*). European Squirrel Initiative, Dorset.

Macmillan DC, Phillip S (2008) Consumptive and non-consumptive values of wild mammals in Britain. *Mammal Review* 38:189–204.

Mayle BA, Peace AJ, Gill RMA (1999) *How many deer? a field guide to estimating deer population size*. Forestry Commission, Edinburgh.

Nichols CP, Drewe JA, Gill R, et al (2016) A novel causal mechanism for grey squirrel bark stripping: The Calcium Hypothesis. *Forest Ecology and Management* 367:12–20.

Pepper HW (1992) *Forest fencing*. HMSO, London.

Quine C, Großbritannien, Mammal Society (eds) (2004) *Managing woodlands and their mammals: proceedings of a symposium organised jointly by the Mammal Society and the Forestry Commission*. Forestry Commission, Edinburgh.

Rosell C, Pericas B, Colomer J, Navàs F (2019*) Guide to measures for reducing damage caused by wild mammals in rural areas, urban areas and infrastructures*. Barcelona Provincial Council Press and Communication Office, Barcelona.

Spake, R., Bellamy, C., Gill, R., Watts, K., Wilson, T., Ditchburn, B., & Eigenbrod, F. (2020) Forest damage by deer depends on cross-scale interactions between climate, deer density and landscape structure. *Journal of Applied Ecology* 57:1376–1390.

Rushton SP, Gurnell J, Lurz PWW, Fuller RM (2002) Modeling Impacts and Costs of Gray Squirrel Control Regimes on the Viability of Red Squirrel Populations. *The Journal of Wildlife Management* 66:683.

Trenkel VM (2001) Exploring red deer culling strategies using a population-specific calibrated management model. *Journal of Environmental Management* 62:37–53.

Trout R, Brunt A (2014) *Protection of Trees from Mammal Damage*. Forest Research, Farnham.

Trout R, Kortland K (2012) *Fence marking to reduce grouse collisions*. Forestry Commission, Inverness.

Ward AI, White PCL, Smith A, Critchley CH (2004) Modelling the cost of roe deer browsing damage to forestry. *Forest Ecology and Management* 191:301–310.

Williams F, Eschen R, Harris A, et al (2010) The Economic Cost of Invasive Non-Native Species on Great Britain. The Scottish Government, DEFRA, Welsh Assembly Government, UK.

Williams LR, Northcroft K (1994) Reclaimed Plastic Containers as Tree Guards Effective against Field Vole Microtus Agrestis Damage. *Arboricultural Journal* 18:81–88.

Witmer GW, Pipas M, Burke P, et al (2008) Raptor Use of Artificial Perches at Natural Areas, City of Fort Collins, Colorado. *The Prairie Naturalist* 40:37–42.

Woodland Infrastructures:

Akay AE, Sessions J (2004) Roading and Transport Operations. In Burley J, Evans J, Youngquist JA, *Encyclopedia of Forest Sciences*. Academic Press, Cambridge (MA): 259-269.

Akay AE (2006) Minimizing total costs of forest roads with computer-aided design model. *Sadhana* 31:621–633.

Akay AE, Serin H, Sessions J, et al (2021) Evaluating the Effects of Improving Forest Road Standards on Economic Value of Forest Products. *Croat j for eng* 42:245–258.

Bajraktari A (2014) The Role of Forest Roads. *Int j ecosyst ecol sci* 4:127–134

Beguš J, Pertlik E (2017) *Guide for planning, construction and maintenance of forest roads*. FAO.

Eskandari S, Hosseini SA (2013) Assessment of Drainage System Standards of Forest Roads in Iran Using GIS. *Pol J Environ Stud* 22:675–682

FAS (2016) *Forest Infrastructure*. Farm Advisory Service, Scotland. Available at https://www.fas.scot/downloads/forest-infrastructure/

Forestry Commission *Forestry Commission Roads Specification*. Forestry Commission.

Forestry Commission (2011) *Forest roads and tracks Grants & Regulations Operations Note 25*. Forestry Commission England.

Forest Research (1999) *Construction of a Stream Crossing in Small Woodlands*. Information Note ODW 7.04. Forest Research Technical Development Branch, Dumfries.

Huggard ER (1957) Roads for Economic Timber Extraction. *Irish Forestry*: 124-131

Jaafari A, Pazhouhan I, Bettinger P (2021) Machine Learning Modeling of Forest Road Construction Costs. *Forests* 12:1169.

Kramer BW (2001) *Forest Road Contracting, Construction, and Maintenance for Small Forest Woodland Owners*. Forest Research Laboratory, Oregon State University, Research Contribution 35.

Layton DA, LeDoux CB, Hassler CC (1992) *Cost Estimators for Construction of Forest Roads in Central Appalachians*. Forest Service, Radnor, Pennsylvania.

Nasiri M, Askari B (2020) Improving drainage conditions of forest roads using the GIS and forest road simulator. *J For Sci* 66:361–367.

Nolan L, Aust W, Barrett S, et al (2015) Estimating Costs and Effectiveness of Upgrades in Forestry Best Management Practices for Stream Crossings. *Water* 7:6946–6966.

Papa I, Picchio R, Lovrinčević M, et al (2023) Factors Affecting Earthwork Volume in Forest Road Construction on Steep Terrain. *Land* 12:400.

Parsakhoo A, Jajouzadeh M (2016) Determining an optimal path for forest road construction using Dijkstra's algorithm. *J For Sci* 62:264–268.

Rowan AA (1976) *Forestry Commission Booklet: Forest road planning*. Forestry Commission, London.

Ryan T (2005) Forest Road manual: guidelines for the design, construction and management of forest roads, 2nd ed. *COFORD*, Dublin.

Toscani P, Sekot W, Holzleitner F (2020) Forest Roads from the Perspective of Managerial Accounting—Empirical Evidence from Austria. *Forests* 11:378.

Visser R, Aust WM, Gallagher T, et al (2003) Cost of Six Different Stream Crossing Options in the Appalachian Area. *Southern Journal of Applied Forestry* 27:66–70.

Weintraub A (ed) (2007) *Handbook of operations research in natural resources*. Springer, New York.

Labour and Forestry Workforce:

Forestry Skills Forum (2021) *Forestry Workforce Research*. Forestry Skills Forum, England and Wales.

Institute of Chartered Foresters (2021) *Can't see the skills for the trees – critical shortages in forestry workforce skills put climate targets at risk*. ICF, Edinburgh.

Zymek R, Jones B (2020*) UK Regional Productivity Differences: An Evidence Review.* Industrial Strategy Council, London.

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