Evaluation of the Success of Urban Tree Planting in England between 2012 and 2022

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Executive Summary

About this research

Government-backed environmental improvement programmes allocate substantial resources to planting new trees in urban locations to improve population welfare and support climate change adaptation. Alongside this, new trees are regularly planted to mitigate the loss of existing ecosystem services during new development. These activities are often widely publicised to stakeholders and the public at the time of planting, while long-term outcomes have seldom been investigated. High mortality rates significantly affect a tree-planting programme's ability to provide long-term ecological benefits. Results of a Scottish Development Agency survey of standard and larger trees planted on land owned and managed by the local authority in 1979 revealed only 54% survival after five years (Skinner, 1979). In 1985, a planted cohort re-investigation revealed that just 28% of the population was growing physically unscathed, with water and nutrient stress affecting over half the trees (Gilbertson & Bradshaw, 1985). Trees and Towns II reported an estimated average mortality rate of 20% for newly planted trees (Britt & Johnston, 2009), and interrogation of available tree inventory data from 2014–2022 showed mortality rates between 20% and 50% for newly or recently planted trees (Walker & Sparrow, 2023).

This project investigates the success of grant-funding-led and development-led urban tree planting efforts which took place between 2012 and 2022. The project investigated 820 planting locations at 48 sites across four cities: Bristol, Birmingham, Nottingham, and Leeds. This is the first time research which retrospectively investigates the survival and condition of multiple cohorts of recently planted trees across different cities has been carried out.

Objectives included determining whether specified cohorts of trees (from each of the two funding sources) had been planted, if the planted trees had survived, and systematically describing the tree, site, planting and post-planting maintenance characteristics using structured observations. The trees were surveyed using an adapted version of the Planted Tree Re-Inventory Protocol (PTRP), developed by the Bloomington Urban Forest Research Group, which was specifically designed to measure factors which influence tree establishment in the urban environment. Chi-squared tests of independence were used to look for significant differences in variable prevalence based on the funding source, and multiple variables' effects on condition outcome were investigated in the same way. Post hoc tests using standardised residuals were carried out to identify significant results. $p<0.05$ was used to determine significant findings.

Results

Regarding the delivery of approved development proposals, 23% of trees specified on approved planting schemes were not planted. It was not consistently possible to investigate the delivery of the grant-funding-led trees in the same way due to data availability, however, in one city where proposed planting plans were available, 42% of proposed Urban Tree Challenge Fund trees appeared not to have been planted in the locations specified.

Of the 687 trees which were planted (from either funding source), 79% survived, however, just 42% were found growing in good condition. 21% of development-led trees and 20% of grant-funding-led trees were found to have died or been removed at the time of the survey. Development-led trees were significantly more likely to be in poor condition than grant-funding-led trees.

The following table illustrates some key findings comparing variable prevalence between funding sources:

Indicator	Development-led (n=377, unless stated)	Grant-funded (n=310, unless stated)	Difference between funding sources
Good condition	38% (145 trees)	48% (148 trees)	Not significant
Fair condition	31% (115)	29% (90)	Not significant
Poor condition	10% (37)	3% (9)	Significant (p<0.01)
Sprouts	1% (2)	4% (12)	Not significant
Dead / removed	21% (78)	20% (63)	Not significant
Incorrect staking of staked trees)	74% (n=241 staked)	36% (n=182 staked)	Significant (p<0.01)
Lower trunk damage (below 45cm)	66% (n=289)	56% (n=233)	Not significant
Epicormic shoots present	39% (n=316)	39% (n=250)	Not significant
Chlorosis (on >25% leaf area)	32% (n=291)	22% (n=241)	Significant (p<0.01)
0% Crown dieback	31% (n=304)	44% (n=243)	Significant (p<0.01)
No visible root flare	19% (n=299)	19% (n=227)	Not significant

Looking at all the trees, those with lower trunk damage, other damage, incorrect staking, no visible root flare, grass at the base of the tree surrounding the stem, had visual chlorosis or dieback over 1% were statistically more likely to be in fair or poor condition (p<0.01).

Trees which were incorrectly staked were more likely to have other damage present. Grass, under the canopy of the tree, was also associated with lower trunk damage (p< 0.01). Trees with weeds at the base of the tree were less likely to have lower trunk damage (p<0.01). These relationships offer evidence of common risk factors that affect establishment success.

Conclusion

The survey recorded high levels of physical damage and signs of establishment stress across both planting types, with poorer outcomes overall for development-led planting compared to grant-funding-led planting. The findings reinforce the importance of proper site preparation, planting technique and regular maintenance. The data indicate that the long-term value of urban tree planting is being eroded by recurrent failures in delivery, insufficient post-planting inspection and/or maintenance and damage sustained post-planting.

Recommendations

- To support trees to establishment and improve return on investment, provide sufficient revenue funding for multi-season post-planting maintenance in all urban planting schemes, with accountability for successful establishment, not just planting.
- Address common failures, e.g. eliminate grass at the tree base before planting to reduce mower and strimmer damage, require stake and tie removal when required, ensure correct planting depth and adequate quantity and quality of soil, and enforce inspections, until established.
- Require minimum compliance with BS8545 planting standards and utilise standardised post-planting monitoring tools such as the PTRP to assess and report survival and condition.
- Incentivise community engagement in planting and aftercare of urban trees, especially for projects near private property and parks.

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1. Introduction

1.1. Background of grant funder

Fund4Trees initiated this project as part of its Research Strategy 2019–2024. Fund4Trees has three main objectives: promoting the conservation and improvement of the natural environment; educating the public, especially young people, about the protection and improvement of trees, particularly in and around urban areas; advancing research in all aspects of trees. The Fund4Trees Research Strategy provides a focus for research supporting sustainable urban treescapes under three interlinked themes: planning for trees in green infrastructure, ensuring successful establishment leading to the delivery of multiple benefits to society and the environment.

1.2. Project background and development

1.1.1. Formulation and evaluation of research proposal

In October 2020, Fund4Trees announced a research tender as part of its 2019–2024 Research Strategy, seeking proposals from researchers to explore the efficacy of tree establishment in urban environments.

Between 2022 and 2024, the author developed a research proposal in response to that tender, assisted by the input of numerous experienced arboricultural professionals. The Fund4Trees Research Advisory Committee (RAC) reviewed and accepted the final proposal in March 2024. The author completed the research and analysis between April and February 2025.

1.1.2. Guidance during the research

Project guidance was provided by Dr. Kieron Doick Ph.D. (Forest Research), and survey induction by Carl Lothian BSc (Hons) Arboriculture and Urban Forestry, MArborA (Crown Tree Consultancy).

2. Project Aims and Objectives

During the research development, a literature review was conducted to describe the project's context and identify knowledge gaps that could be addressed by the research.

This research aimed to investigate the success of urban tree planting funded through the creation of new developments or facilitated by a government grant, at sites planted between 2012 and 2022, in four different English cities.

Key research objectives included looking at whether specified cohorts of trees (from each of the two funding sources) had been planted, if they had survived, and describing the condition they were in using structured observations.

Another objective was to investigate the prevalence of specified variables that can influence successful tree establishment in the urban environment; looking to see if there were any significant differences between funding sources, and whether any of the factors investigated were significantly associated with different condition outcomes.

A final objective was to consider any other information from the collected data that could be used to evaluate the success of urban tree planting by either funding source.

3. Literature Review

3.1. Focus of review

To describe the historical context and investment landscape in which the research project was initiated, this literature review outlines common pathways to urban tree planting in England, high levels of investment in urban tree planting programmes, and the benefits these investments hope to realise. Established factors that impact urban tree establishment and survival rates are described, focusing on publicly funded tree planting programmes and planting associated with new housing development. Common and best practices for urban tree planting and urban tree planting programme evaluation are summarised.

3.2. Project context, planting pathways, investment and historic trends

3.2.1. Urbanisation, benefits of urban trees and adaptation to climate change

Characterised by high human population density and densely built features compared to their surroundings, urban areas presently provide homes to more than four and a half billion people globally. The proportion of the world's population who live in urban areas is set to increase from 55% to 68% by 2050 (UN, 2018), by which point the population of the UK could reach 77 million (ONS, 2024). Trees' physiological and psychological benefits to the human inhabitants of urban environments are largely well understood (Ferrini et al., 2017; Davies et al., 2017; Konijnendijk, 2023; Trees for Cities, 2024).

Urban trees provide habitat and forage for diverse life forms (Somme et al., 2016), supporting biodiversity, which is recognised as the foundation of other ecosystem services[1] (Robinson & Lundholm, 2012; Pinho et al., 2017). The psychological well-being of inhabitants of urban environments is closely related to both the actual (Fuller et al., 2007) and perceived (Dallimer et al., 2012) level of biodiversity. Foundational to the functioning of a city's green infrastructure, the urban forest[2] provides essential ecosystem services through its interaction with natural components of the urban environment (Pearlmutter et al., 2017).

The benefits of ecosystem services derived from the urban forest can be categorised into cultural services (including benefits to physical health, social development, cognitive capacity, the economy and cultural connections), regulating services (including carbon sequestration, temperature regulation, stormwater regulation, air purification, noise mitigation) and provisioning services (food, fuel and materials) (Davies et al., 2017). Trees can also result in some disservices, including allergenicity and blocking of light (Davies et al., 2017). Governments are frequently turning to nature-based solutions including tree planting for regulation services that mitigate against the effects of climate change and help adapt to more frequent extreme weather events (Forestry Commission England, 2010; Forestry Commission Working Group (FCWG), 2013; Pearlmutter et al., 2017; HMG, 2018; Forestry Commission, 2022).

3.2.2. Overview of key urban tree planting pathways

Government-backed grant-funded tree planting programmes are a key delivery pathway for new urban trees. Funding allocated in government budgets for specific environmental improvement goals is often followed by the elaboration and administration of individual grant schemes by the Department for Environment, Food & Rural Affairs (DEFRA), the Forestry Commission and local authorities (NAO,

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[1] Ecosystem Services are "the benefits human populations derive, directly or indirectly, from ecosystem functions (Constanza et. al, 1997), or "the direct and indirect contributions of ecosystems to human well-being" (Kumar, 2012).

[2] "The Urban Forest is an ecosystem characterized by the presence of trees and related flora, funga and fauna, the soils and landscapes they populate and the air and water resource they coexist with, all in a dynamic association with people and their human settlements" (Zürcher, 2022). "The urban forest comprises all the trees in the urban realm – in public and private spaces, along linear routes and waterways and in amenity areas. It contributes to green infrastructure and the wider urban ecosystem. It provides numerous benefits to human society and it does so in vast quantities" (Doick, n.d.).

2022). Grant-led planting is delivered by local authorities, NGOs and community groups who demonstrate they meet a grant's criteria, plus any volunteers or subcontractors such organisations later engage (Silvanus, 2013 FCWG, 2013).

When planning permission is sought for new developments, compliance with the National Planning Policy Framework, Local Plans, and supplementary planning guidance can result in the specification of new trees as part of the landscape proposals (National Planning Policy Framework, 2023; National Model Design Code, 2022). Delivery of these is another pathway via which new trees are added to urban landscapes.

The only statutory mechanism via which new trees are added to the landscape is the replacement of removed trees with Tree Preservation Orders on them, or instances where restocking is mandated because a felling licence was required to remove the trees (FCWG, 2013).

3.2.3. Economic investment in urban tree planting and maintenance

Mass tree-planting announcements have been a frequent feature of national news over the past decade, with many grant-funded schemes targeting urban, and often financially deprived, areas (Silvanus, 2013; Trees for Cities, 2024). Launched in 2010, with a funding commitment of £4 million from the coalition government, the Big Tree Plant (BTP) aimed to plant one million trees in towns across the UK. Groundwork London administered the application process, which was aimed at civic groups and non-profit organisations wanting to establish community-led tree-planting projects. The grants were supposed to target areas that would benefit most.[3] However, realising these aspirations proved difficult.[4] The millionth tree was planted in 2015 at Eastville Park in Bristol by Secretary of State for Environment, Food and Rural Affairs, Elizabeth Truss (DEFRA, 2015).

To be eligible for the BTP grant, proposers needed to demonstrate, at the application stage, a 'method for ensuring the trees are cared for in the future'.[5] However, the grant did not require a specific proportion of issued money to be allocated to specific maintenance activities by recipients. A cost-per-unit method was used by stakeholders to assess project viability (with applicants in later funding rounds receiving increased guidance on how to achieve this), and match-funding (which could include volunteer time) was viewed favourably by assessors (Silvanus, 2013). An unintended consequence of prioritising applications in line with reaching the aim of planting a million trees was that successful applicants often needed to incorporate planting a large area of whips to bring the cost of planting to under £4/tree. Concerns were raised by stakeholders and planting organisations (especially smaller ones) about the impact of this assessment approach on tree survival, delivery of benefits to the community and sufficiency of resources for ongoing tree maintenance (Silvanus, 2013).

For the three years following the final funding round of the Big Tree Plant, there were few specified urban tree-planting grants available to organisations (Friends of the Earth, 2019). Total Forestry Commission grant expenditure[6] in England was an average of £20.1 million a year between 2015–2018, compared with an average of £33 million a year in the preceding period (Forestry Commission, 2018). A survey of tree officers conducted during this period highlighted concerns regarding austerity measurements on the maintenance of the urban forest (Arboricultural Association, 2017).

In May 2019, the Urban Tree Challenge Fund (UTCF) launched with initial aims to support the planting of more than 130,000 trees in urban and peri-urban areas, a target it achieved by January 2022 (Forestry Commission, 2022). In 2022, the National Audit Office (NAO) "Planting Trees in England" report

[3] Areas of need were established by mapping potential sites against the 30% most deprived and the 30% least green areas in England, based on the Index of Multiple Deprivation (IMD) and the Generalised Land Use Database (Silvanus, 2013).
4 Groundwork estimated in 2012 that 22% of BTP recipients were not from deprived communities. 46% of participants in Silvanus research into the BTP project were not from deprived communities; grant issuers were found to have been flexible on this criterion (Silvanus, 2013).
[5] Applicants were asked to demonstrate that they had a long-term plan of community partnership and involvement which would ensure continued maintenance of the trees they planted (DEFRA/FC, 2010; Silvanus, 2013).
[6] Including grant expenditure managed by the Forestry Commission on behalf of DEFRA.

identified 764 million pounds being made available for tree canopy and peatland restoration projects between 2020 and 2025. This included a £48 million investment in the UTCF, £32 million for the Local Authority Treescapes Fund (LATF) and £117 million for England's Community Forests (NAO, 2022). Funds allocated to the latter two pots are not exclusively for planting trees in urban areas but contribute to doing so (Forestry Commission, 2021).

From 2019 until the 5th funding round in 2023, the UTCF provided successful applicants with 50% of the standard published cost of tree planting, including payments specifically for maintenance in the first three years after planting. Since the 5th funding round in 2023, the UTCF grant provides successful applicants with 80% of their planting and maintenance costs. The UTCF Manual states an expectation that, for a period of five years after the final grant payment, recipients will use reasonable endeavours to ensure the trees planted are maintained and agree to potential inspections to ensure capital assets are maintained during this period (Forestry Commission, 2022).

3.2.4. Best practices and established standards in urban tree planting

There is a large volume of information in the public domain regarding correct specification, planting and aftercare techniques for trees in the urban environment (Sacre, 2019). Forest Research[7,8], the Tree Council[9,10,11], the Arboricultural Association[12,13], and the Woodland Trust[14], along with many other professional associations[15], national charities (Groundwork, Trees for Cities, The Conservation Volunteers), local charities[16], and private organisations; have released volumes of freely available written guidance and videos on the topic. The Trees and Design Action Group (TDAG) has also released two planning resources focused on urban trees; *Trees in the Townscape: A Guide for Decision Makers*[17] and *Trees in the Hard Landscapes: A Guide for Delivery* [18]. Dr Andrew Hirons and Dr Henrik Sjöman's *Tree Species Selection for Green Infrastructure: A Guide for Specifiers*[19] is also a highly regarded resource (Sacre, 2022). For a fee, the British Standards Institution offers guidance via BS 8545 *Trees from Nursery to Independence in the Landscape* and BS 5837:2012 *Trees in relation to design, demolition and construction.*

Beyond physiological best practices, there is also sufficient publicly available advice on planning and delivering urban tree planting programmes (Britt & Johnston, 2008; Hirons & Percival, 2012; Eisenman et al., 2024). Working groups have been formed to learn from previous programmes (FCWG, 2013), and workshops and webinars on the topic are frequently delivered (TDAG, 2020–2024; Treeconomics, 2020–2024; Trees For Cities, 2024).

3.2.5. Historical trends in newly planted urban tree survival

High mortality rates significantly affect a tree-planting programme's ability to provide benefits (Widney et al., 2016). Low urban tree planting survival rates have been queried by arboricultural professionals since at least the 1980s when the Southwest Chapter of the Landscape Institute convened a Tree Establishment Symposium to address the issue (Matthews, 1983). The results of a Scottish Development Agency survey of standard and larger trees planted on land owned and managed by the local authority in 1979 revealed only 54% survival after five years (Skinner, 1979). In 1985, a specific cohort investigation revealed that just 28% of the urban tree population studied was growing physically unscathed, with water and nutrient stress the most damaging factors, affecting 56% of cases (Gilbertson

7 https://www.forestresearch.gov.uk/tools-and-resources/fthr/urban-regeneration-and-greenspace-partnership/greenspace-establishment-practices/planting-practice/
8 https://cdn.forestresearch.gov.uk/2022/02/7111_fc_urban_tree_manual_v15.pdf
9 https://treecouncil.org.uk/product/tree-growers-guide/
10 https://treecouncil.org.uk/wp-content/uploads/2019/12/Tree-planting-guide-2019-updates_1.pdf
11 https://treecouncil.org.uk/wp-content/uploads/2022/07/National-Tree-Week-planting-guide-1-2.pdf
12 https://www.trees.org.uk/Help-Advice/Young-Tree-Establishment
13 Young Tree Maintenance Tips https://www.youtube.com/watch?v=PsVVaTfhIng
14 https://www.woodlandtrust.org.uk/plant-trees/advice/
15 https://www.ltoa.org.uk/docs/LTOA_aftercare_of_trees.pdf
16 During The Big Tree Plant, The Mersey Forest produced guidance https://www.merseyforest.org.uk/howtoguides/plantandcarefortrees.pdf
17 https://www.tdag.org.uk/trees-in-the-townscape.html
18 https://www.tdag.org.uk/trees-in-hard-landscapes.html
19 https://www.tdag.org.uk/tree-species-selection-for-green-infrastructure.html

& Bradshaw, 1985). In 1990, further work by the same researchers indicated mortality rates of 39% in the first five years; 23% occurred in the first three years after planting and a further 16% occurred in the following two (Gilbertson & Bradshaw, 1990). A study from the US, conducted at a similar time, revealed that 34% died or were removed two years after planting (Nowak et al., 1990). UK research undertaken in the early 2000s reported an estimated average mortality rate of 20% for newly planted trees (Britt & Johnston, 2008). An interrogation of available tree inventory data from 2014–2022 showed mortality rates between 20% and 50% for newly or recently planted trees (Walker & Sparrow, 2023).

UK-based arboricultural consultants, tree officers, researchers and government appointed working groups have repeatedly articulated that urban tree planting survival rates must be improved (Britt & Johnston, 2008; Hirons & Percival, 2012; FCWG, 2013). In 2017, responding to Secretary of State for Environment, Food and Rural Affairs Michael Gove's announcement to plant 11 million new trees in the next parliament, the Arboricultural Association emphasised the need for tree management strategies that match planting targets with commitments to aftercare, citing high mortality rates as evidence of inadequate aftercare consideration, and stating, "Mortality rates of 30–50% are still commonplace during the first year after planting urban trees. This is clear evidence of the need for more consideration of a post-planting tree-management strategy and consultation of tree-care professionals" (Landscape and Amenity Product Update, 2017). 75% of tree officers who responded to a survey after the National Tree Officers Association Conference in 2022 agreed that "in comparison to other arboricultural research, urban planting mortality rates are an important subject for further investigation" (Brasington, 2022).

3.3. Factors influencing establishment and survival

3.3.1. Pre-planting: biophysical and human factors

Native biome, taxa characteristics, nursery stock, tree age, tree size, tree condition, planting season, and site characteristics are all statistically significant predisposing factors to mortality outcomes (Hilbert et al., 2019). Nursery production practices can impact tree root formation, and if necessary, roots should be pruned before planting (Watson & Hewitt, 2020). Contractors should inspect a sample of delivered root balls before planting (TDAG, 2014; Barcham's, n.d.) and poor-quality nursery stock should be rejected (NYC Root Zone, 2007; Cadwallader, 2016).

Non-profit governance, homeownership, socioeconomic status, and land use are all significant predisposing factors to mortality (Hilbert et al., 2019). Management practices themselves affect tree establishment; many local authorities fail to make following best practice guidance a requirement for developers and contractors – only 37% of tree strategies reviewed in 2018 mentioned specific protocols for planting and establishment and just 14% required compliance with BS 8545 (Hand & Doick, 2019). Tree officers have stated they have limited control over procurement decisions (Hand et al., 2022), and this supports comments by practising arborists that bridging communication gaps between a complex network of urban realm stakeholders is essential for planning the establishment of, and maintaining, green infrastructure (Ugolini et al., 2015). The author has encountered instances of the incorrect standard being specified during procurement by local authorities awarding tree planting tenders (i.e. BS 3998:2010, which is for tree works, instead of BS 8545, which is for tree planting).

3.3.2. Planting

Adequate access to uncompacted soil reduces the stress burden on urban trees (GreenBlue Urban, 2018), aiding them to overcome transplant shock (Watson & Himelick 2014). The consequence of failing to provide enough quality soil volume is evidenced in carpark tree stunting (FCWG, 2013; Grabosky & Gilman, 2004), with trees in one study showing up to 64% smaller stem diameters and 20% reduced height compared to the same species, size and age of tree growing in the peripheral landscape (Richards et al., 2020).

A sufficiently wide area of any existing competitive vegetation should be removed before planting, and a tree should be planted flush with the soil's surface, with the root collar slightly protruding, not below it (Kiser, 1996). Planting too deep restricts the tree's access to oxygen, induces water and nutrient stress, negatively affects mortality outcomes and causes the formation of girdling roots in landscape trees (Wells et al., 2006). Mulch can improve soil moisture retention and reduce weed growth, but it must be applied correctly to avoid negative consequences (Gilman & Grabosky, 2004; Bartlett, n.d.).

3.3.3. Post-planting

The frequency, severity, and duration of multiple abiotic stressors' can influence successful establishment (Percival, 2017). Extended periods of drought, high-temperature episodes, atmospheric pollution, soil contamination (for example, by salt or road pollutant contaminants), and root deoxygenation (via waterlogging or soil compaction) can, singly or in combination, negatively affect a tree's development and growth (Hirons & Percival, 2012). Tree condition is significantly associated with mortality (Hilbert et al., 2019). Climate-induced physiological stress is a qualitatively important inciting factor to mortality outcomes (Hilbert et al., 2019.) and is a cause for concern among urban foresters due to the increasing frequency of extreme weather events (Ferrini et al., 2017).

Watering is a critical component of successful tree establishment (Gilman et al., 1998; Arboricultural Association, 2023). The absence of adequate water during the establishment period can exacerbate transplant shock and lead to increased water stress (Hirons & Percival, 2012; Wattenhofer & Johnson, 2021). Irrigation regimens should be specific to local climate, weather and soil considerations (Hirons & Percival, 2012), failure to deliver a tailored regimen can result in a decline in condition and an increased likelihood of mortality (Vogt, 2018). A general lack of resources coupled with great variation in annual rainfall poses huge challenges to planting organisations; one current strategy for addressing it appears to be requesting public involvement with watering efforts (Arboricultural Association, 2023; Trees for Cities, 2023). Engaging local residents in tree care activities through outreach can significantly improve soil moisture, although the effects diminish over time (Moskell et al., 2016). Street trees with volunteer stewards had a mortality rate three times lower than those without after 5 years (Boyce, 2011).

Tree support and protection systems (TSPS) are frequently specified to provide stability while the root ball re-establishes (BS8545:2014) despite their potential negative effects on thigmomorphogenesis[20] (Patch, 1989; Kiser, 1996), and that they can result in morphological changes to the stem even before the trunk is constricted (Brown, 1987). Best practice guidance advocates the removal of TSPS components within one to two years following planting (Gilman & Sadowski, 2007; Patch, 1987; Hirons & Percival, 2012). Although one researcher (Tony Bradshaw) stated in the discussion section of Brown's research paper titled "Suffering at the Stake", that he thought removal after a year would only work if trees were growing vigorously and suggested 5 years (Brown, 1987), this was countered by Patch in later research which stated that, planted correctly, in suitable soil for root growth, sufficient anchorage should have formed by the end of the first growing season, after which stakes should be checked and removed when no longer needed, if the tree has not formed roots after the first couple of growing seasons it may never do so and may need to be staked all of its life (Patch, 1989). Failing to remove TSPS components at the correct time has a considerable impact on the severity of TSPS-associated damage; 35% of staked trees in one London-based study were found damaged by their TSPS (Thacker et al., 2018). 12% of dead trees found in one study were attributed to poorly maintained 'vandal guards', whilst 18% of the deaths were attributed to signs of vandalism itself – however, the same study suggested that stress from weeds and tie strangulation could have predisposed 70% of the trees to said vandalism (Gilbertson & Bradshaw, 1985). Vandalism is a historically cited issue for tree failure, especially by the public (*Halifax Courier*, 1959). However, whilst found to be a qualitatively important predisposing factor to mortality, it was not a statistically significant factor in 54 reviewed studies relating to urban tree mortality (Hilbert et al., 2019). Vandalism and accidental damage typically account for just 10% of urban tree planting failures (FCWG, 2013).

[20] Thigmomorphogenesis is the response of plant growth and development to mechanical stimulation (Jaffe, 1973). For example, the thickening of stems in response to windy environments.

Redevelopment policies, construction, demolition and inappropriate maintenance all impact tree mortality (Hilbert et al., 2019). Many local authorities report budget allocations that fall short of the identified needs for effective tree management (Wattenhofer & Johnson, 2021). Insufficiency of funds for monitoring and maintaining new tree planting has been cited as a problem by surveyed tree officers (FCWG, 2013; Brasington, 2022). Conflicts between existing local authority public realm management practices and the aims of tree planters also exist; basal trunk wounding by strimmers and ride-on mowers prevents many young trees from ever reaching maturity (Barrell, 2021).

3.3.4. Post-planting: monitoring and evaluation of urban tree planting programmes

In 1983, one researcher found that no records were being kept of tree planting survival rates (Patch, 1983); this surprised researchers of the day given the high level of public investment in planting programmes (Gilbertson & Bradshaw, 1990). Standardised data collection using tree inventories is critical to monitoring the effectiveness of ecosystem service delivery (Zürcher, 2017), and yet only four out of ten local authority tree data sets recently analysed by researchers were collecting data on new tree planting locations, and only one was collecting dates of removal (Walker & Sparrow, 2023). The Nature for Climate Fund Tree Planting Programme was launched without a robust monitoring framework, which could have ultimately increased the number of trees delivered and enabled more effective learning for future programmes (NAO, 2022).

3.4. Research gaps

Published in 2019, *Urban Tree Mortality: A Literature Review* revealed a critical need for more research into institutional structures and the effectiveness of various management strategies on urban tree mortality, as well as site characteristics, micro-climate and soil constitution influence (Hilbert et al., 2019). The cost and subsequent outcomes of different maintenance methods need to be studied further, noting the intensity, frequency, duration and type of aftercare which is delivered (Vogt, 2018). UK research supports the urgent need to better understand survival rates (Britt & Johnston, 2008; Walker & Sparrow, 2023) and to properly evaluate outcomes from urban planting initiatives (NAO, 2022).

To address some of the current research gaps, this project will use structured observations of tree characteristics, site characteristics, planting and post-planting maintenance practices to evaluate grant-funding-led and development-led tree planting completed between 2012 and 2022.

4. Research Method

4.1. Site and tree selection

At the proposal stage, cities were identified that demonstrated good variation geographically and were large enough that multiple large development sites where specified tree planting had taken place were likely to be found within them. From a practical perspective, the locations also needed to be accessible within the scope of the project resources. The four locations selected were Bristol, Birmingham, Nottingham and Leeds. These cities were also chosen because it was believed (at the proposal stage) that both BTP and UTCF-enabled tree planting may have taken place in each of them. In 2019, the average local authority district Index Multiple Deprivation rank for the primary local authority in Birmingham and Nottingham was in the upper quartile (i.e. highest deprivation) and Bristol and Leeds were in the second quartile (Index Multiple Deprivation, 2019). London was excluded to conserve project resources and because it was considered that tree planting in London may have been better resourced compared to the rest of England (additional planting grants were available there during the years of interest).

4.1.1. Development-led tree planting

In each city, housing development sites which were built between 2013 and 2021 were sought within a six-mile radius of the (approximate) city centre. Sites were identified by searches of the relevant local authority’s Planning Portal, its housing supply lists, and approved planning application publications.

Google searches for development plan announcements and aerial scanning for large-scale developments on historical Google Earth imagery were also used; this was followed up by searching for a proposed site's landscaping and tree planting proposals on the Planning Portal.

Approved landscaping or tree planting proposals were downloaded from the Planning Portal and checked to see if they contained proposals for planting large trees. Standard, selected standard, heavy standard and extra-heavy standard sizes (as described in BS 8545:2014) were all considered. The desirable survey design was to achieve five repetitions of four different species at each site (total desired *n* trees per site = 20). Although desirable, it was not required for the same exact species to be repeated at each site. A constrained set of easily identifiable species, likely to be abundant across many development sites, was agreed upon between the researcher and funders at the proposal stage, and this formed the priority basis on which species were selected.

When a plan was identified as having sufficient repetitions of each individual species, trees were then selected based on their proximity to one another; both to make the project more feasible and remove as much surveyor bias in which trees were being selected as possible. This method was fully adopted after two site survey plans were prepared slightly differently in Bristol (trees simply selected based on species, dispersed across the site). This happened at the beginning of the surveying period and was not corrected due to the required pace of ongoing survey delivery throughout the summer – at these particular sites it is not thought to have influenced the outcome and was a matter of around six trees which ultimately may have been selected slightly differently if the stated method was used. Corrections to other plans prepared in this way were made for the other four sites in Bristol. Trees on private property were excluded at the selection stage, although occasional oversights distinguishing property boundaries on landscaping plans resulted in 14 trees on private property being included.

In each of the cities, if after more than a reasonable number of otherwise appropriate sites failed to meet the experimental design requirements when planting plans were checked (species/size/replications), planting plans which did not specify species were used. When this type of plan was used, a block of 20 consecutive trees was identified for the survey. Four of the 24 development site proposals used in this project did not have species identified on the plan.

4.1.2. Grant-funding-led tree planting

Tree planting delivered using funds from the Big Tree Plant (BTP) or the Urban Tree Challenge Fund (UTCF) was identified in a number of different ways. Searches were made of existing Freedom of Information Requests (FOIs), published Big Tree Plant data, local authority websites, their relevant annual reports and social media posts, as well as the websites and social media of relevant tree planting organisations and friends of parks pages. National news announcements from the time were also checked. FOI requests were issued by the researcher to relevant local authorities to try and confirm whether the cities had planted larger (standard) trees in urban areas, using money from either grant. Standards, selected standards and heavy standards were included (as described in BS 8545:2014). Half standard size trees were not intentionally included, but it is thought that a few of the trees which were surveyed may have been planted as half standards. The FOI requests were only partially successful in retrieving the required information; further triangulation of available information was necessary via personal correspondence with local authority staff and tree-planting partners. Locations of BTP planting captured in an available Forestry Commission dataset[21] were not found to be accurate in all instances. It is possible (but unconfirmed) that these locations and numbers may have been submitted by the tree planting organisations themselves via a 'planting numbers tracking form' accessible on the BTP website while the project ran (accessed by the researcher using the Wayback Machine).[22]

The researcher wanted to survey as similar a type of tree planting as possible between funding sources so that it was relevant to compare the data. The constrained set of easily identifiable species was used as a starting point where possible. However, in many instances, information regarding what species had

[21] https://www.data.gov.uk/dataset/2ad276b4-2b2c-4834-ba15-663c31a852cd/big-tree-plant-sites
[22] https://web.archive.org/web/20130325032041/http://www.defra.gov.uk/bigtreeplant/get-involved/tell-us/

been planted was not found or not provided. It was only possible to select five repetitions of the same species for the UTCF grant in one of the four cities (Bristol). It was also more difficult to ascertain tree planting locations associated with a specific grant than anticipated, and to know how many were planted. Although attempted, it was too constraining to look for 20 trees per site for this funding source, so smaller or larger groups of trees had to be included.

Species and planting location data for UTCF trees planted in Bristol were available via an open dataset. Sites were then chosen based on the sufficiency of species repetitions, attempting to make five repetitions of four species (from the preferred species list) at each site (total n=20). Individual tree selections were made by ordering the spreadsheet data by local area (ward), then by species. Coordinates of the first five trees of each species on the spreadsheet were plotted on Google My Maps. Groups of 20 trees in close proximity to each other were considered as one site, and a site plan showing their locations was created to carry out the survey.

For BTP trees in Bristol, one site was identified as having had direct BTP funding in an end-of-year report. For this site, a draft planting proposal plan which appeared to be followed through was available via a 'Friends of the Park' page and 20 trees were sampled from it. Three other, older planting sites in Bristol were sampled for convenience from sites known to have been planted by the same organisation that received BTP funding during some of the years the grant ran. BTP funding is unlikely to have been the exclusive funding source for the planting at these three sites, as the organisation pooled money from multiple sources at the time. However, no record of exactly which sites were planted using BTP funding could be corroborated. At these three sites, all visible newly planted trees on historical Google Earth aerial imagery (taken as close to the date of planting as possible) was used to define the number of trees planted.

In Birmingham, for UTCF trees, the researcher had access to an organisation's planting plans which had been submitted as part of an awarded grant's application process. These plans contained proposed tree planting locations but no species information.

BTP sites in Birmingham were found by matching pins on the Forestry Commission dataset[21] with announcements on the grant recipient's website and Facebook pages, some of which detailed the number of trees and species planted. Using these announcements, the researcher used the Google Earth history function to identify the trees at the sites as close to the stated planting date as possible. Screenshots were captured where the planted trees could be seen on the historical aerial imagery, and these were used to create a site plan for the survey.

In Nottingham, email correspondence with a tree planting organisation yielded information about where some UTCF-funded trees were planted. The exact number at each site, and the particular species planted at the site, were not provided in this correspondence. After locating these sites, the researcher used the Google Earth history function to identify the trees at the sites as close to the stated planting date as possible. Screenshots were captured where the planted trees could be seen on the historical aerial imagery, and these were used to create a site plan in order to carry out the survey. No information about BTP planting locations in Nottingham was found via FOI request to the local authority.

In Leeds, in response to the researcher's FOI request, the local authority did not provide any information about larger tree planting locations or species planted via the BTP or the UTCF. The FOI response stated that it would take over 18 hours to ascertain information about larger tree planting locations delivered through the UTCF by planting partners of the local authority. A planting organisation contacted by the researcher also did not provide this information. The impression formed by the researcher from correspondence with the organisation was that the requested information was not available. It is quite possible that little BTP planting happened in the city; there were not very many locations in the Forestry Commission dataset within the specified survey zone. Because it was not possible to source sites funded by either the BTP or UTCF in Leeds, a comparable project (species and size of tree planted), partially funded by the Community Forests Trust, was surveyed instead. Following the methods described above, Table 1 sets out the number of trees that were specified for survey in each city from each funding source.

Table 1. Number of sites and trees identified for inclusion in the survey

	Number of development-led sites	Number of development-led trees	Number of grant-led sites	Number of grant-led trees
Bristol	6	120	7	136
Birmingham	6	117	9	82
Nottingham	6	115	7	94
Leeds	6	136	1	20
Total	24	488	24	332

4.2. Survey Method

4.2.1. Planted Tree Re-Inventory Protocol and modifications

The Planted Tree Re-Inventory Protocol[23] (PTRP) was developed by the Bloomington Urban Forest Research Group and designed to "provide a set of procedures that tree-planting organisations and their volunteers can use to keep track of planted urban trees over time". The creators of the protocol state, "The protocol … can serve as a beginning of a conversation between researchers, urban forestry practitioners, and the public about the measurement of the factors that influence the success of recently planted urban trees" (Vogt et al., 2014). As it was designed for use by both professionals and citizen scientists it was considered a suitable protocol for the researcher to use for this project.

The PTRP provides a method of collecting data on 41 variables (included in Table 2 below) that enables organisations to look at how different tree outcomes (e.g. survival, condition, dieback) may be related to other variables. A more detailed description of all the PTRP variables collected in this research, and any variations on the original methodology are described in Table 12, Appendix 1. A weekend of PTRP survey training was scheduled in Bristol between the researcher and a suitably qualified arboricultural consultant to confirm understanding of the protocol's procedures.

4.2.2. Addition variables collected

To provide extra details that may later be used in the analysis, 14 additional (to the PTRP) variables were included in this research. These additional variables are italicised below:

- Two additional interference variables: *hedges* and *vegetation (other than hedges)*. Interference from green infrastructure features was found during the survey training days.
- *Diameter at 1m* above ground level (mm).
- *Road congestion* (parking availability at the tree's planting location) was assessed as described[24] by the organisation Birmingham Tree People.
- Separate variables for whether *tree guards* (around the main stem and most often stake) and *stem guards* (at the base/root collar of the tree) were present/maintained correctly.
- Presence of a *water pipe* and if it had been maintained correctly.
- Visual evidence of a *guying system* maintained incorrectly.
- Visual evidence of suspected *compaction* (i.e. tyre track marks, vehicles parked on top of the planting area), suspected *reinstated soil* (i.e. building rubble in soil), *soil contamination* (chemicals/oil on the surface of planting area).
- A second set of *compaction* and *reinstated soil* variables were added after the fieldwork if Google Earth aerial imagery evidence of either was found after the survey.
- *Waterlogging* (water not draining from planting site).

[23] https://urbanforestry.indiana.edu/doc/publications/2014-planted-protocol.pdf

[24] Variables Handout v2 2024 https://birminghamtreepeople.org.uk/wp-content/uploads/2024/02/BTP-Variables-Handout-2024.pdf, page 9.

A detailed description of the additional variables collected and the methodology for collecting them is provided in Appendix 1, they can be looked up by variable ID number.

Table 2. Variables collected

Variables collected *denotes an additional variable, not described in the Planted Tree Re-inventory Protocol.	This Research's Variable ID	**Variables collected** *denotes an additional variable, not described in the Planted Tree Re-inventory Protocol.	This Research's Variable ID
Tree ID	V1	**Planting area type**	V33
Location	V2	**Planting area relative to road**	V34
***City**	V3	**Planting area width**	V35
***Funding source**	V4	**Planting area length**	V36
***Grant type**	V5	***Planting area (m^2)**	V37
***Planting season**	V6	**Kerb presence**	V38
Species	V7	**Number of trees 10m radius (of measured T)**	V39
DBH	V8	**Number of trees 20m radius (of measured T)**	V40
***Diameter at 1m**	V9	**Number of trees in same planting Area (as measured T)**	V41
Caliper	V10	**Distance to road**	V42
Total height	V11	**Distance to building**	V43
Height to crown	V12	**Maintenance variables: pruning, mulching, staking, *tree guard,*stem Guard, *water bag,*water pipe**	V44-50
Crown dieback	V13	***Guying**	V51
Crown exposure	V14	**Rubbish/debris**	V52
Chlorosis	V15	***Road congestion**	V53
***Epicormic shoots**	V16	***Compaction 1**	V54
Root flare	V17	***Compaction 2**	V55
Lower trunk damage	V18	***Possible site compaction**	V56
Other damage	V19	***Reinstated soil 1**	V57
Condition category	V20	***Reinstated soil 2**	V58
***Consolidated tree condition category**	V21	***Possible poor soil quality**	V59
Interference variables: utilities, buildings, fences, signs, lighting, pedestrian traffic, road traffic, *hedges, *other vegetation	V22–30	***Waterlogging**	V60
Ground cover type (at base)	V31	***Contamination**	V61
Ground cover type (under canopy)	V32		

4.2.3. Further explanations

Data was collected using an iPhone 13pro and the application Epicollect5 (a mobile data gathering software suitable for the project because of its on and offline functionality, cost and output file type). To avoid any confusion between chlorosis and early autumnal tinting of the leaves, training and physical surveys were completed between 8th June and 7th August 2024, except for nine trees which were surveyed on 24th August.

Bird feeders and yard art (as described in the PTRP) were noted but not assigned their own variable in this research, i.e. there was not an individual prompting question set up for these variables. Similarly, notes were made on suspected weedkiller use, and if suspected insect or animal damage was present. Suspected weedkiller use was identified by its neat, wide, circular application around the tree, at multiple trees in a row on a site, or by a resident informing the researcher of its use.

During and after the data collection, it was necessary to conduct further investigation to learn how many of the specified trees (not present at the time of the survey) were originally planted. Enquiries were made about this with local people encountered during the fieldwork. Following the field campaigns, the coordinates of the tree locations were plotted on Google Earth and each site was further investigated using historical Google Earth aerial imagery and multiple angles and years of Google Street View to corroborate or determine if and when each of the specified trees were planted.

After the survey, data cleaning and standardisation were carried out, and summary statistics were produced. Chi-squared tests of independence were used to look for significant differences in variable prevalence based on the funding source, and multiple variables' effects on condition outcome were investigated the same way. $p<0.05$ or $p<0.01$ was used to determine significant findings. Post hoc tests using standardised residuals were carried out to identify significant results. The tests used a two-tailed hypothesis (to check for differences in either direction), and significance level $\alpha=0.05$ (adjusted for the number of tests using a Bonferroni correction) to determine significant results.

Annual mortality rates were calculated for each site, and the proportion of 'unscathed trees' was investigated (i.e. those with no defects as recorded through the collected variables).

5. Results

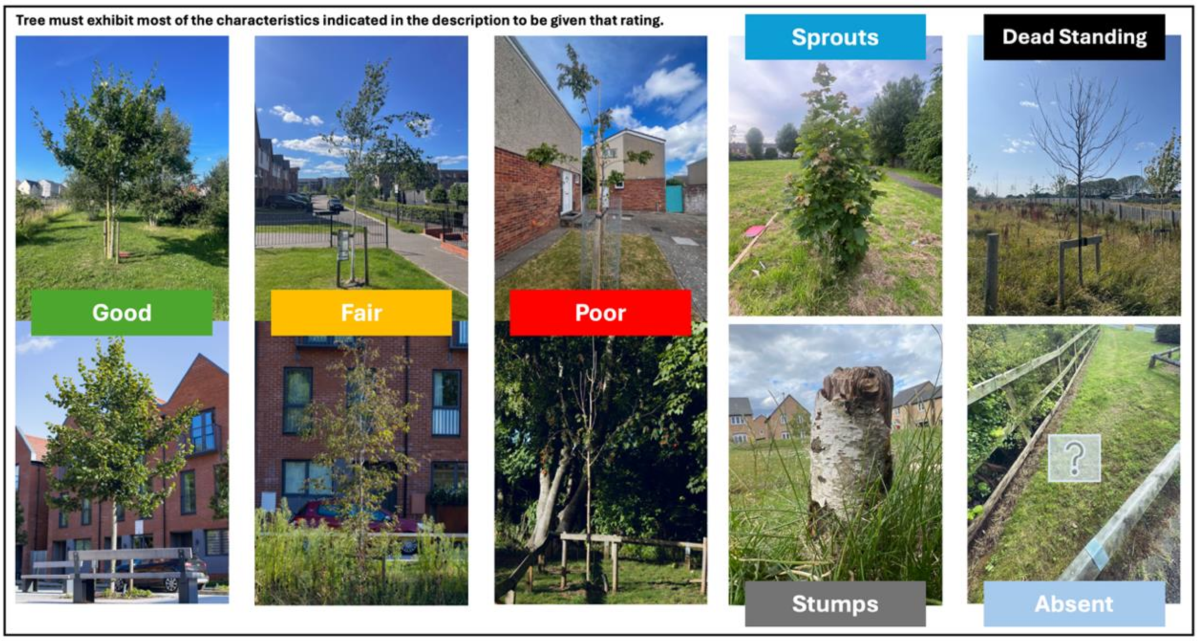
5.1. What condition were the trees in on the day of the survey?

The Planted Tree Re-Inventory Protocol (PTRP) condition categories are described, as they appear in the protocol, below. A tree had to "indicate most of the characteristics indicated to be given that rating".

> **Good**: full canopy, minimal to no mechanical damage to trunk, no branch dieback over 5cm (2") in diameter, no suckering (root or water sprouts), form is characteristic of species.
>
> **Fair**: thinning canopy, new growth in medium to low amounts, tree may be stunted, significant mechanical damage to trunk (new or old), insect/disease is visibly affecting the tree, form not representative of species, premature fall colouring on foliage, needs training pruning.
>
> **Poor**: tree is declining, visible dead branches over 5cm (2") in diameter in canopy, significant dieback of other branches in inner and outer canopy, severe mechanical damage to trunk usually including decay from damage, new foliage is small, stunted or minimum amount of new growth, needs priority pruning of dead wood.
>
> **Sprouts**: only a stump of a tree is present, with one or more water sprouts of 45cm (18") or greater in height growing from the remaining stump and root system.
>
> **Stumps:** only a stump of a tree is present, with no water sprouts greater than 45cm
>
> **Dead Standing:** a standing dead tree, with no signs of life with new foliage, bark may be beginning to peel
>
> **Absent:** no tree present not even a stump remains visible in the location where the tree should have been.

The following plate is a visual reference created by the author to illustrate the condition categories used in the PTRP.

Figure 0: Planted Tree Re-Inventory Protocol condition key



5.1.1. Planted Tree Re-Inventory Protocol results

Figure 1 shows the percentage of trees in each PTRP *condition category* on the day of the survey, from all funding sources and planting categories. The 31% of trees in the absent category were not present at the time of the survey. Trees in all other categories were present at the time of the survey.

Figure 1. Planted Tree Re-Inventory Protocol condition category (all trees *n*=820)

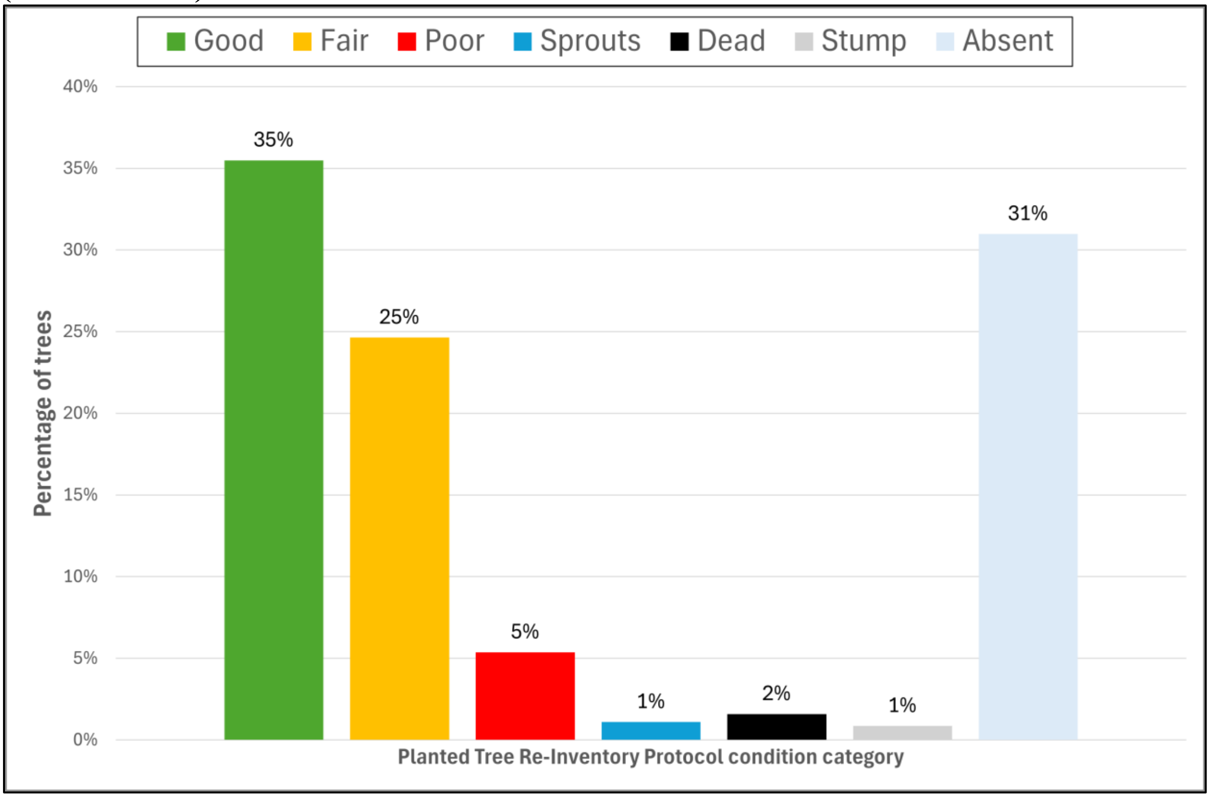
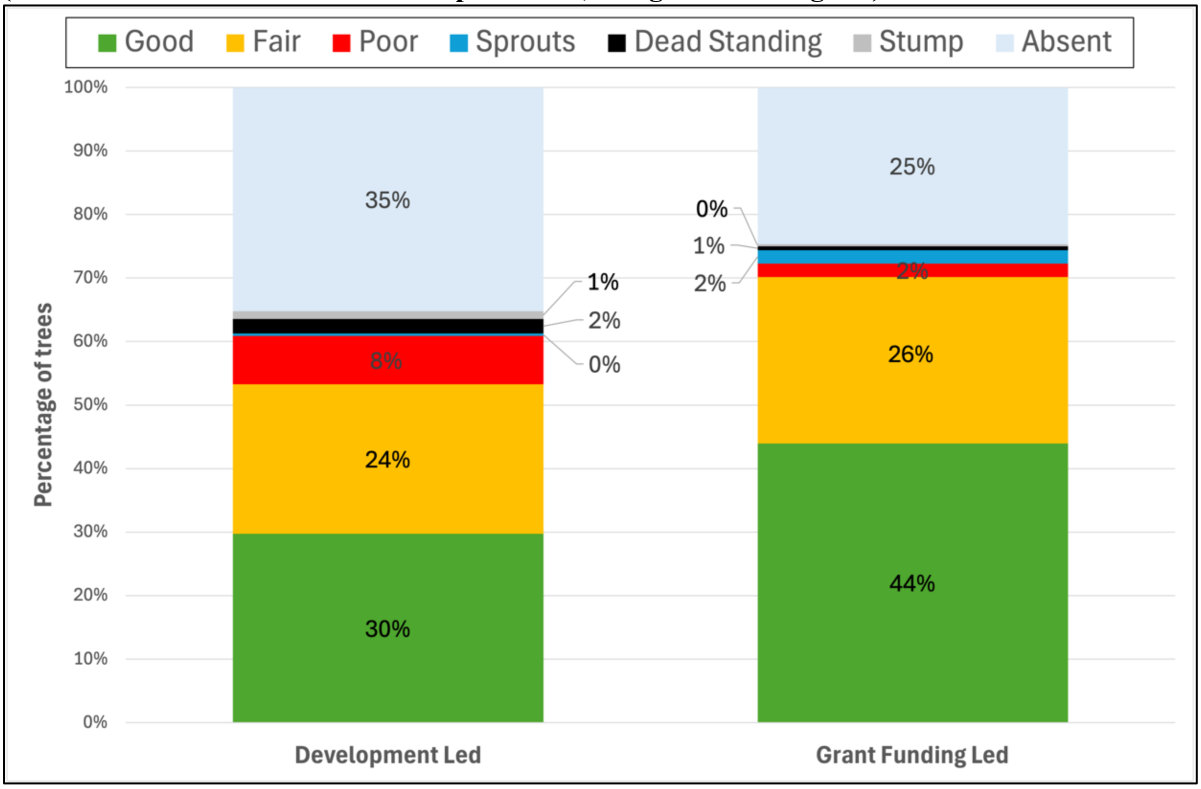


Figure 2 shows the percentage of the trees in each PTRP *condition category* on the day of the survey, split by funding source.

Figure 2. Planted Tree Re-Inventory Protocol condition category split by funding source (total observation *n*=820: 488 development-led, 332 grant-funding-led)



5.2. Were the trees planted?

With such a large proportion of the trees in the *absent* category, it was necessary to investigate if the trees had been planted. It was determined that 687 of the 820 trees looked for *were* planted; 377 development-led trees and 310 grant-funding-led trees.

5.2.1 Development-led

Planting of the trees specified on approved planting proposals at development-led planting sites ranged from 5% to 100% (78% average). Table 3 shows that 77% of the trees specified on the planting plans *were* planted, while 23% of the trees specified on the planting plans *were not* planted. The percentage of expected trees planted at each site can be found in Appendix 2.

Table 3. Development-led planting delivery

	Expected number of trees	Trees *not* planted	% of expected trees planted
Bristol	120	27	78%
Birmingham	117	30	74%
Nottingham	115	21	82%
Leeds	136	33	76%
Total (Development-led Planting)	488	111	77%

Although it is not quantified in this research, the researcher surveyed trees at several development sites where a smaller tree than expected (based on the landscaping proposal specifications) appeared to have been planted.

5.2.2. Grant-Funding-led

In Bristol, the sampled trees were partially compiled from planting plans and partially from online announcements or records made at the time of planting, so to report a planting delivery percentage for all grant-funding-led trees would not be accurate. Two UTCF trees that were planted (according to online records) were not present at the time of the survey and did not appear to have been planted based on aerial imagery. However, they could have been planted and removed before the date the satellite imagery was captured. One BTP tree specified on the draft planting proposal (that was otherwise followed through with) did not appear to have been planted (or may have been planted and removed before the satellite imagery was captured).

In Birmingham, for UTCF sites, the researcher was sent tree planting proposals which were submitted by a planting organisation before they received the grant. These proposals indicated what should have been planted and therefore the researcher could calculate the percentage of proposed trees that *were* planted. 42% (18/42) of UTCF trees that were proposed were found not to have been planted at the specified locations or in the vicinity. It is possible that some of these trees were planted but removed before the satellite imagery was captured, or were planted in places in the shadows on available satellite imagery and had been removed by the time the surveys took place. Anecdotal evidence from a member of the planting organisation also suggested that some of the proposed trees might have been planted in more suitable locations after the grant was received, based on local knowledge at the time. It is not unreasonable to consider this a possibility – at one of the sites, of seven proposed trees, the four which *were* planted all later died.

No delivery calculation was done for the BTP sites in Birmingham. Only one tree that was said to have been planted (in a planting announcement online) was conceived not to have been planted at the time/location specified, and it could have been planted and removed before the satellite imagery was captured.

It was not possible to calculate a planting delivery percentage for grant-funding-led planting in Nottingham or Leeds, as all the trees were identified as planted before the survey of the sites.

5.3. What condition were the planted trees in?

To enable further analysis, a new variable titled *consolidated condition category* was formed, and within it a condition category created which combined the PTRP condition categories *stumps* and *dead standing*, and added to it trees which were known to have been planted but which were *absent* at the time of the survey (indicating they had either died or been removed). This condition category was titled "*stumps, dead standing, died or removed*".

5.3.1. Tree condition outcomes compared by funding source and city

Figure 3 shows the percentage of planted trees from each funding source in each *consolidated condition category*. 21% of development-led trees had died or been removed since planting compared to 20% of the grant-funding-led trees.

A chi-square test of independence was performed to look for significant differences in condition outcomes based on funding source. The relationship between these variables was significant, X^2 (4, n=687) = 22.39, p<0.01. Post hoc testing using adjusted residuals was used to determine where any significant differences occurred within the data. Development-led trees were significantly more likely to be in the poor condition category than grant-funding-led trees (p<0.01).

The data showed 2.4% more development-led trees in the *fair* condition category, and 1.8% more grant-funding-led trees in the *sprouts* category – but these differences were not statistically significant.

Figure 3. Consolidated condition category
(planted trees n=687; development-led *n*=377, grant-funding-led *n*=310)

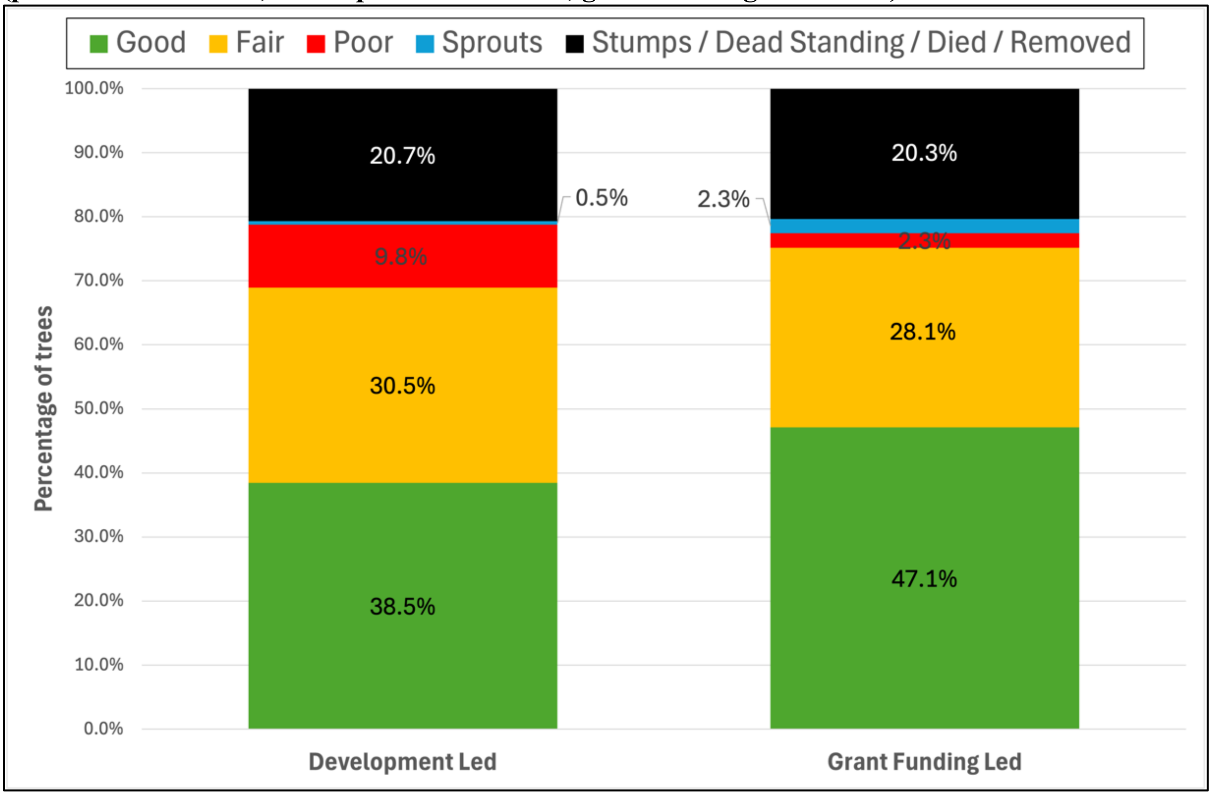


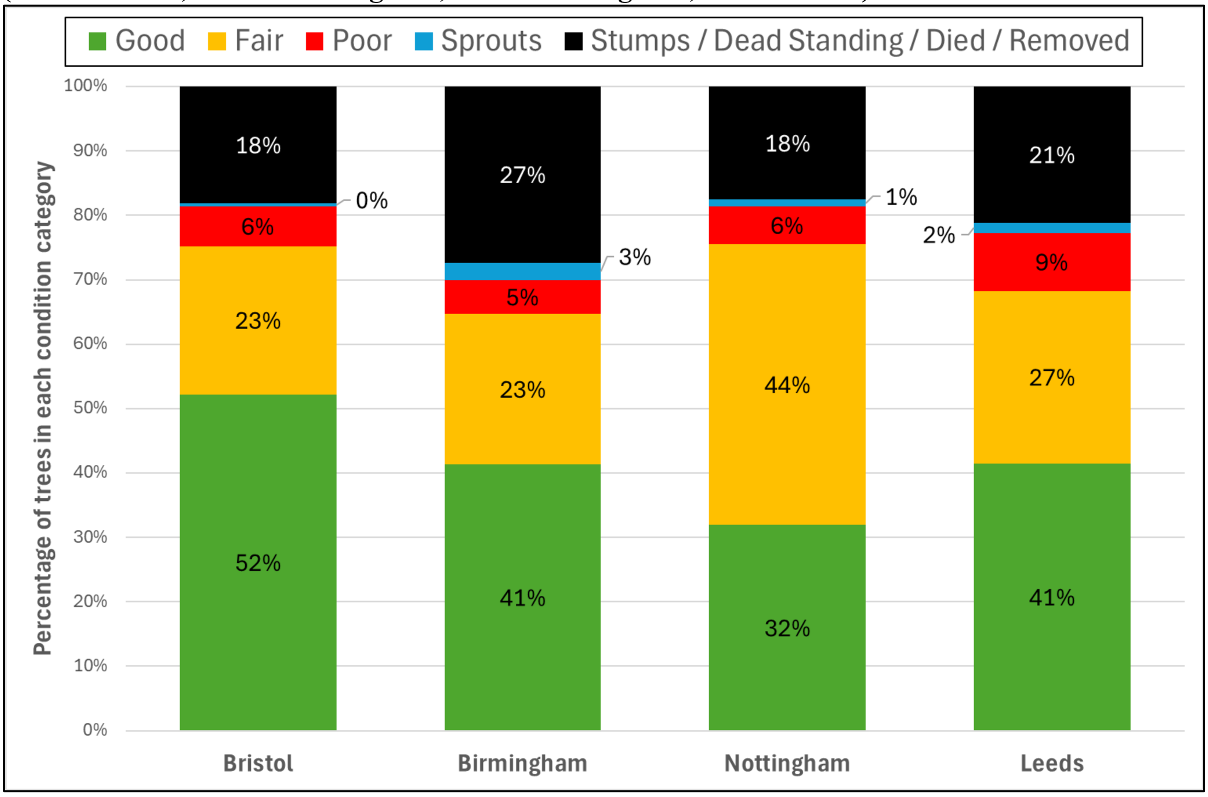
Table 4 shows the number and percentage of trees at each site in each condition category, for each of the *sites, cities* and *funding sources*. The *planting season* is stated after the site name for sites where all of the trees were planted in the same season, or the range in planting years when planting happened in multiple years at the same site (this occurred when development was completed over more than one year, or a tree was found to have been replaced).

Table 4. Number and % of planted trees in each condition category by site, city and funding source

Funding source / City / Site/ Planting season	Good		Fair		Poor		Sprouts		Stumps / Dead Standing / Died / Removed		Grand Total
Development Led	145	38%	115	31%	37	10%	2	1%	78	21%	377
Bristol	50	54%	25	27%	10	11%			8	9%	93
1.A, 2020–2021	9	60%	4	27%	1	7%			1	7%	15
1.B, 2018–2022	6	33%	7	39%	3	17%			2	11%	18
1.C, 2015–2016	7	44%	3	19%	2	13%			4	25%	16
1.D, 2012–2020	14	88%	2	13%		0%					16
1.E, 2017–1018	5	56%	2	22%	1	11%			1	11%	9
1.F, 2016–2022	9	47%	7	37%	3	16%				0%	19
Birmingham	35	40%	21	24%	8	9%			23	26%	87
2.A, 2015–2020	6	32%	4	21%	3	16%			6	32%	19
2.B, 2018–2019	8	62%	5	38%							13
2.C, 2013–2016	7	33%	2	10%					12	57%	21
2.D, 2021–2022	8	42%	3	16%	3	16%			5	26%	19
2.E, 2021–2022					1	100%					1
2.F, 2020–2021	6	43%	7	50%	1	7%					14
Nottingham	25	27%	40	43%	8	9%			21	22%	94
3.A, 2021–2022	3	20%	9	60%	1	7%			2	13%	15
3.B, 2018–2020	2	10%	4	20%	2	10%			12	60%	20
3.C, 2018–2019	3	23%	6	46%	2	15%			2	15%	13
3.D, 2016–2017	7	58%	4	33%	1	8%					12
3.E, 2020–2021	4	27%	6	40%	1	7%			4	27%	15
3.F, 2020–2021	6	32%	11	58%	1	5%			1	5%	19
Leeds	35	34%	29	28%	11	11%	2	2%	26	25%	103
4.A, 2018–2021	5	36%	7	50%	1	7%			1	7%	14
4.B, 2018–2019	10	50%	7	35%	1	5%	2	10%			20
4.C, 2019–2020	2	10%	2	10%	3	15%			13	65%	20
4.D, 2019–2022	7	35%	7	35%	5	25%			1	5%	20
4.E, 2018–2019	6	32%	5	26%	1	5%			7	37%	19
4.F, 2017–2018	5	50%	1	10%		0%			4	40%	10
Grant Funding Led	146	47%	87	28%	7	2%	7	2%	63	20%	310
Bristol	68	51%	27	20%	4	3%	1	1%	33	25%	133
1.G, 2014–2020	18	95%	1	5%							19
1.H, 2012–2013	12	60%	2	10%			1	5%	5	25%	20
1.I, 2013–2014	3	60%	1	20%					1	20%	5
1.J, 2019–2021	15	75%	5	25%							20
1.K, 2020–2021	8	44%	9	50%					1	6%	18
1.L, 2020–2021	9	45%	7	35%	3	15%			1	5%	20
1.M, 2013–2014	3	10%	2	6%	1	3%		0%	25	81%	31
Birmingham	27	43%	14	22%			4	6%	18	29%	63
2.G, 2019–2020									4	100%	4
2.H, 2019–2020	3	75%	1	25%							4
2.I, 2019–2020	3	23%	7	54%					3	23%	13
2.J, 2019–2020	3	100%									3
2.K, 2014–2015	7	70%	2	20%					1	10%	10
2.L, 2014–2015	1	20%	3	60%					1	20%	5
2.M, 2014–2015	3	60%							2	40%	5
2.N, 2015–2016	4	44%	1	11%			1	11%	3	33%	9
2.O, 2014–2015	3	30%					3	30%	4	40%	10
Nottingham	35	37%	42	45%	3	3%	2	2%	12	13%	94
3.G, 2020–2021	10	34%	15	52%					4	14%	29
3.H, 2020–2021	4	40%	5	50%	1	10%					10
3.I, 2020–2021	2	20%	7	70%			1	10%			10
3.J, 2020–2021	2	33%	4	67%							6
3.K, 2020–2021	8	57%	4	29%	1	7%	1	7%			14
3.L, 2020–2021	5	50%	4	40%	1	10%					10
3.M, 2019–2020	4	27%	3	20%					8	53%	15
Leeds	16	80%	4	20%							20
4.G, 2015–2016	16	80%	4	20%							20
Grand Total	291	42%	202	29%	44	6%	9	1%	141	21%	687

Looking at all the planted trees from both funding sources, a significant difference in the relationship between the *consolidated condition category* and *city* was found, X^2 (12, *n*=687) = 38.34, *p*<0.01 (Figure 4). Post hoc testing using adjusted residuals showed that more trees in Bristol were in *good* condition (*p*<0.01). In Nottingham, fewer trees were in *good* condition (*p*<0.01) and more were in *fair* condition (*p*<0.01).

Figure 4. City and consolidated condition outcome
(*n*=226 Bristol, *n*=150 Birmingham, *n*=188 Nottingham, *n*=123 Leeds)



Development-led condition outcomes in each city were compared using a chi-squared test of independence, with the *sprouts* category removed due to low observation numbers. The outcome was significant X^2 (9, *n*=375) = 25.27, *p*<0.01. Development-led trees in Bristol were more likely to be in *good* condition (*p*<0.01) and less likely to be in *poor* condition (*p*<0.01). See Appendix 3 for further details.

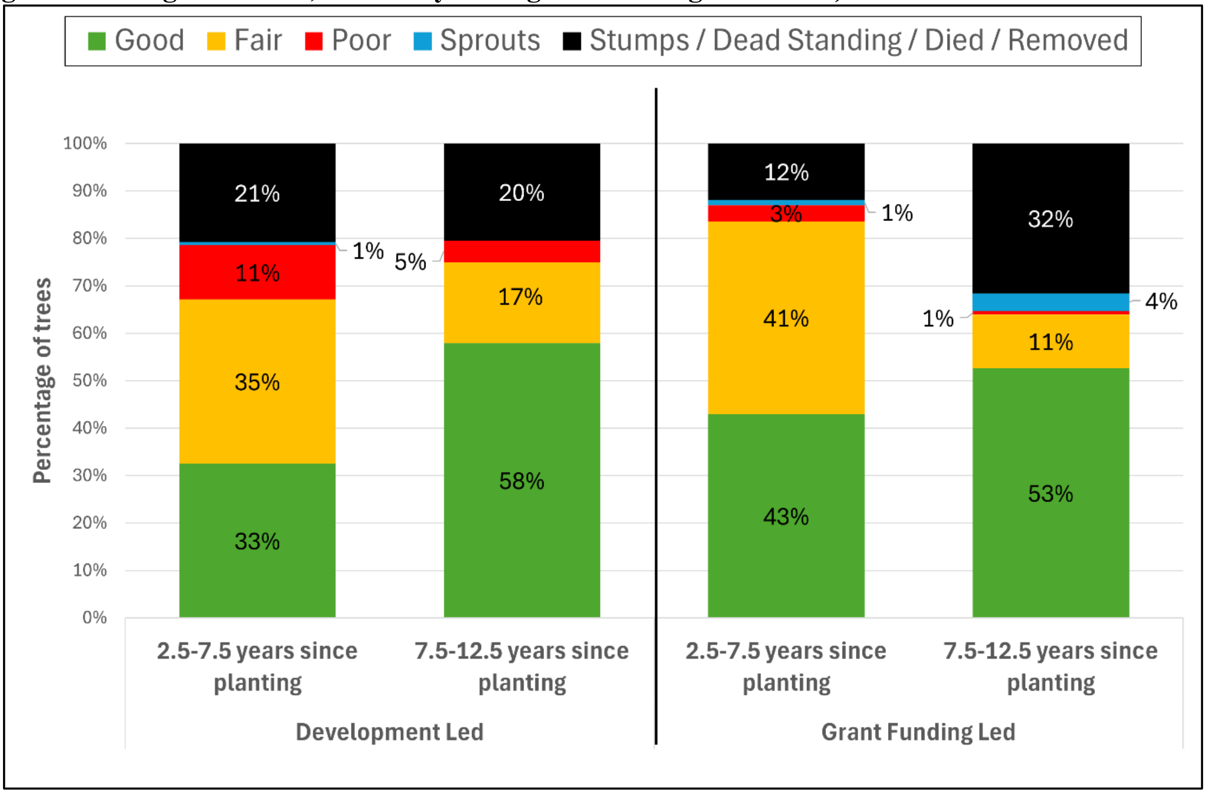
Grant-funding-led condition outcomes in each city were compared, with the *sprouts* and *poor* categories removed due to low observation numbers. Leeds was also removed from the comparison as only one grant-funding-led site was sampled there. The outcome was significant X^2 (4, *n*=276) = 20.64, *p*<0.01. Grant-funding-led trees in Nottingham were more likely to be in *fair* condition (*p*<0.01), while grant-funding-led trees in Bristol were less likely to be in *fair* condition (*p*<0.01). See Appendix 3 for further details.

5.3.2. Tree condition outcomes compared by funding source and planting recency

It was possible to compare the condition outcomes of newer and older tree planting from each funding source (Figure 5). Grant-funding-led trees planted 2.5–7.5 years ago are all Urban Tree Challenge Fund trees. Grant-funding-led trees planted 7.5–12.5 years ago are made up of Big Tree Plant trees (43%), trees planted by an organisation who combined Big Tree Plant funds with other sources to deliver new urban trees (42%) and one site planted with funding from the Community Forest Trust.

A chi-squared test of independence revealed a significant difference in condition outcomes for these four different groups, X^2 (4, *n*=687) = 88.21, *p*<0.01. Post hoc testing revealed that more recently planted development-led trees were less likely to be in *good* condition ($p<0.01$) and more likely to be in *poor* condition ($p<0.01$). Older development-led planting was more likely to be in *good* condition ($p<0.01$), while older grant-funding-led trees were more likely to be in the *stumps/dead/died/removed* category ($p<0.01$) and less likely to be in the *fair* category ($p<0.01$). More recently completed grant-funding-led tree planting was more likely to be in the *fair* category ($p<0.01$) and less likely to be in the *stumps* category (Figure 5). The sample size of older planting was smaller for both funding categories, and for grant-funding-led it is predominantly from just two of the four cities, so more data is needed to check the generalisability of these outcomes.

Figure 5. Percentage of trees in each consolidated condition category split by funding source and years since planting
(2.5–7.5 yrs old development-led *n*=289, 7.5–12.5 yrs old development-led *n*=88, 2.5–7.5 yrs grant-funding-led *n*=177, 7.5–12.5 yrs old grant-funding-led *n*=133)



5.4. Tree characteristics

5.4.1. Species

Table 5 shows how many trees of each species were surveyed from each funding source. Because the sufficiency of repetitions of a constrained set of species formed the basis for selecting which trees to survey the results do not necessarily mean species diversity was greater in grant-funding-led planting than in development-led planting in England in general during the period.

Table 5. Species surveyed, by funding source

Development Led		Grant Funding Led	
Acer campestre	71	*Acer campestre*	8
Acer platanoides	3	*Acer platanoides*	8
		Acer pseudoplatanus	3
Alnus glutinosa	11	*Aesculus indica*	2
		Ailanthus altissima	3
Amelanchier sp.	2	*Amelanchier* 'Robin Hill'	4
		Betula albosinensis	3
Betula pendula	46	*Betula pendula*	14
Betula utilis	14	*Betula utilis*	15
Carpinus betulus	24	*Carpinus betulus*	7
		Castanea sativa	2
		Corylus avellana	1
		Crataegus × lavalleei	8
		Crataegus crus-galli	3
		Crataegus monogyna	2
Fagus sylvatica	1	*Fagus sylvatica*	2
		Fraxinus excelsior	2
Liriodendron tulipifera	1	*Liriodendron tulipifera*	4
		Magnolia kobus	2
		Malus domestica	10
Malus sp.	1	*Malus Rudolph*	5
Not Recorded	1	*Malus* sp.	13
Pinus sylvestris	2	*Platanus × hispanica*	2
Prunus avium	65	*Prunus avium*	44
Prunus padus	6	*Prunus domestica*	6
Prunus sp.	1	*Prunus* sp.	13
Pyrus calleryana	9	*Pyrus calleryana*	20
Quercus palustris	2	*Pyrus communis*	13
Quercus robur	13	*Quercus robur*	5
Sorbus aria	1	*Sorbus aria*	4
Sorbus aucuparia	19	*Sorbus aucuparia*	16
Tilia cordata	6	*Ulmus* sp.	3
Not Planted, Dead, Absent, Died, Removed	189	Not Planted, Dead, Absent, Died, Removed	85
Funding source total	**488**	**Funding source total**	**332**

From section 5.4.2 of this report, the total number of observations varies for each variable because it was not logistically or safely possible to retrieve every data point from each tree. In most instances, this was due to something injurious or immovable limiting access to part of the tree, or the position required to take the measurement. Occasionally, one aspect of a tree's condition prevented another from being recorded (e.g. it was not possible to give a chlorosis rating if no leaves were present). A few observations were also lost to human error.

In later sections with photographs, red borders signify less positive outcomes, black are neutral or reference photos, and green borders signify more positive outcomes.

5.4.2. Size – DBH, diameter at 1m, caliper, total height and height to crown

In Figure 6 and Figure 7, the box and whisker plots show the distribution of data for each of these variables, with the median line in the middle of each box and the first and third quartiles marked at the edge of the box above and below the median line.

Diameter at Breast Height (DBH) was measured 1.5m from ground level. *Diameter at 1m* measured 1m from ground level. *Caliper* was measured at 15cm from ground level or 7.5cm above an obvious graft. In the interests of time, if the location of a graft was not immediately obvious, the caliper was measured at 15cm from ground level, and as such most measurements were taken at 15cm from ground level. 60 caliper measurements taken at 20cm above ground level due to immovable stem guards have been excluded from the results presented. See Appendix 4 for summary statistics for these variables.

Height was measured from the base of the tree (ground level) to the top of the tallest branch, including dead branches. *Height to crown* was measured between the ground and the lowest hanging part of the live crown (at the bottom of the lowest hanging leaf). Figure 7 depicts the distribution for these variables. See Appendix 4 for summary statistics for these variables.

Figure 6. Distribution in DBH, diameter at 1m and caliper by funding source
The cross in the middle represents the mean. Datapoints falling more than 1.5 times the interquartile range away from the mean are marked as outliers (outside whiskers).

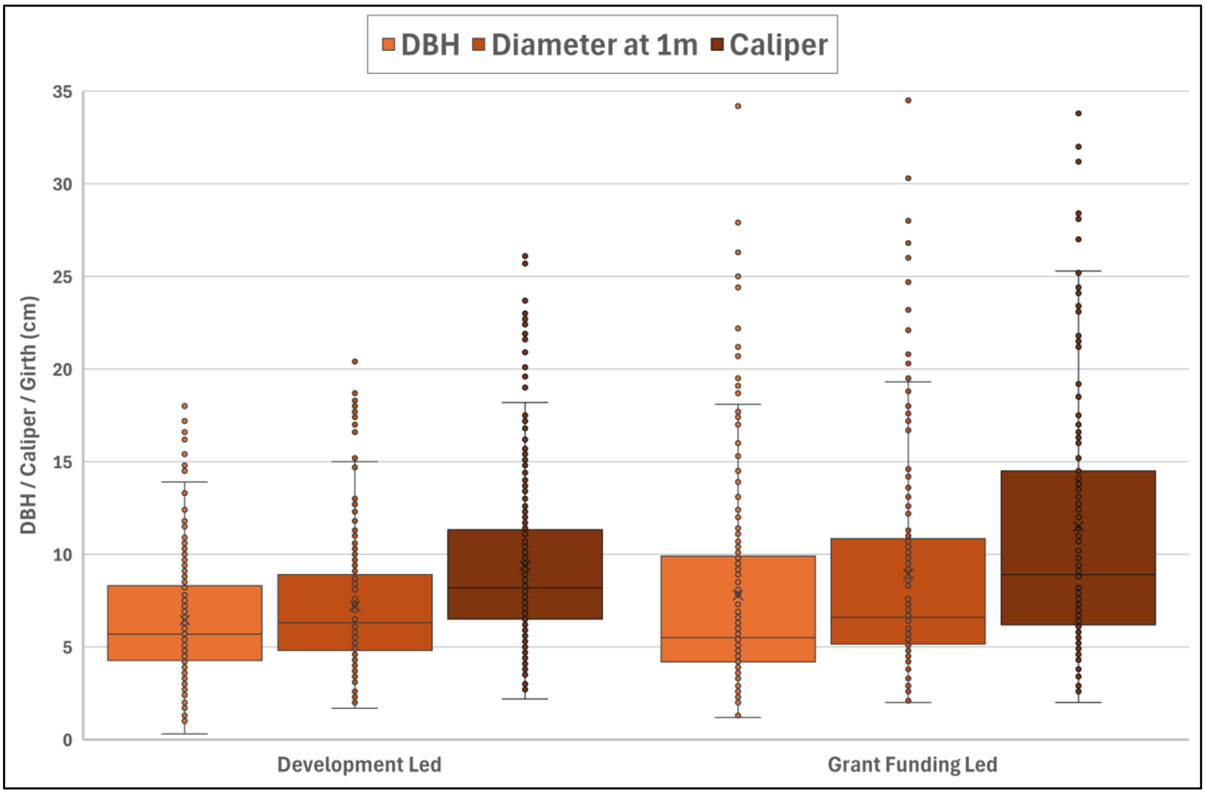


Figure 7. Distribution in height and height to canopy by funding source

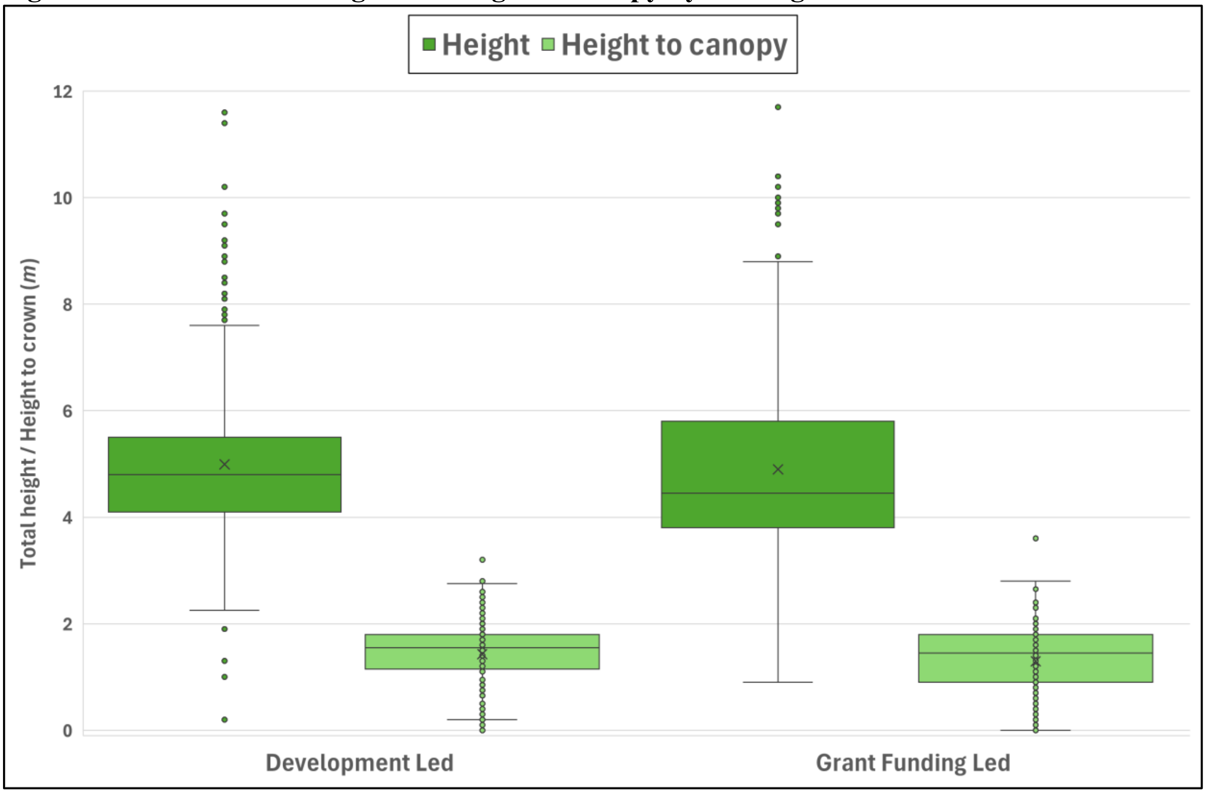


Table 6 shows basic summary statistics for the three most commonly surveyed species in this research, by year planted. Where five or more repetitions of a species were made from both funding sources, and planted in the same year, the larger of the two averages is outlined and highlighted in bold.

Table 6. Minimum, maximum, range and average of variables height and DBH, for the three most surveyed species in the research, split by funding source and planting years.

Species / Years since planting	Development Led									Grant Funding Led								
	Number of Repetitions	Min. of Total height (m)	Max. of Total height (m)	Range in Total Height (m)	Average of Total height (m)	Min. of DBH (cm)	Max. of DBH (cm)	Range of DBH (cm)	Average of DBH (cm)	Number of Repetitions	Min. of Total height (m)	Max. of Total height (m)	Range in Total Height (m)	Average of Total height (m)	Min. of DBH (cm)	Max. of DBH (cm)	Range of DBH (cm)	Average of DBH (cm)
Acer campestre	**71**	**2.9**	**7.1**	**4.2**	**4.9**	**1.8**	**13.9**	**12.1**	**6.1**	**8**	**3.4**	**7.0**	**3.7**	**4.7**	**3.9**	**13.9**	**10.0**	**7.0**
2.5	7	4.3	5.0	0.7	4.7	3.6	5.5	1.9	4.9									
3.5	12	3.6	6.4	2.8	**4.5**	3.2	6.7	3.5	5.1	5	3.9	4.9	1.0	4.4	3.9	7.0	3.1	**5.3**
4.5	6	4.4	5.0	0.6	4.7	3.9	6.1	2.2	5.4									
5.5	25	2.9	7.1	4.2	4.8	1.8	9.8	8.0	5.9									
6.5	13	4.3	5.6	1.3	5.1	3.4	9.3	5.9	7.0									
7.5	6	3.9	6.1	2.2	5.1	4.5	10.6	6.1	6.8									
8.5										3	3.4	7.0	3.7	5.2	9.1	13.9	4.8	11.5
9.5	2	6.9	6.9	0.0	6.9	13.3	13.9	0.6	13.6									
Betula pendula	**46**	**2.0**	**11.6**	**9.7**	**6.0**	**0.3**	**17.4**	**17.1**	**6.6**	**14**	**3.0**	**11.7**	**8.7**	**5.7**	**1.5**	**17.4**	**15.9**	**7.1**
2.5	3	5.0	5.5	0.5	5.3	4.6	5.2	0.6	5.0									
3.5	10	2.6	6.5	3.9	**4.6**	2.0	6.6	4.6	**4.7**	5	3.2	7.2	4.0	4.4	2.1	7.3	5.2	4.2
4.5	6	2.0	4.0	2.1	3.3	0.3	3.9	3.6	2.2	4	3.0	4.3	1.3	3.6	1.5	2.8	1.3	2.4
5.5	9	3.6	8.8	5.2	6.1	2.2	11.5	9.3	6.7									
6.5	7	4.7	9.5	4.8	6.5	3.9	11.6	7.7	6.8									
7.5	8	4.9	10.2	5.3	8.0	4.8	16.4	11.6	10.3									
10.5										4	6.3	11.7	5.4	8.8	9.0	17.4	8.4	13.7
11.5	3	8.9	11.6	2.7	10.6	11.1	17.4	6.3	14.5	1	7.4	7.4	0.0	7.4	14.5	14.5	0.0	14.5
Prunus avium	**65**	**2.8**	**9.1**	**6.3**	**5.2**	**2.5**	**18.2**	**15.7**	**8.3**	**44**	**2.1**	**13.2**	**11.1**	**5.5**	**2.8**	**34.2**	**31.4**	**10.6**
2.5	6	4.5	5.5	1.0	4.9	4.8	6.1	1.3	5.7									
3.5	10	2.8	5.6	2.8	**4.8**	2.8	9.9	7.1	**7.0**	22	2.1	4.9	2.8	3.8	2.8	7.3	4.5	5.2
4.5	12	3.8	5.5	1.8	4.3	3.0	9.0	6.0	4.9	1	4.3	4.3	0.0	4.3	5.3	5.3	0.0	5.3
5.5	18	3.4	7.0	3.7	5.1	2.5	11.9	9.4	8.2									
6.5	4	3.9	5.2	1.3	4.5	4.7	7.6	2.9	6.3									
7.5	3	4.6	5.6	1.0	5.3	8.3	15.4	7.1	11.0									
8.5	4	3.5	5.6	2.1	4.8	5.6	9.7	4.1	6.7									
9.5										14	3.9	10.2	6.4	6.5	6.9	24.4	17.5	13.2
10.5	3	8.5	9.1	0.6	8.8	14.5	18.0	3.5	16.4	2	7.8	8.9	1.1	8.4	19.1	21.2	2.1	20.2
11.5	5	6.1	8.8	2.7	7.7	11.9	18.2	6.3	15.8	5	4.8	13.2	8.4	**9.4**	6.5	34.2	27.7	**22.0**

5.5. Planting area type, size and ground cover

5.5.1. Planting area type and planting area surface area (m²)

The *planting area type* describes the contiguous, permeable physical place within which the tree is planted. It describes the available growing space for the tree when combined with information about the surface area**.** It can sometimes also provide insight into who is responsible for the management of the area and the tree. 80% of the trees in this survey (551 trees) were planted in *open areas* (Table 7). Open areas are characterised as park-like areas or pocket parks.

Table 7. Planting area type by funding source
(total observation *n*=687: 377 development-led, 310 grant-funding-led)

	Open area	Median	Shoulder	Front yard	Side yard	Tree lawn	Tree pit	Tree grate
Development-led	**77%**	5%	5%	4%	3%	2%	2%	1%
Grant-funding-led	**84%**	0%	0%	8%	5%	2%	2%	0%
Grand Total	**80%**	3%	2%	6%	4%	2%	2%	1%

The *surface area* was calculated from planting area length and width data either measured at the site or on Google Earth after the survey (where measuring in person was not practicable). Five trees from the grant-funding-led sample were growing in a planting area with a *surface area* of less than 1m² (Appendix 5). For both funding sources, 6% of the trees were growing in planting areas with permeable *surface areas* of up to 26m² (just over 5m by 5m); the rest were in larger planting areas, with over 50% of the trees surveyed in this study planted in areas with a permeable *surface area* over 1000m² (1000m² is 20m by 50m, e.g., small park). Surface area measurement did not detect an issue with the availability of rooting space for most of the trees in this research.

5.5.2. Ground cover at base and tree and ground cover under canopy

Ground type at base and *ground type under canopy* describe the predominant ground covering at the base of the trunk (in an approximate 15cm radius surrounding the tree stem) and the predominant ground covering under the canopy of the tree (beyond *ground type at base* measurement). Together these describe the vegetative ground where the tree was planted. These variables can assist in indicating the availability and potential competition for nutrients and water resources; they may also indicate if and how the planting area is being maintained.

Considering all the trees, from either funding source, for which these variables were recorded (*n*=564), 31% were found with *weeds* as the *ground type at base*, 25% had *grass*, and 25% had bare *soil*. The predominant *ground type under canopy* for all the trees was *grass* (57%, *n*=564). 19% had *other, permeable* surfaces (often a mixture of permeable vegetation types), and 16% had *weeds*.

Figure 8 shows the percentage of trees in each *ground cover at base* category by funding source. 13% of the development-led sample compared with 52% of the grant-funding-led sample, were found with *weeds* at the base. 29% of development-led trees, and 20% of grant-funding-led trees, had *grass* at the base. 36% of development-led, and 12% of grant-funding-led trees, had bare *soil*. Inorganic mulch observations were removed from the comparison due to low observation numbers (*n*=2). A chi-squared test of independence showed significant differences in the *ground cover at base* by funding source (X^2 (6, *n*=562) = 129.95, p<0.01). Post hoc analysis using standardised residuals showed that development-led trees were significantly more likely to be surrounded by bare *soil* or *other, permeable* surfaces at the base, and they were less likely to have *weeds* at the base compared to grant-funding-led trees. Grant-funding-led trees were significantly more likely to be found with *weeds* at the base and less likely to have bare *soil* or *other, permeable* surfaces at the base. The outcomes described above had p<0.01.

The predominant ground cover under the *canopy* of the development-led trees was *grass* (57%, total observation *n*=314, appears as 56% in Figure 9 due to rounding). This was followed by *other, permeable* surfaces at 29% and *weeds* under 5% of development-led tree canopies. 58% of grant-funding-led trees had grass under the canopy, 29% had weeds and 6% had perennial plants. A chi-squared test of independence showed significant differences in the *ground cover under canopy* by funding source, X^2 (6, n=563) = 110.22, p<0.01, organic mulch removed from the comparison due to low observation numbers (n=1). Post hoc analysis using standardised residuals showed that development-led trees were significantly more likely to have bare *soil* (p<0.01) or *other, permeable* (p<0.01) surfaces under the canopy, and they were less likely to have *weeds* (p<0.01) under the canopy compared to grant-funding-led trees. Grant-funding-led trees were significantly more likely to be found with *weeds* (p<0.01) under the canopy, and less likely to have bare *soil* (p<0.01) or *other, permeable* (p<0.01) surfaces under the canopy.

Figure 8. Ground covering at the base of the tree by funding source (total observation *n*=564: 314 development-led, 250 grant-funding-led)

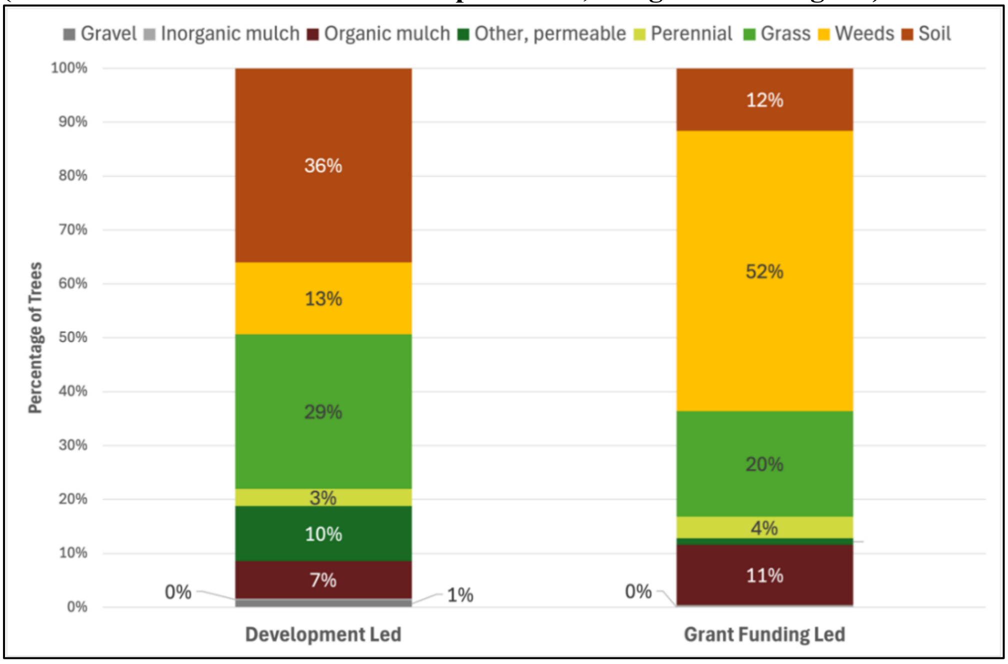
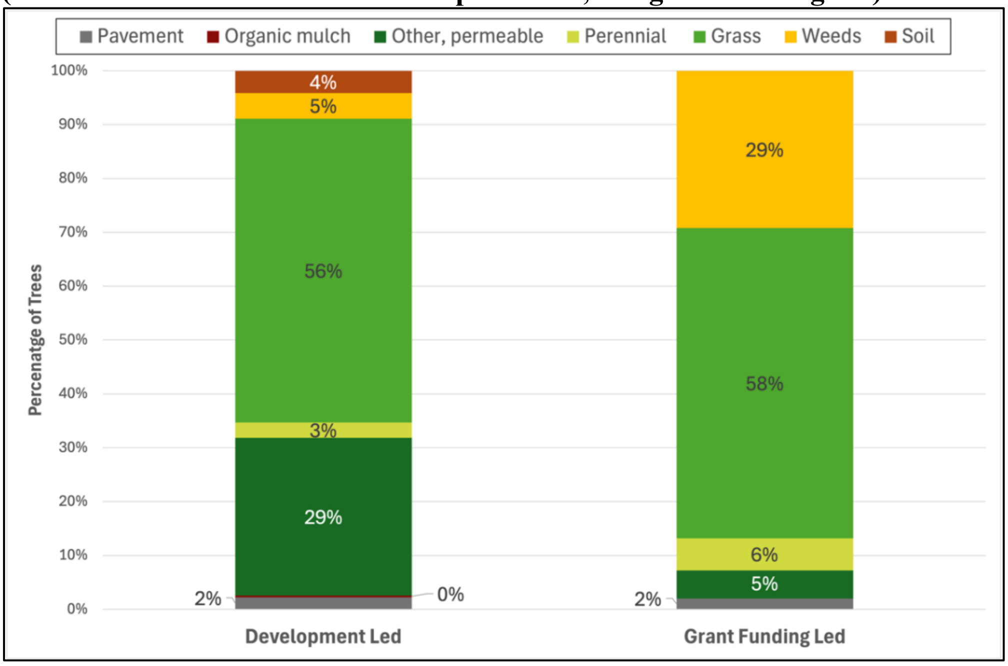


Figure 9. Ground covering under the canopy of the tree by funding source (total observation *n*=564: 314 development-led, 250 grant-funding-led)



5.6. Trunk and canopy condition

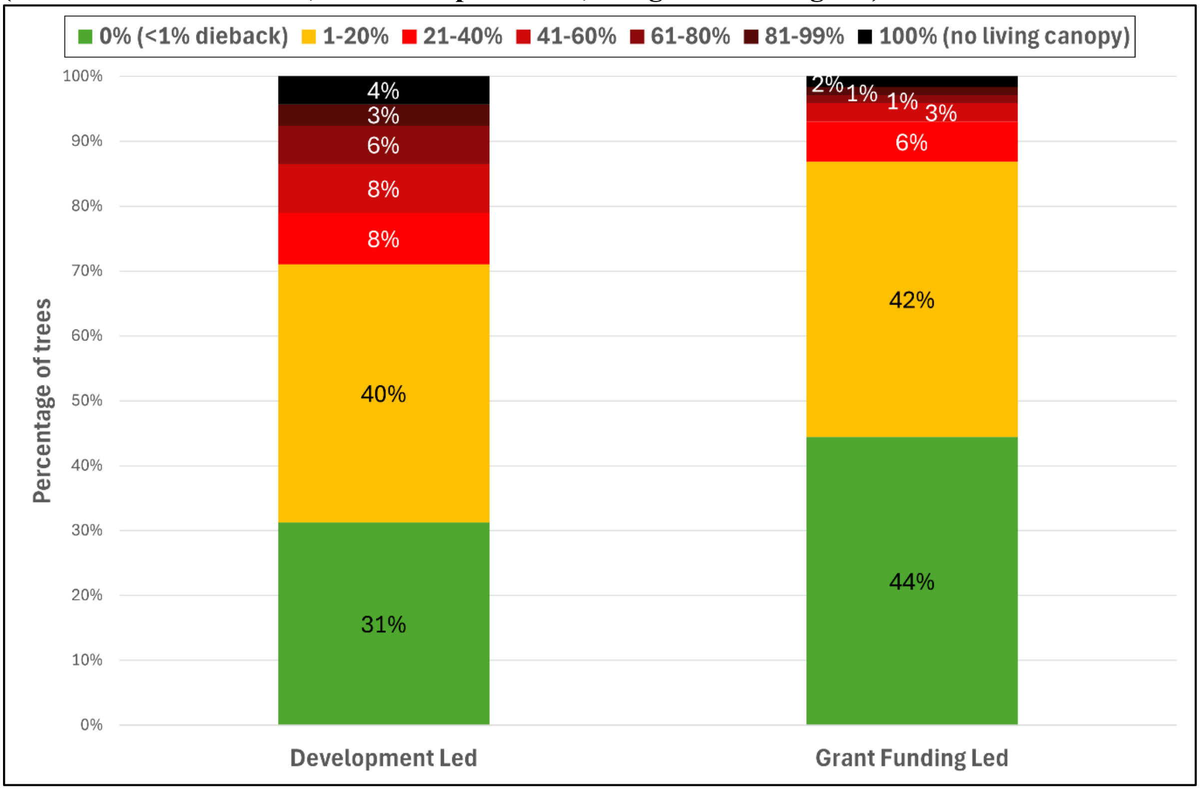
5.6.1. Canopy – crown dieback

Crown dieback (dead branches in the tree canopy) is a stress indicator, often of root zone stress, and can be a precursor to tree failure. Some studies have suggested that trees expressing more than 20% dieback are more susceptible to mortality (Morin et al., 2012; Ribeiro et al., 2024) and are more vulnerable to the combination of heat and drought stress (Marchin et al., 2022). Another study found that high levels of canopy loss (more than 50%) was associated with higher mortality (Seaton, 2015). Looking at trees from both funding sources (*n*=547), 63% had some form of dieback and 22% had over 20% dieback.

Crown dieback was present on 69% of all development-led trees, with 29% of the trees showing more than 20% dieback. 13% of the development-led trees exhibited over 60% dieback. *Crown dieback* was present on 56% of grant-funding-led trees; 14% had more than 20% dieback and 4% had over 60% dieback (Figure 10).

A chi-square test of independence was performed to examine the relationship between *crown dieback* categories and funding source. The relationship between these variables was significant, X^2 (6, *n*=547) = 25.65, $p<0.01$. Post hoc analysis using residuals determined there were significantly more grant-funding-led trees with 0% dieback ($p<0.01$) and significantly fewer development-led trees with 0% dieback ($p<0.01$). With dieback categorised into 0% dieback, 1-20% dieback and 20-100% dieback; the differences between funding sources were significant in each category ($p<0.01$).

Figure 10. Crown dieback
(total observation *n*=547; 304 development-led, 243 grant-funding-led)



5.6.2. Canopy – crown exposure

96% of the trees in the survey were growing with either a *fully exposed canopy* or *four sides* of the canopy exposed. Full results Appendix 6.

5.6.3. Chlorosis

Chlorosis indicates stress, usually nutrient deficiencies. 10% more trees with *chlorosis* were observed in the development-led tree planting sample. A chi-square test of independence was performed to examine the relationship between *chlorosis* and funding source. The relationship between these variables was significant, X^2 (1, n=532) = 7.96, p<0.01(Figure 11). Post hoc testing using residuals showed that the development-led trees were more likely to have chlorosis than the grant-funding-led trees (p<0.01).

Figure 11. Chlorosis on more than 25% of total leaf surface area (total observation *n*=532; 291 development-led, 241 grant-funding-led)

5.6.4. Trunk – root flare

A tapered or flared base of the trunk as the tree enters the soil indicates the presence of root flare and that the tree has been planted at the correct level in the soil. 19% of trees in each funding category had *no visible root flare* at ground level (Figure 12). Digging below the soil level was not possible during this research, but effort was made to locate the first lateral root.

Figure 12. Visibility of root flare (total observation *n*=526; 299 development-led, 227 grant-funding-led)

5.6.5. Trunk – epicormic shoots

Epicormic shoots can be induced by stressors in either the above- or below-ground environment. Alteration of soil conditions, root severance or damage to the crown or stem may all stimulate epicormic growth (Patch, 1989). 39% of trees in each funding category had epicormic shoots present at the time of the survey (total observation n=566; 316 development-led, 250 grant-funding-led).

Figure 13. Epicormic shoots

Image descriptions, left to right: a) shoots growing through poorly fitted or since damaged tree cage; b) shoots regrowing from multiple heights after lead growing stem was snapped; c) shoots growing through poorly installed stem guard (plastic wrap had not been removed and leaves were not separated); d) shoots growing through fitted cage; e) shoots growing through a different type of stem guard which was buried quite deeply under overgrown vegetation and was rubbing stem.

5.6.6. Trunk – lower trunk damage

Damage to the lower part of the stem near the ground can increase the risk of fungal infection and susceptibility to premature death, and repeated injuries can cut off vascular tissue, girdling the tree. Lower trunk damage was classified as historical or recent damage below 45cm on the stem, in the form of peeling or broken bark or damaged wood.

66% of development-led trees had *lower trunk damage* (historical or recent) below. 56% of grant-funding-led trees had *lower trunk damage* (Figure 14). It was often possible to determine that the damage had been caused by vegetation management equipment (strimmer or mower) due to the presence of dry or fresh cut grass in the resulting wound. Occasionally wounds in this area were so severe that over half the circumference of the bark was missing at a particular point on the stem (Appendix 11, Figure 43).

A chi-square test of independence was performed to examine the relationship between *lower trunk damage* and funding source. The relationship between these variables was significant, X^2 (1, n=522) = 5.38, p<0.05 indicating that there were fewer grant-funding-led trees with *no lower tunk damage* than development-led trees with *no lower trunk damage*. However, post hoc testing using standardised residuals showed no statistically significant differences between development-led and grant-funding-led trees with regard prevalence lower trunk damage.

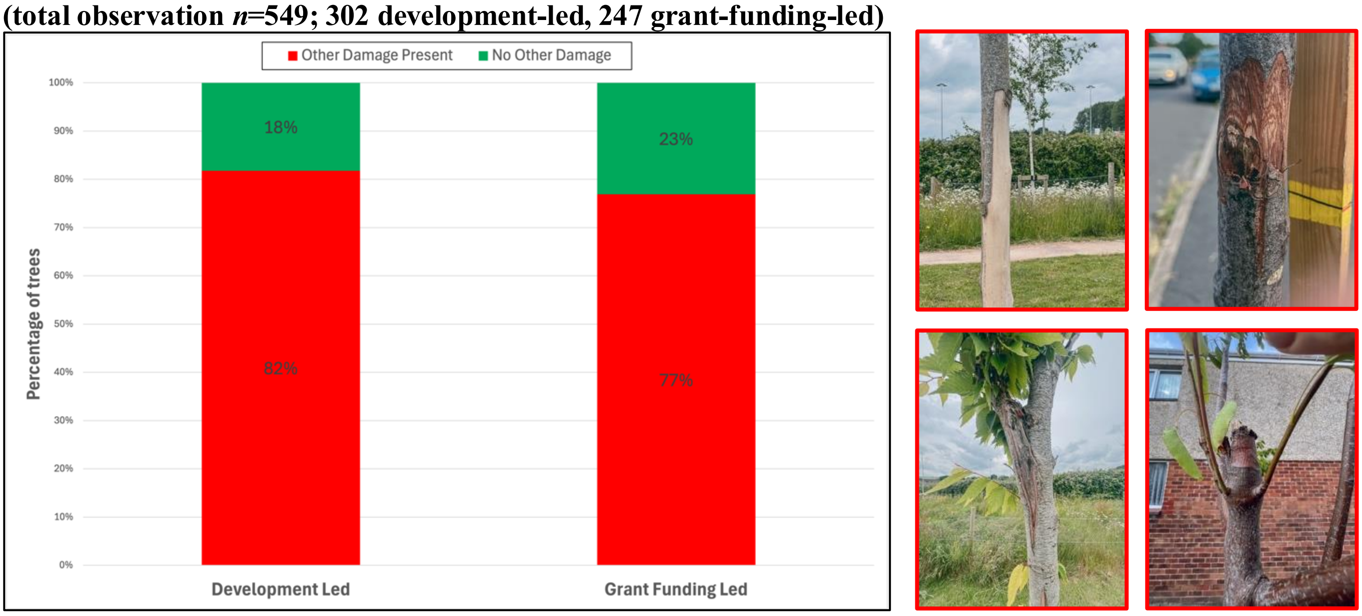
Figure 14. Lower trunk damage - historical or recent, below 45cm on stem (total observation *n*=522; 289 development-led, 233 grant-funding-led)

5.6.7. Trunk and canopy – other damage

Damage to the branches or canopy can harm a tree by reducing its capacity for photosynthesis and, thus, growth. Bark loss or wounds increase the risk of fungal infection. *Other damage* was classified as historical or recent above 45cm on the stem. 82% of development-led and 77% of grant-funding-led trees had *other damage* (Figure 15).

There was no statistically significant difference in the presence of *other damage* based on *funding source*. *Other damage* was highly prevalent in the sampled populations from both funding sources. The PTRP did not further classify the type of *other damage* by severity, so these results include some damage which was quite minor. Some of the *other damage* observed was caused by vandalism but *other damage* caused by poorly maintained tree protection equipment was felt to be more prevalent. This could not be quantified by this research, as damage was not classified by (suspected) cause during the survey. However, poorly maintained tree protection equipment is covered in the next part of this report.

Figure 15. Other damage – historical or recent, above 45cm on stem (total observation *n*=549; 302 development-led, 247 grant-funding-led)



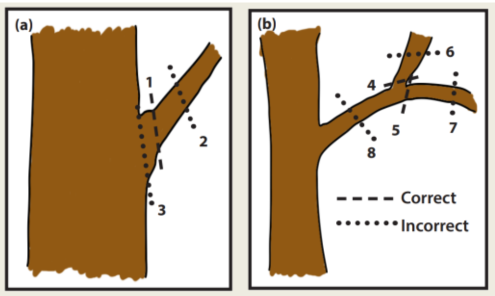
5.7. Evidence of maintenance

Pruning, *mulching*, *staking*, *stem guards* and *tree guards* were rated as either *correct*, *incorrect* or *none*. The descriptions of what qualified as *correct* or *incorrect* are briefly explained in this section. Diagrams and further explanations can be found in the PTRP.

5.7.1. Pruning

The following descriptions from the PTRP were used to determine classifications for this variable:

Pruning diagram from p.63 of the PTRP:



Correct: Evidence of tree pruning exists and this pruning was done correctly, according to the diagram (left).
Incorrect: Evidence of tree pruning exists, but pruning is not done correctly.
None: No evidence of pruning visible.

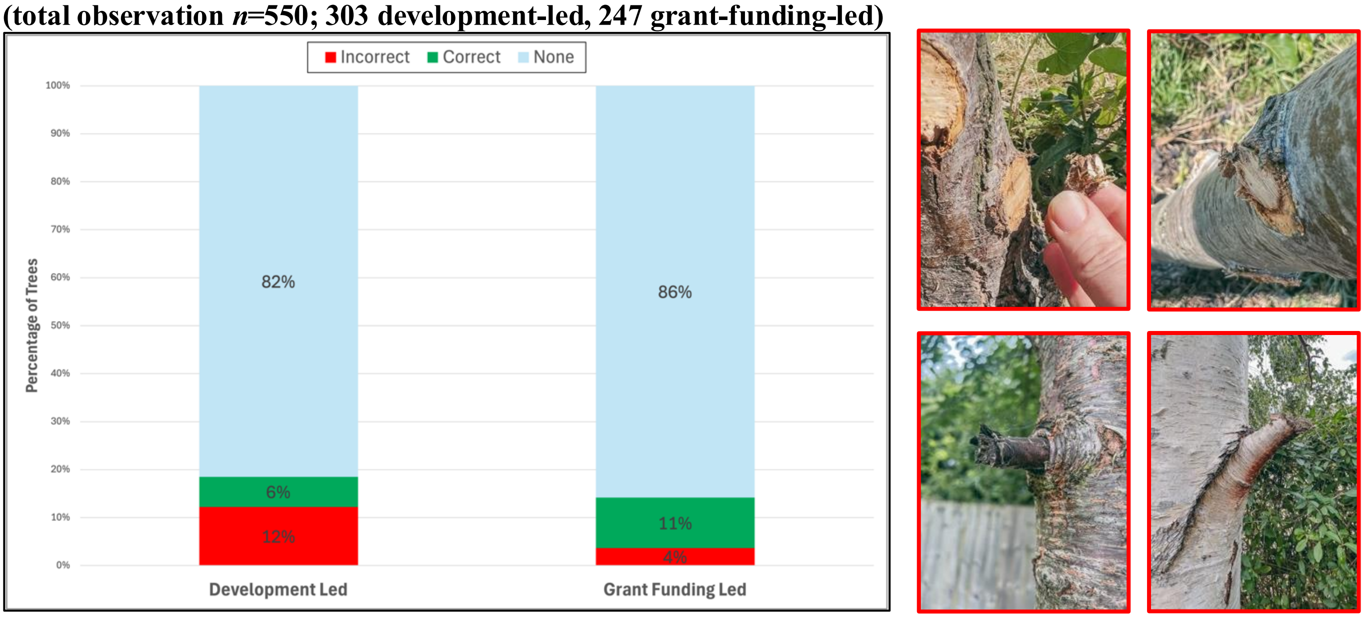
Tiny, fully occluded pruning wounds on the main stem, likely from training pruning at the nursery, were not counted as evidence of pruning.

18% of development-led trees had signs of being *pruned*, 66% of which had been carried out *incorrectly* (Figure 16). 15% of grant-funding-led trees had signs of being *pruned*, 26% of which had been carried out *incorrectly*.

For trees that *were* pruned, a significant difference in outcomes (*correct* vs. *incorrect*) was found between funding sources X^2 (1, n=91) = 14.03, p<0.01. Post hoc testing using standardised residuals showed a statistically significant difference: trees at development sites were less likely to have been pruned *correctly* (p<0.01).

For both funding sources, more than 80% of trees had had no formative pruning since planting.

Figure 16. Pruning works carried out
(total observation n=550; 303 development-led, 247 grant-funding-led)



5.7.2. Mulching

The following descriptions from the PTRP were used to determine classifications for this variable:

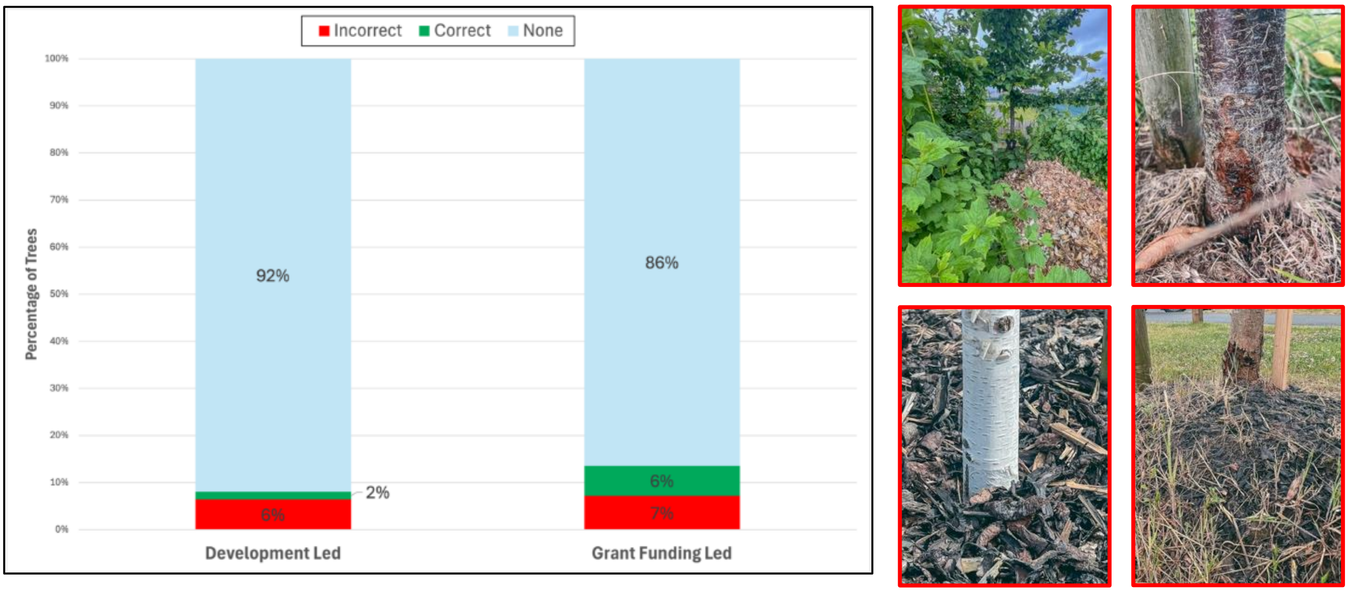
> **Correct:** Mulch less than 5cm (<2”) deep is approximately evenly distributed in a ‘donut’ shape around the base of the tree and under the canopy.
> **Incorrect:** Mulch is greater than 5cm (>2”) deep piled up around the base of the tree in a ‘volcano’ formation.
> **None:** Mulch is not present, or is very old and visible only in the form of a few remaining wood chips or bark fragments.

8% of development-led trees were found *mulched.* However, 80% of the mulching effort on development sites was *incorrectly* executed (e.g. mulch piled too high, burying the root flare, Figure 17).

14% of grant-funding-led trees were found mulched, 53% of which had been mulched had been mulched *incorrectly*.

For trees that *were mulched*, a statistically significant difference in outcomes was found between funding source (X^2 (1, n=59) = 4.6, $p<0.01$), but post hoc testing using standardised residuals did not show this to be significant.

Figure 17. Mulch application and maintenance
(total observation *n*=561; 311 development-led, 250 grant-funding-led)



5.7.3. Staking

The following descriptions from the PTRP were used to determine classifications for this variable:

> **Correct:** Stake and line are correctly attached to the tree, providing support but not pulling the tree over in one direction or the other, or otherwise injuring the tree.
> **Incorrect:** Tree is staked, but incorrectly (tree may be pulled over by the stake, a stake line, tree-tie or rope girdling the tree, constricting the trunk or digging into the bark, etc.). Note that a leaning tree does not necessarily indicate incorrect staking, because the stake may in fact be an attempt to correct the lean.
> **None:** No evidence of staking. No remaining stake or staking line around the tree OR Present stake but nothing remains tying the stake to the tree and the stake is out of the way of trunk growth.

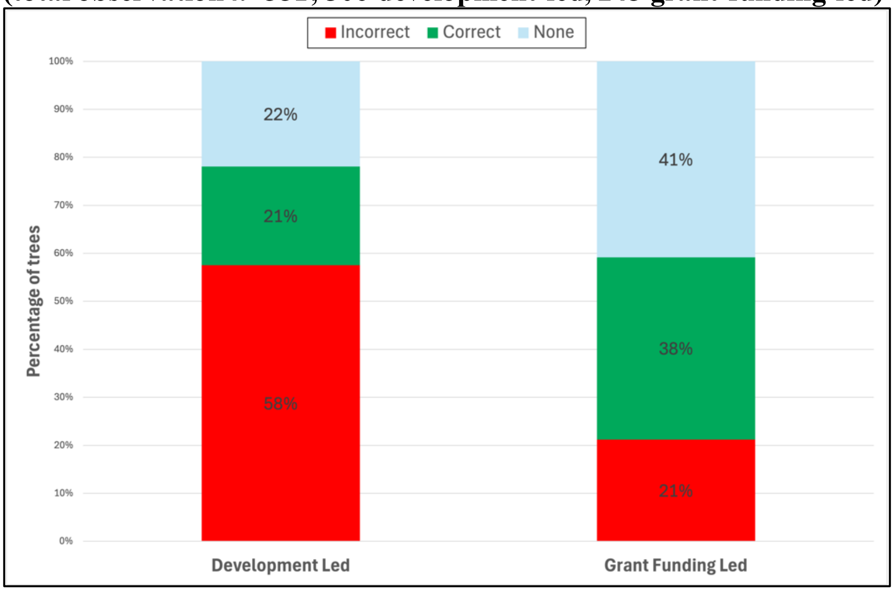
Trees were found *staked* at 79% of the development-led sites (Figure 18). Where trees *were* staked on development sites, they were found staked *incorrectly* 74% of the time.

At grant-funding-led sites, 59% of the trees were found *staked*. Where trees *were* staked at grant-funding-led sites, they were done so *incorrectly* 36% of the time.

A chi-square test of independence was performed to examine the relationship between *stake maintenance* and *funding source*. The relationship between these variables was significant: X^2 (2, *n*=551) = 73.88, $p<0.01$. Post hoc analysis using standardised residuals showed that development-led trees were significantly more likely to be staked *incorrectly* and less likely to be found *correctly* staked or with *no stakes* at all. Grant-funding-led trees were significantly more likely to be staked *correctly* or found with *no stakes*, and significantly less likely to be staked *incorrectly*.

Likewise, a significant difference in outcomes for the trees that *were* staked was found (*correct* vs. *incorrect*): X^2 (1, *n*=384) = 53.36, $p<0.01$. If trees *were* staked, development-led trees were significantly more likely to be staked *incorrectly* and less likely to be staked *correctly* than grant-funding-led trees, while grant-funding-led trees were significantly more likely to be staked *correctly* and less likely to be staked *incorrectly* (all statements $p<0.01$).

Figure 18. Tree stake fitting and maintenance
(total observation *n*=551; 306 development-led, 245 grant-funding-led)



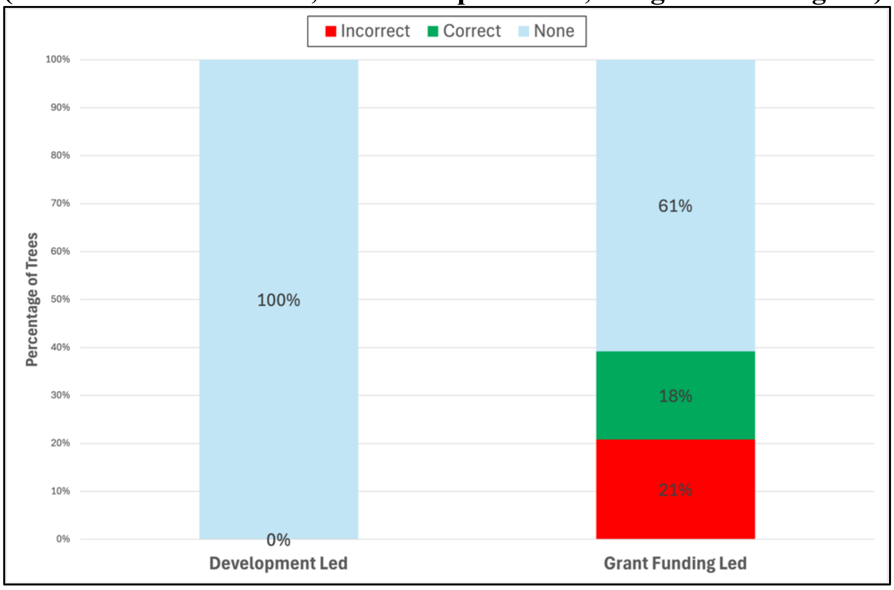
5.7.4. Tree guards

The following descriptions were used to determine classifications for this variable:

> **Correct:** the guard is correctly attached to its support system; it is not inhibiting the tree's growth, or otherwise injuring the tree.
> **Incorrect:** a tree guard is present, but incorrectly attached or maintained (the tree may have outgrown the guard, it could be girdling a branch, piercing or visibly compressing the bark, causing the tree to grow in an unusual form, etc.).
> **None:** No guard is present on the tree.

Tree guards were found fitted at 39% of grant-funding-led trees (18% + 21%, Figure 19). Where guards *were* fitted (98 trees), they were installed or maintained *incorrectly* in 53% of cases (52 trees).

Figure 19. Tree guard fitting and maintenance
(total observation *n*=561; 311 development-led, 250 grant-funding-led)



5.7.5. Stem guards

The following descriptions were used to determine classifications for this variable:

> **Correct:** the stem guard is correctly fitted around the stem of the tree, not inhibiting growth or otherwise injuring the tree.
> **Incorrect:** a stem guard is present, but incorrectly fitted or maintained (the guard may have been forgotten and become embedded in the ground or otherwise stuck on the tree, or it could be girdling a branch, rubbing or digging into the bark, etc. Stem guards that had been mown or strimmed through were also classified as incorrect.
> **None:** No guard is present on the tree. Note: Stem guards were often found full of ants' nests, or with weeds growing up through them; this had no bearing on whether they were classified as correct or incorrect.

Stem guards were found on less than 1% of the development-led trees (Figure 20).

Stem guards were found at 41% of grant-funding-led planting sites. Stem guards were installed or maintained *incorrectly* at 59% of the planting locations where they were found being used.

Figure 20. Stem guard fitting and maintenance
(total observation *n*=556; 311 development-led, 245 grant-funding-led)

5.7.6. Watering bags and pipes

Figure 21. Blocked water pipes

12% of development-led trees (36 of 331 observations) had *waterpipes* installed. 31% of these were installed *incorrectly* or were now unusable (e.g. found full of debris, Figure 21).

4% of grant-funding-led trees (11 of 247 observations) were found with *waterpipes* installed. 55% of installed pipes were installed *incorrectly* or were now unusable.

Only one *watering bag* (on a UTCF-funded tree) was found during the surveys.

5.7.7. Guying

Five development-led trees and 12 grant-funding-led trees were found with improperly maintained *guying* systems visible at the time of the survey. Figure 22 depicts some of them.

Figure 22. Poorly maintained guying

Left to right: a) guying ratchet strap exposed at ground level (under tree guard); b) embedded in cambium, compressing root; c) breaching cambium d) rubbing root collar

5.8. Proximity and surroundings

5.8.1. Litter

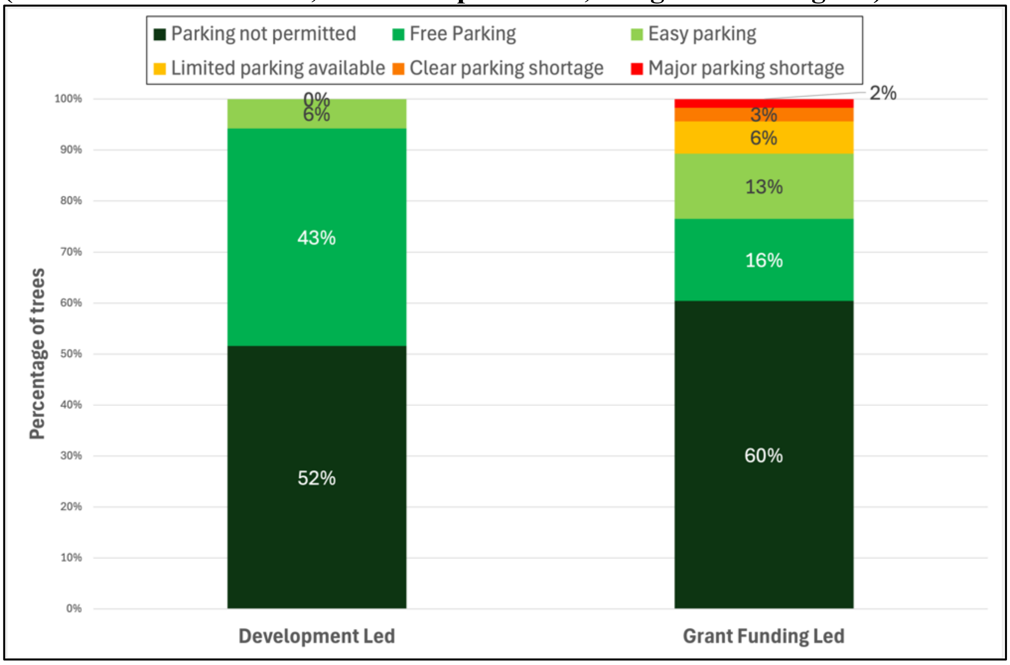
Litter was found at 23% of development-led tree planting locations and 27% of grant-funding-led tree planting locations. This difference was not significant.

5.8.2. Parking

During their initial street tree survey project, Birmingham Tree People found "many trees were struggling in compacted ground due to cars parked on verges" (Birmingham Tree People, 2022), and it is also not uncommon to see trees which have been damaged by traffic in urban areas. 6% of grant-funding-led trees were planted in locations with limited parking availability in the immediate vicinity, 3% where there was a clear parking shortage and 2% where there was a major parking shortage (Figure 23).

There were no issues with parking at any of the development-led tree-planting locations (Figure 23). Figure 23 depicts an example of a location where parking was not permitted and a location with limited parking available.

Figure 23. Parking availability near the tree
(total observation *n*=643; 345 development-led, 298 grant-funding-led)



5.8.3. Proximity and relativity of road, kerb presence

These variables help inform how likely the tree is to be exposed to other factors which may impact its health, including the likelihood of contamination with fuel oils, salt or other chemical particulates in surface water runoff, as well as the likelihood of the tree being injured by a vehicle, or requiring management for road safety/visibility.

Distance from the tree to the *nearest road* was recorded for 405 trees (249 development-led, 156 grant-funding-led). 57% of development-led trees were planted 0–5m from the road, and 26% were planted 5–10m from the nearest road.

58% of grant-funding-led trees were planted 0–5m from the road, and 14% were planted 5–10m from the nearest road. The remaining trees were planted more than 10m from the road (Figure 24).

Trees planted below the road level are more likely to be impacted by polluted surface water runoff. The *relative ground level* of the tree's planting location to the nearest road was recorded for 528 trees (299 development-led, 229 grant-funding-led).

70% of development-led trees were planted above the nearest road, 18% were planted at the same level as the nearest road, and 12% were planted below the nearest road. 93% of grant-funding-led trees were planted *above* the nearest road, 4% were planted at the *same level* as the nearest road, and 3% were planted *below* the nearest road.

Kerbs help prevent vehicle and runoff incursion to a planting site. A *kerb was present* at the edge of 68% of the development-led tree planting sites. In 4% of cases, there was a *partial or damaged kerb*. A kerb was present at the edge of 89% of the grant-funding-led tree planting sites. In 5% of cases, there was a partial or damaged kerb. The rest of the sites had *no kerb*.

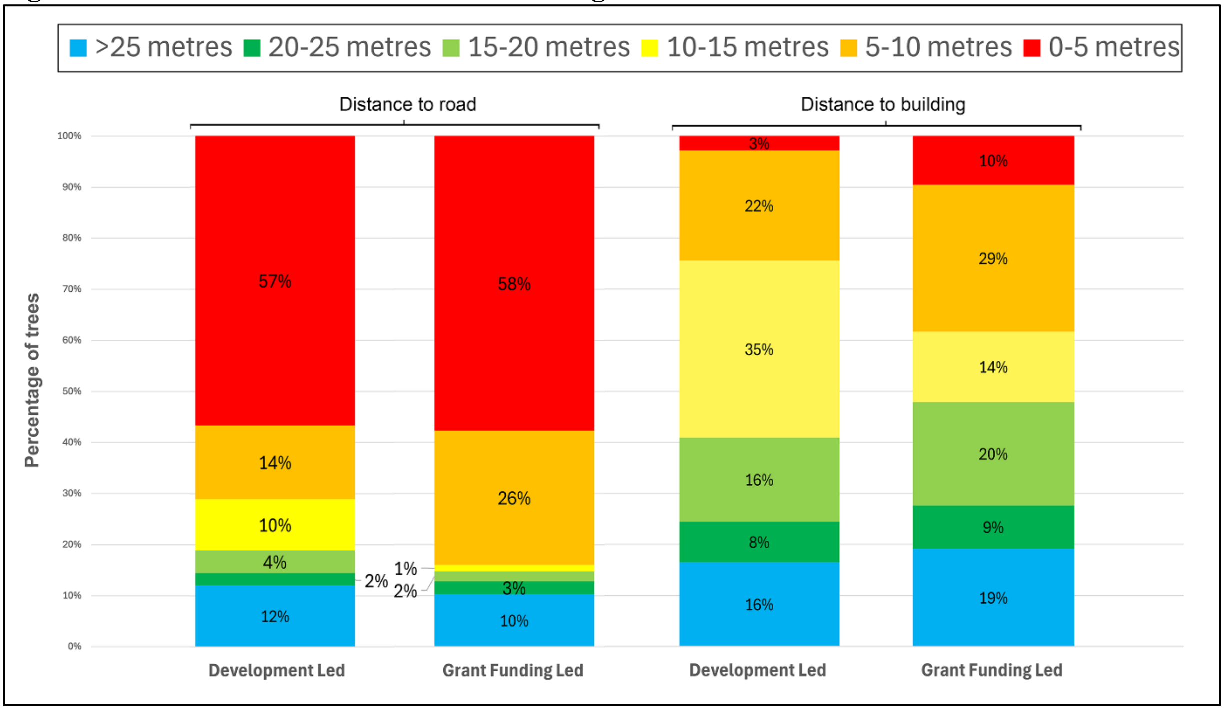
5.8.4. Distance to buildings

Distance from the tree to the *nearest building* was recorded for 270 trees (176 development-led, 94 grant-funding-led). This variable tells us about potential exposure to radiant building heat and shading from the building.

3% of development-led trees were planted 0–5m from the nearest building, 22% were planted 5–10m from the nearest building, 35% were planted 10–15m from the nearest building (Figure 24).

10% of grant-funding-led trees were planted 0–5m from the nearest building, and 29% were planted 5–10m from the nearest building. 14% were planted 10–15m from the nearest building.

Figure 24. Distance to nearest road and building



5.8.5. Number of trees in a 10m radius, number of trees in a 20m radius, number of trees in the same planting area

The number of other trees in the immediate proximity of a tree tells us about its potential competition, now and in the future.

12% of development-led trees had no other trees growing within a *10m radius*, compared with 25% of grant-funding-led trees. 24% of both funding sources had one tree growing within a *10m radius*. 6% of development-led trees and 1% of grant-funding-led trees had 25 or more trees growing within a *10m radius*.

2% from each funding source had no other trees growing within a *20m radius*. 17% of development-led trees and 8% of grant-funding-led trees had 25 or more trees growing within a *20m radius*.

See Appendix 7 for the full results of this variable.

5.8.6. Interference variables.

The variables in Table 8 were recorded as present if there was a *current* conflict with the specified variable only, future conflicts were not considered.

Table 8. Interference variables

Utilities	Building	Fences	Sign	Lighting	Road traffic	Pedestrian	Hedge	Other vegetation
0	0	3	1	1	0	0	24	45

5.9. Other observations

5.9.1. Planting area characteristics – soil compaction and reinstated soil

Compact soil can prevent trees from establishing as their roots cannot penetrate the soil in order to gain access to nutrients and water. Combining both physical survey observations and data from aerial imagery taken during the construction period, *soil compaction* was suspected at 87% of development-led planting locations surveyed. Poor soil quality impacts establishment and negatively affects tree growth. *Reinstated soil* was suspected at 97% of the development-led planting locations.

For grant-funding-led projects, visual evidence of *soil compaction* was observed at 2% of planting sites, and *reinstated soil* was observed at 3%. The grant-funding-led results do not include any aerial imagery assessments, as many parks and road verges used for grant-funded tree planting were created before sufficient aerial imagery was available to investigate.

5.9.2. Planting area characteristics – waterlogging and contamination

No trees were found in *waterlogged* conditions. Just two instances of observable *contamination* were found. No verification of substances was done; neither looked deliberate.

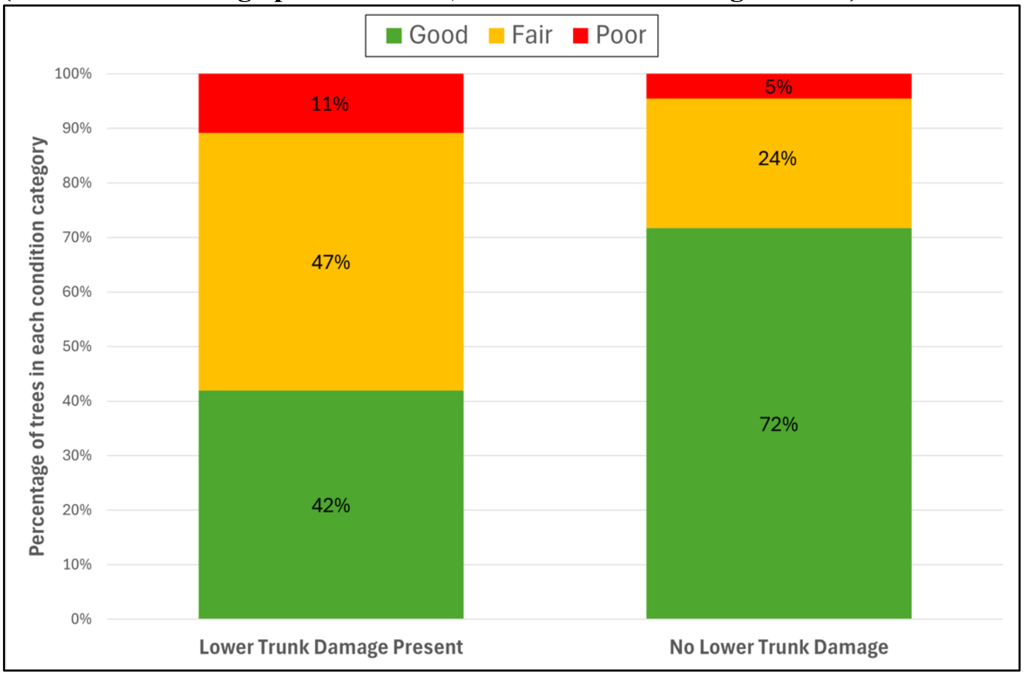
6. Analysis

6.1. Variables significantly associated with condition outcomes

Chi-squared tests of independence were used to look for significant differences between three condition category outcomes (good, fair and poor) based on the outcomes of the variables *lower trunk damage*, *other damage*, *root flare visibility*, *staking maintenanc*e, and the five predominant ground cover at base categories. The condition categories *sprouts* and *stumps, dead, died or removed* trees, were excluded from this analysis because of low observation numbers. Significant findings (p<0.05) from the chi-squared tests are presented below. Post hoc testing using adjusted residuals was used to determine where any significant differences occurred within the data.

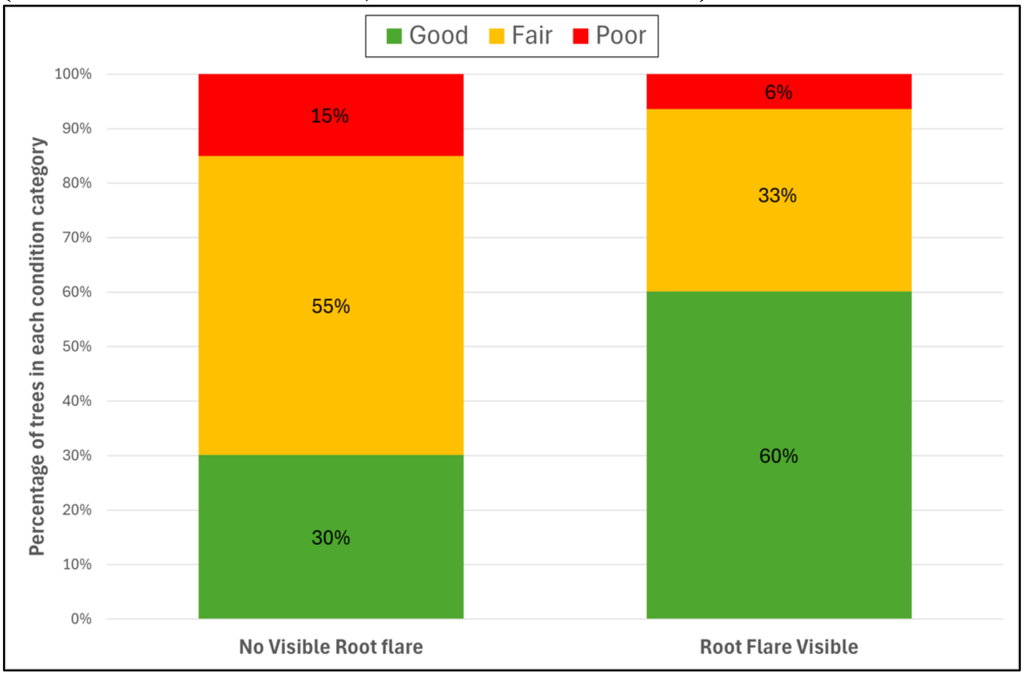
The relationship between *lower trunk damage* and *condition category* was significant: X^2 (2, n=503) = 42.88, p<0.01 (Figure 25). Post hoc analysis using standardised residuals showed that trees *with* lower trunk damage were significantly more likely to be in the *fair* condition category and significantly less likely to be in *good* condition (p<0.01). While trees *without* lower trunk damage were significantly more likely to be in the *good* condition category and significantly less likely to be in the *fair* condition category (p<0.01).

Figure 25. Lower trunk damage and consolidated condition outcome (lower trunk damage present *n*=305, no lower trunk damage *n*=198)



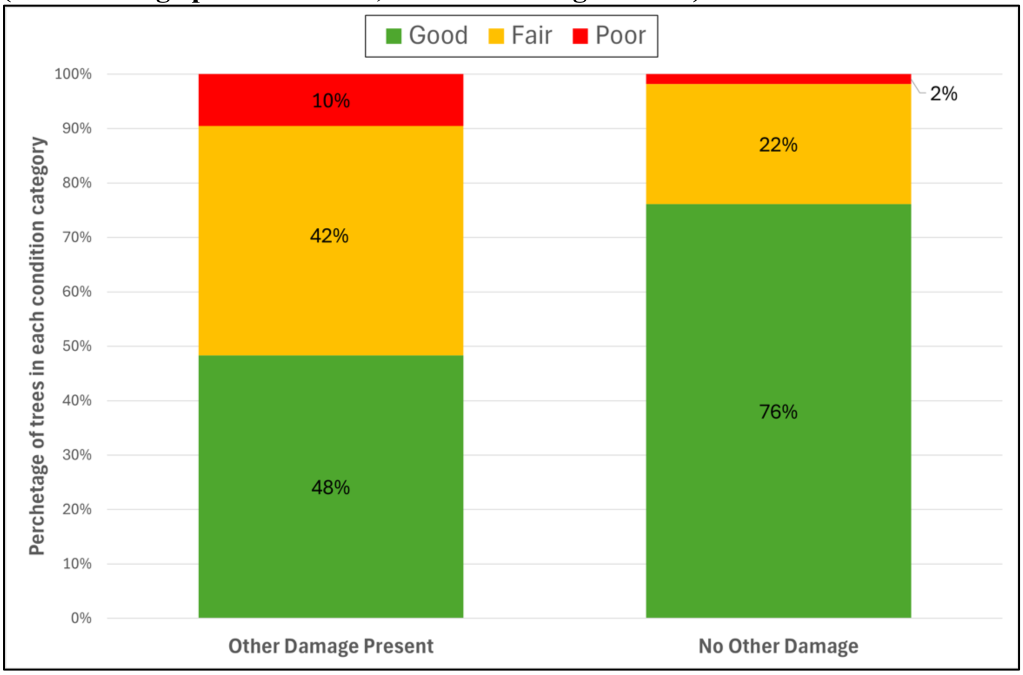
The relationship between *root flare* and *condition category* was significant: X^2 (2, *n*=499) = 28.74, *p*<0.01 (Figure 26). Post hoc analysis using standardised residuals showed that trees with *visible root flare* were significantly more likely to be in *good* condition and significantly less likely to be in *fair* or *poor* condition (*p*<0.01). While trees with *no visible root flare* were significantly more likely to be in *fair* or *poor* condition and significantly less likely to be in the *good* condition category (all statements *p*<0.01).

Figure 26. Root flare and consolidated condition outcome (with visible root flare *n*=406, no visible root flare *n*=93)



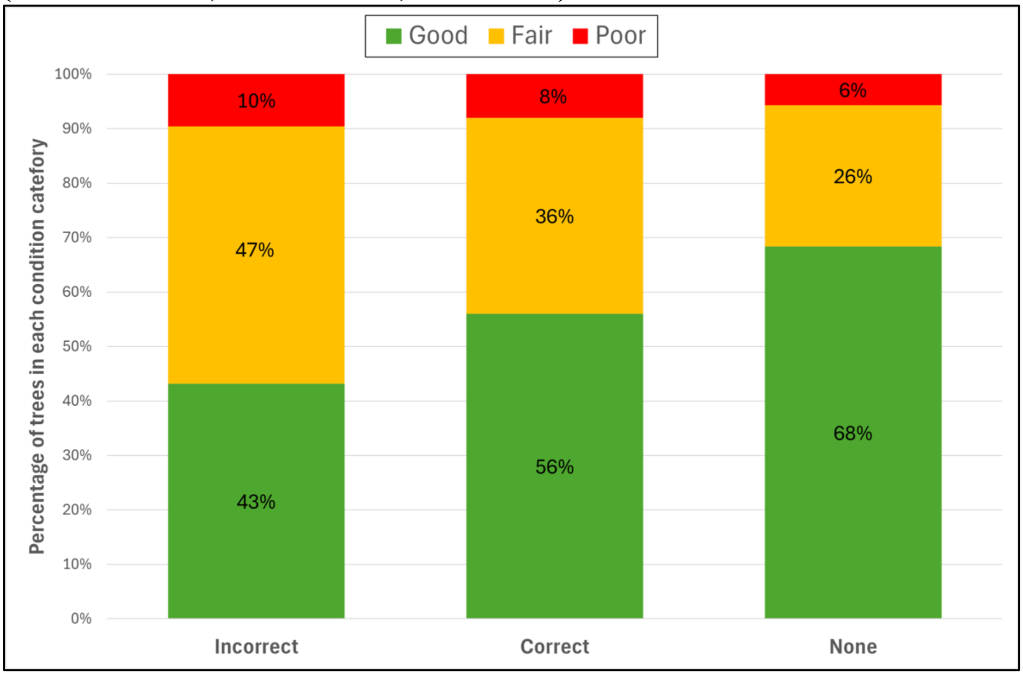
The relationship between *other damage* and *condition category* was significant: X^2 (2, *n*=529) = 28.05, *p*<0.01 (Figure 26). Post hoc analysis using standardised residuals showed trees with *no other damage* were more likely to be in *good* condition and less likely to be in *fair* or *poor* condition ($p<0.01$). It also showed that trees with *other damage present* were less likely to be in *good* condition ($p<0.01$).

Figure 27. Other damage and consolidated condition outcome (other damage present *n*=420 , no other damage *n*=109)



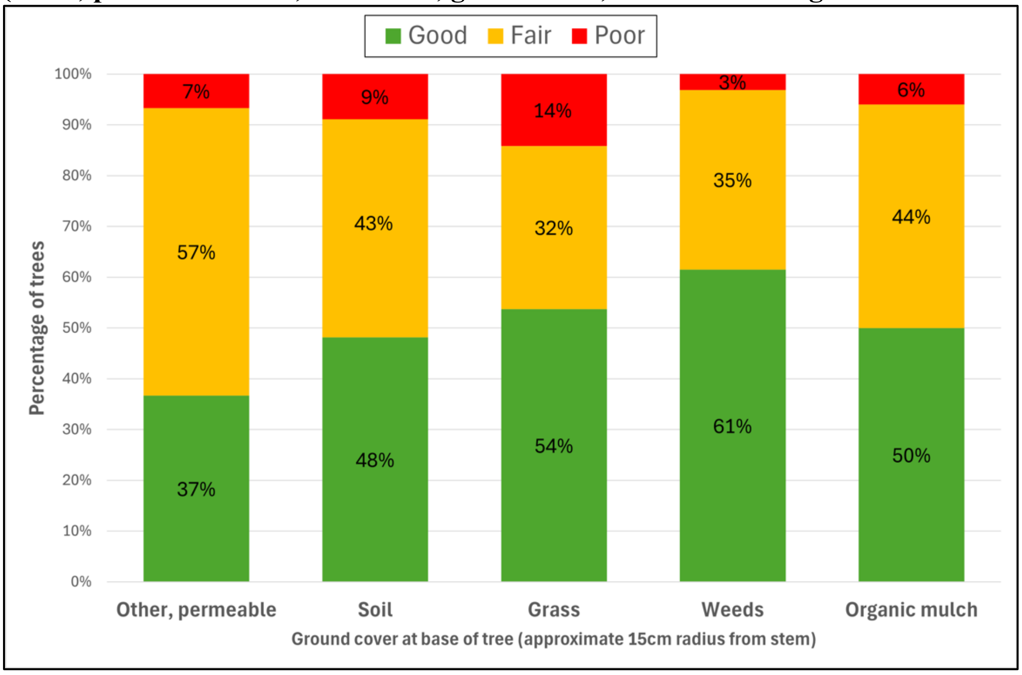
The relationship between *staking maintenance* and *condition category* was significant: $X^2(4, n=528) = 24.34$, $p<0.01$ (Figure 28.) Post hoc analysis using standardised residuals showed there were significantly fewer *incorrectly staked* trees in *good* condition ($p<0.01$), and that *incorrectly staked* trees were more likely to be in *fair* condition ($p<0.01$). Trees which were *not staked* were more likely to be in *good* condition ($p<0.01$) and were less likely to be in *fair* condition ($p<0.01$).

Figure 28. Staking maintenance and consolidated condition outcome (incorrect *n*=220, correct *n*=150, none *n*=158)



The relationship between the five most prominent ground cover at base types (*grass, weeds, soil, organic mulch* and *other, permeable*) and *condition category* was significant: X^2 (4, *n*=430) = 15.49, *p*<0.01 (Figure 29). Post hoc analysis using standardised residuals showed trees with *grass* surrounding the base of the tree were more likely to be in *poor* condition (*p*<0.01). No significant differences were found looking at *ground cover under canopy* and condition outcomes.

Figure 29: Ground cover at base and consolidated condition outcome (other, permeable *n*=30, soil *n*=135, grass *n*=134, weeds *n*=161 organic mulch *n*=50)



In addition to the variables mentioned above, chlorosis had a significant relationship with tree condition outcome (*p*<0.01); trees *with chlorosis* were significantly more likely to be in *fair* or *poor* condition categories (*p*<0.01). See Figure 36, Appendix 8.

There was also a significant relationship between *dieback* and tree *condition category*. Due to low observation numbers in some dieback categories, to carry out this Chi-squared test of independence, dieback categories were consolidated to *0% dieback, 1–40% dieback, 41–80%, 81–100%* dieback. The difference was found to be significant (*p*<0.01).

Post hoc testing showed that trees which had *0% dieback* were significantly more likely to be in *good* condition and significantly less likely to be in *fair* or *poor* condition (*p*<0.01). Trees with *1–40% dieback* were significantly more likely to be in *fair* condition (*p*<0.01) and significantly less likely to be in *good* or *poor* condition (*p*<0.01). Trees with *40–80% dieback* were significantly more likely to be in *poor* condition and significantly less likely to be in *good* condition (*p*<0.01). Trees with *80–100% dieback* were significantly more likely to be in *poor* condition and significantly less likely to be in *good* or fair *condition* (*p*<0.01). See Figure 37, Appendix 8.

No significant relationship was found between the presence or absence of *epicormic shoots* and tree *condition category* outcomes using chi-squared test independence (*p*=0.3).

6.2. Other variables with a significant relationship to each other

No count of when *incorrect* staking was the cause of *other damage* was made during the surveys. However, it was frequently observed by the researcher that this was the reason *other damage* had occurred. Chi-squared tests of independence showed a significant relationship between the presence of *other damage* and staking classification (*correct, incorrect, none*): X^2 (4, *n*=542) = 41.47, *p*<0.01. Post hoc analysis using standardised residuals showed that trees which were staked *incorrectly* were more likely to have *other damage* present, and less likely to have *no other damage* present. The opposite was also true; trees which were staked *correctly* were more likely to have *no other damage* and less likely to have *other damage* (all results $p<0.01$).

The three most predominant *ground cover at base* types (*grass, weeds, soil*) were investigated to see if there was a significant relationship between a particular ground covering and *lower trunk damage*. Chi-squared test of independence showed a significant relationship: X^2 (4, *n*=432) = 10.48, $p<0.01$. Post hoc analysis with standardised residuals showed that trees found with *weeds* at the base were significantly less likely to have *lower trunk damage* and significantly more likely to have *no lower trunk damage* ($p<0.01$).

The *ground cover under canopy* types *grass, weeds* and *soil* were also investigated to see if there was a relationship with *lower trunk damage*. Chi-squared tests of independence showed a significant relationship: X^2 (4, *n*=408) = 12.68, $p<0.01$. Post hoc analysis with standardised residuals showed that trees found with *grass* as the *cover under canopy* type, were significantly more likely to have *lower trunk damage* and significantly less likely to have *no lower trunk damage* ($p<0.01$).

6.3. Annual mortality rate

Annual mortality rate is the percentage of trees being lost each year from a particular cohort. It is useful for comparing mortality between planting cohorts of different ages like the ones in this research. It is based on the percentage remaining at the time of survey relative to the total number planted, and how long the trees have been planted. *Annual mortality rate* was calculated for each of the sites, enabling us to calculate the range and the average annual mortality rate for each of the funding sources and each city. A proxy midpoint in the tree planting season (January 20th) and survey period (July 20th) was used for each site rather than actual planting dates, which were not available for most sites. Weighted averages were calculated for sites which had multiple planting years in the same cohort.

The *annual mortality rate* for development-led sites ranged from 0–21.2%. The annual mortality rate for grant-funding-led trees ranged from 0–100%. The *average annual mortality rate* for development-led sites was 4.5%, and the *average annual mortality rate* for grant-funding-led planting was 6.9%. Averages for each of the cities ranged between 1.7%–6.1% for development-led tree planting and 2.8%–13.8% for grant-funding-led tree planting. Table 9 summarises this information.

These results were very sensitive to the incorporation of one site with a 100% mortality rate (site 2.G in Appendix 9, comprised of just four planted trees). With site 2.G removed, *annual mortality rate* for grant-funding-led sites ranges from 0 to 15.6%. With 2.G removed, the *average annual mortality rate* for grant-funding-led tree planting in each city ranges from 2.8% to 3.2%. The total *average annual mortality rate* for grant-funding-led sites drops to 2.9%. The total grant-funding-led *average annual mortality rate* for Birmingham drops significantly, from 13.8% with the site incorporated, to 3% without. It also impacts Birmingham's total *average annual mortality rate*, which drops from 10% to 3.6%, and in turn lowers the total *average annual mortality* rate to 3.7%. Table 9 and Table 10 summarise this information. The Leeds grant-funding-led result (highlighted by * in the tables) is based on just one site. Appendix 9 shows mortality rates for each individual site by city and funding source, with and without the sensitivity analysis.

Table 9. Mortality rates summary statistics

	Average annual mortality rate		
	Develop -ment- led	Grant-funding-led	City
Bristol	1.7%	3.2%	**2.5%**
Birmingham	4.3%	13.8%	**10.0%**
Nottingham	6.0%	2.8%	**4.3%**
Leeds	6.1%	0.0%*	**5.2%**
Funding source	**4.5%**	**6.9%**	
All planted trees			**5.7%**

Table 10. Mortality rates summary statistics (site 2.G omitted)

	Average annual mortality rate		
	Develop-ment- led	Grant-funding-led	City
Bristol	1.7%	3.2%	**2.5%**
Birmingham	4.3%	3.0%	**3.6%**
Nottingham	6.0%	2.8%	**4.3%**
Leeds	6.1%	0.0%*	**5.2%**
Funding source	**4.5%**	**2.9%**	
All planted trees			**3.7%**

6.4. Unscathed trees

The variables investigated in this research do not occur in isolation. When following the survey method described in the PTRP, the compounding of factors increases the likelihood of a tree ending up in a worse condition category. Conversely, the existence in isolation of a negative attribute decreases the likelihood of a tree suiting a poorer condition category, despite the existence of a defect. The proportion of trees with no dieback, no epicormic shoots, no chlorosis, no lower trunk damage, visible root flare, no other damage, and staked correctly is presented in Table 11. Just 3% of the trees planted were found growing 'unscathed'. The full results of this filtering process are shown in Appendix 10.

Caution should be taken with the assumption that these unscathed trees have the best chance of growing to maturity (from the surveyed sample). Some of these trees may have been correctly staked at the time of this survey, but without timely intervention will not be. Soil and rooting environment were not considered in this filtering process, and there may be other trees in the survey, for instance, a tree recorded as having had *other damage* - but which in reality was only minor damage, from which the tree has recovered - which could go on to perform just as well as a presently unscathed tree, provided no further harm came to them.

Table 11. Unscathed trees

Unscathed trees/Funding	**Development-led**	**Grant-funding-led**
Total number of "unscathed trees"	11	9
As percentage of funding source total (development-led *n*=377, grant-funding-led *n*=310)	3%	3%
As percentage of grand total planted (*n* =687)	2%	1%

7. Discussion

7.1. Key findings

This research aimed to evaluate the success of urban tree planting for two funding sources. The trees investigated were planted at 48 different sites in four cities between 2012 and 2022. Tree condition and survival rates were assessed. Factors which may have influenced these outcomes were considered.

23% of the development-led trees specified for planting were found not to have been planted. 21% of development-led and 20% of grant-funding-led trees that were planted had died or been removed at the time of the survey. Poor condition outcomes, chlorosis, and incorrectly staked trees were significantly more prevalent in the development-led sample compared to the grant-funding-led trees. The research revealed widespread damage to the trees, both above and below 45cm, as well as signs of insufficient aftercare, both of which could undermine their long-term ecological and financial benefits.

7.1.1. The impact of poor planting and maintenance on condition outcomes

Incorrect staking was occasionally recorded because the tree had been incorrectly staked from the day it was planted, for example, a nail installed incorrectly through a rubber spacer pierced the bark of the tree.

Trees with grass at the base of the stem were more likely to have poor condition outcomes compared to other ground cover at base types. This research indicates that trees planted where grass will be the predominant ground covering under the canopy are more likely to have lower trunk damage, which is often caused by lawn maintenance equipment, than those planted in weeds or soil. This type of lower trunk damage was observed regularly during the surveys (Appendix 11, Figure 43). Residents and contractors encountered by the researcher during the surveys indicated that grass length was regularly maintained (through management contracts) at many of the open urban areas visited in this research. The researcher visited some development sites where the new homeowners are required to pay annual service maintenance charges, a proportion of which is specified for landscaping, but, according to residents, the service is limited to strimming the grass and hedges - in some cases damaging the newly planted trees.

Trees with weeds at the base surrounding the trunk were less likely to have lower trunk damage and weeds were more prevalent at grant-funding-led planting sites. However, weeds also present a problem for newly planted trees in terms of competition for water and nutrient resources. Thirty instances of weed killer use at the base of the tree were observed, and it was noted that its use did not necessarily prevent mechanical damage by grass maintenance equipment (Figure 45, Appendix 12). The successful practice of growing healthy trees in the urban environment requires experienced planning long before the day the tree is planted (Zürcher, 2022). Mowing regimens should be checked and, if necessary, amended *before* planting, not, as was observed at some sites visited in this project; after the trees are already damaged. At several sites, it appeared grass had (at some point in a previous growing season) been mown right up to the stem of the tree, whereas it was now being allowed to grow long in a circle around the tree, lessening the chance of further strimmer or mower damage, but increasing the competition in the root zone for nutrients and water.

Protective measures meant to support tree health are often poorly installed or maintained, leading to increased stress for the tree (Thacker, 2019). In this research, a significant relationship was observed between staking maintenance and tree condition outcomes; fewer incorrectly staked trees were found in good condition. At development-led planting sites, where trees *were* staked, they were staked incorrectly 74% of the time. Although not quantified, a large proportion of incorrectly staked trees were categorised as such because their stakes had been left in place too long (Appendix 11, Figure 41). Thirty-four trees[25] could have been planted during the 2021 to 2022 planting season and, therefore, conceivably been in the ground for around 1.5 years at the time of the survey. All the remaining trees in this survey would have been in the ground for more than 2.5 years and, by best practice standards, should have had their support structures removed. If left in place for too many years, trees may then need careful weaning from their support structures to prevent leaning or snapping (Patch, 1989). These findings suggest that the quality of post-planting maintenance, rather than the mere presence of protective measures, can contribute to establishment outcomes. While a few residents were aware, many of the people encountered during the surveys at the new housing developments did not know that their trees were being damaged by unremoved tree ties and stakes. A handful, both at new developments and nearby grant-funding-led projects, communicated with the researcher that they had wanted to intervene in the correct management of new trees near them but did not feel they could or did not know how to.

[25] These were development-led trees (condition: 4 good, 19 fair, 7 poor, 4 stumps).

A lack of visible root flare was associated with poorer condition outcomes, and no root flare was visible at 19% of trees, indicating they were planted too deep. The high prevalence of epicormic shoots (39% of trees) and dieback in trees from both funding sources indicate the presence of stressors in the environment surrounding the tree. These findings highlight the importance of proper site selection, site preparation and planting technique.

7.1.2. Condition, survival rates and ecosystem service delivery

The quantity of ecosystem services delivered by an individual tree, such as carbon storage, rainfall interception and air pollution removal, is determined by characteristics including size and condition (Davies et al., 2017a; Hand et al., 2019). Young trees are especially sensitive to early trauma, including mechanical wounding and inadequate maintenance (Barrell, 2021). These issues can affect the tree's condition and reduce the likelihood that it will achieve its full growing potential. Lower trunk damage affected more than half of the trees surveyed (from either funding source) and was significantly associated with fair tree condition outcomes (p<0.01). The presence of other damage was significantly assiciated with fair and poor condition outcomes (p<0.01). During the surveys, five instances of suspected damage caused by dogs were noted (Figure 44, Appendix 12) and other forms of vandalism (snapped branches, peeled bark, stripped leaves) were encountered. A resident with a view of a tree at a planting site near a busy children's play area (where 53% of planted trees had died) stated that the reason the tree in front of their property remained was because they had been regularly intervening to stop children from damaging it.

The volume of strimmer damage encountered by tree planting organisations in England is not trivial and was cited as a barrier to successful planting outcomes by multiple stakeholders who attended the Tree People conference, hosted by Trees for Cities in June 2024. Despite the use of tree guards and tree cages in an attempt to mitigate strimmer damage and vandalism at some grant-funding-led sites, over half of these were incorrectly installed or maintained, often exacerbating rather than mitigating damage. High levels of damage by lawn management equipment are a global urban landscaping problem; the figures in this study are not dissimilar to research from urban areas in New Zealand, where at least one mechanical damage wound was found on 63% of all surveyed trees (Morgenroth et al., 2015).

In Tony Bradshaw's oft-quoted 1985 research into urban tree mortality, only 28% of the population were found growing "unscathed"; and whilst this research's survey methods were not the same as his, it is troubling to have found just 3% "unscathed" trees using the PTRP metrics. This supports existing sentiments that more focus on aftercare is required and that when trees are planted, the focus should be on the establishment of quality treescapes as opposed to simply planting high numbers of trees (MacKenzie, 2020; Rodgers & Sacre, 2022). In one study of five different species, trees expressing over 11% dieback were significantly associated with increased risk of mortality (Morin et al., 2012), and this research showed dieback to have a clear relationship with condition category. It is considered unlikely that the 22% of 547 surveyed trees which were already expressing over 20% dieback will all survive, or if they do that they will provide the full quantity of ecosystem services which they could have in the right conditions. Grant-funding-led trees were significantly more likely to have no dieback compared to development-led trees.

If a scenario is imagined in which 20 trees are planted at a new development site, the average annual mortality rate for development-led trees of 4.5% results in just 5 trees remaining at 30 years. Recently enacted Biodiversity Net Gain legislation in England now creates a legal requirement for some developments to successfully deliver biodiversity outcomes 30 years after planning permission is granted; some of this is expected to be achieved through new tree planting. The new legislation could lead to an improvement in outcomes for development-led tree planting. However, due to financial constraints faced by many local authorities, there is anxiety about the burden of monitoring and enforcing compliance with the new regulation. Data in this research suggests many of the trees planted through development-led initiatives will fail to deliver their intended ecological benefits without improved post-planting maintenance coupled with effective monitoring and enforcement.

7.1.3. Financial implications for tree planting initiatives

A study from America demonstrated that trees can be expected to provide increasing annual benefits during the 10 years after planting if the annual survival rate is higher than 93% during the establishment period, but that with continued 93% or lower annual survival, the increase in annual benefits from tree growth will not be able to make up for the loss of benefits as trees die (Widney et al., 2016). Similar results were found from investigations in the UK, which looked into breakeven and payback points for delivering canopy cover under different growing conditions (GreenBlue Urban, 2018). This research indicates annual mortality rates close to and over these thresholds at some sites. At the more conservative of the two average annual mortality rate calculations for grant-funding-led projects in this research (2.9%), if you calculate how many trees will remain at 30 years out of 20 planted, less than half will have survived. The government is investing large sums of money into tree planting projects, which (at the average annual mortality rates calculated in this study) risk not breaking even with the investment in terms of delivered benefit.

Using total investment figures from the UTCF grant to crudely[26] evaluate the investment outcome by looking at the percentage of UTCF trees[27] in different condition categories further highlights this issue. Of the £48 million total invested in the UTCF by the government, £5.76 million (12%), would have been spent on a now-non-existent product (dead or removed trees), £1.4 million (3%) would have been spent on trees which are now in poor condition and £19.6 million (42%) would have been spent on an investment that is now in only moderate condition (the fair condition category). These would not be considered acceptable results from military or healthcare budget spending, and nor are they acceptable results for tree planting.

7.2. Recommendations for further research

To understand why, when extensive literature setting out correct practice exists, poor planting and maintenance occurs, qualitative investigations into the causes should be made at a high operational level by engaging in dialogue with developers, tree planting organisations, local authorities and the communities into whose neighbourhood trees are planted. Some qualitative enquiries were made during this research and the responses were insightful. Similar research has recently been conducted in the US (Schubert et al., 2024). To improve planting programme delivery practices, research is required into different communication strategies targeted at a tangible improvement in planting techniques, post-planting maintenance quality, quantity, duration and frequency. This type of research should be set against realistic and measurable target outcomes, such as increased ground moisture levels in summer at a location targeted with a watering campaign or an increasing number of de-staked trees from three years after planting at development sites following a communication campaign with developers and new homeowners.

UK-costed empirical research into specific types of post-planting maintenance practices and their long-term impact on ecosystem service delivery and payback periods is urgently required. The higher prevalence of chlorosis and compacted or reinstated soil on development-led planting sites may indicate an issue with soil quality, which would be worthwhile investigating further.

Results from the grant-funding-led sites studied in this research show a marked difference in current condition outcomes between the trees planted from 2017 to 2022 (UTCF funded) and those planted between 2012 and 2017 (predominantly BTP funded). Recipients of both grants should have had suitable aftercare plans, however the UTCF provided more structured support than the BTP grant in this respect. A retrospective cohort analysis via planting records by one London borough showed initial survival rates of around 90%. However, in the period between the fourth and seventh year following planting, these rates dropped dramatically to 65% survival (FCWG, 2013). Investigating the condition

[26] in the absence of published numbers, the analysis assumes all trees planted were standards, akin to those studied in this research. While this assumption is not correct, it does still adequately indicate the less than acceptable return of investment.

[27] UTCF trees are identified on Figure 5, categorised as 2.5–7.5 years grant-funding-led planting.

of the UTCF trees at two- and five-year intervals from now would provide insight into whether the additional provision of financial support for maintenance (provided throught the UTCF) has had a positive impact on longer term condition outcomes, or if there is a decline in condition.

8. Conclusion

Physiological outcomes for young urban trees are impacted by the level of harm or correct attention they receive in their formative years. This research highlights factors that are significantly associated with different tree condition outcomes in the establishment phase, reaffirming the importance of correct planting and post-planting maintenance techniques. Incorrect staking, lower trunk damage, other damage, lack of visible root flare above the soil level, and grass covering the ground under the tree all had a negative impact on tree condition outcomes. Incorrect staking maintenance and chlorosis were significantly more prevalent at development-led trees.

In the sampled cohort, 79% of planted trees survived. However, less than half of the trees from either funding source investigated were found growing in good condition. Survival rates alone are not sufficient to determine how successful tree-planting efforts have been. The high prevalence of damage (80% of trees), lower trunk damage (60% of trees), dieback (63% of trees) and epicormic shoots (39% of trees) indicate a planting environment which is hostile for young trees and this needs careful consideration when planning and delivering new tree planting in the urban realm.

Failure to follow best practices for planting and post-planting maintenance is consequentially eroding the long-term value of some of the tree planting investigated. An improvement in the proportion of newly planted urban trees growing in good condition might be realised by improvements in their aftercare and by enforcing measures that prevent avoidable damage.

9. Limitations

The study design provides a snapshot of tree conditions at a single point in time, limiting the ability to infer long-term trends, growth patterns or causal relationships. Longitudinal studies with standardised data collection protocols are recommended to address these limitations and provide further understanding of urban tree establishment success. The research relied heavily on visual assessments, and despite the use of a standardised protocol, observations are subject to error and bias; they also cannot detect subtle physiological issues which may have been present but invisible.

The sample size, although robust, still cannot fully capture the variability present across the broader English urban treescape due to the sheer scale of urban tree planting. The reliance on existing records and available local authority data to find grant-funding-led projects meant it was not possible to investigate actual 'delivery' against what was promised in the funding proposals.

The inclusion of an outlier with 100% mortality in the grant-funding-led sample significantly influenced the overall annual mortality rate statistics. Although a sensitivity analysis was performed, the potential skew introduced by this site may impact the interpretation of grant-funding-led annual mortality rates.

10. Evaluation of PTRP for Future Use in the UK

Training and engaging citizen scientists in the use of structured protocols like the PTRP can provide meaningful data to local authorities (Birmingham Tree People, 2023). To improve treescape managers' understanding of the current condition of their young trees, a system of reporting this type of data to local authorities or site managers could be established. The app used to collect data in this research was customisable and was open source. It could be used by planting organisations at little expense. Some of the prevalent variables with an impact on tree condition outcomes could also be integrated into a local authority's tree management system. More granular metrics reporting severity and recency of damage variables could be specified; this would allow for greater analysis of the impact on tree condition and, if integrated into tree management software, could cue response to severe issues. To reduce the time and cost taken to collect newly planted tree data and improve its utility, non-prevalent variables, and some variables which were particularly time-consuming to collect without specialist equipment or additional surveyors - such as distance to road and property measurements, and numbers of trees within 10m and 20m radius - could be omitted.

11. Final Thoughts

Some of the trees classified as *sprouts* in the overall condition variable, the "Sycamore Gap" style trees, were re-growing remarkably well despite their historical misfortune. If each new urban tree received the same care and attention as the Sycamore Gap tree has received, we could collectively improve the lives of our urban trees this decade. To realise this, the public needs a clear understanding of what is and is not good tree planting practice, when and how to intervene, and who to hold accountable for poor planting or maintenance. Community-based stewardship can foster feelings of ownership towards urban trees, which in turn can improve tree planting outcomes (Berger et al., 2019; Eisenman, 2024). Adequate revenue funds should be allocated for stewardship and aftercare initiatives from the point when a new planting scheme is conceptualised. The best time to look after newly planted urban trees was 20 years ago; the second-best time is now (adapted from a Chinese proverb).

12. Acknowledgements

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Appendix 1: All recorded variables

The descriptions of the original Planted Tree Re-Inventory Protocol variables in this table are closely worded, with important protocol snippets described verbatim from J. M. Vogt, S. K. Mincey, B.C. Fischer and M. Patterson (2014), Planted Tree Re-Inventory Protocol. Version 1.1. Bloomington, IN: Bloomington Urban Forest Research Group at the Centre for the Study of Institutions, Population and Environmental Change, Indiana University. 96 pp.
www.indiana.edu/~cipec/ research/bufrg_protocol.php

Table 12. All Recorded Variables

Variables collected * denotes an additional variable, not further described in the Planted Tree Re-inventory Protocol.	**Further information** * denotes a modification from original Planted Tree Re-inventory Protocol, subsequently described	**This research's variable ID**	**PTRP variable number**
Tree ID	Unique to each tree.	V1	V1
Location	**Latitude and longitude coordinates.** Recorded via GPS on Epicollect5. Very occasionally, plotting accuracy was impaired by GPS signal.	V2	V2
*City	Describes the urban area around the city studied within which the sites were found.	V3	
*Funding Source	The primary source of finance to plant the trees. Development-led or grant-funded.	V4	
*Grant Type	**The specific grant type if grand funded.** Big Tree Plant, Urban Tree Challenge Fund, England's Community Forests	V5	
*Planting Season	**The period from winter to spring in which the tree was presumed planted.** (i.e. 2018–2019 planting season was planted between the start of winter (end of 2018) and the beginning of spring (beginning of 2019.))	V6	
Species	**Latin name and common name.** Recorded to species level (cultivars recorded where known)	V7	V3
DBH	***Diameter of stem at 1.5m[28] above ground level.** Recorded to the nearest millimetre and otherwise as described in the PTRP.	V8	V4
*Diameter at 1m	***Diameter of stem at 1m above ground level.** *Recorded to the nearest millimetre and otherwise as other stem measurements are described in the PTRP. Can be converted to girth measurement.	V9	
Caliper	**Caliper refers to the diameter of the trunk of the tree at 15cm above the first lateral root or ground level/soil line.** Recorded to the nearest mm and otherwise as described in the PTRP. *If prevented by an immovable stem guard, this was measured at 20cm above ground level. (Caliper measurements taken at 20cm were later excluded from summary statistics calculations for this variable, n=60.)	V10	V5
Total Height	**Total Height (in m) is the height of a tree from the base of the tree (ground) to the tops of its branches.** *Trees under 5m measured to the nearest to the nearest 5cm using a purpose made telescopic ruler. Trees over 5m estimated to the nearest 10cm (T over 5m) using the Arboreal Tree app on the iPhone 13 Pro. Estimated heights were sense checked against the telescopic ruler and very occasionally, if the GPS failed and Arboreal Tree was unusable, height was estimated by eye checked against the telescopic ruler lined up with a handheld ruler or metre stick.	V11	V6
Height to Crown	**Height to Crown is the distance along a tree's main trunk between the ground and the beginning of the canopy or crown.** *Heights up to 2m measured to the nearest to the nearest 5cm with a tape measure, heights over 2m measured to the nearest to the nearest 5cm with the telescopic ruler.	V12	V7

[28] 1.5m was chosen over 1.37m as there is a tree planting organisation in the UK already using the Planted Tree Re-Inventory Protocol, and this was their opted height.

Variables collected * denotes an additional variable, not further described in the Planted Tree Re-inventory Protocol.	**Further information** * denotes a modification from original Planted Tree Re-inventory Protocol, subsequently described	**This research's variable ID**	**PTRP variable number**
Crown Dieback	**Crown Dieback is the amount of dead branches on the top and outsides of the tree canopy.** Measured on a scale from 0 to 6. **0** = 0% (no dieback) **1** = 1–20% dieback **2** = 21–40% dieback **3** = 41–60% dieback **4** = 61–80% dieback **5** = 81–99% dieback (very few living branches) **6 =** 100% dieback (complete dieback, no living canopy)	V13	V8
Crown Exposure	**Crown Exposure measures how open the canopy of the tree is to sunlight**. Specifically, Crown Exposure estimates the number of sides of the crown that would be exposed to sunlight if the sun were directly overhead. Measured on a scale from 0 to 5. **0** = Tree receives no light on any sides, because it is shaded by other trees/vegetation, buildings or other infrastructure. **1** = Tree receives light from the top or only one side. **2** = Tree receives light from two sides but not the top, or from the top and one side. **3** = Tree receives light from three sides but not the top, or from the top and two sides. **4** = Tree receives light from the top and three sides. **5** = Tree receives light from all four sides and the top.	V14	V9
Chlorosis	**Evidence of leaf chlorosis on at least 25% of leaf surface of the entire tree.** Leaf chlorosis is chronic yellowing between the veins of a leaf. Pictures of leaf chlorosis on individual leaves are presented in the PTRP. **0** = No leaf chlorosis present or chlorosis present on less than 25% of leaf surface area of the entire tree. **1** = Evidence of leaf chlorosis on at least 25% of leaf surface of the entire tree.	V15	V10
*Epicormic shoots	Signs of fast growing, weakly attached shoots/branches on the stem. **0** indicates absence **1** indicates presence	V16	
Root Flare	The root flare is the gradual taper of the trunk of a tree as it enters the ground. **0** indicates absence **1** indicates presence	V17	V11
Lower Trunk Damage	Present or historical damage to the lower trunk (<45cm above ground level). **0** indicates absence **1** indicates presence	V18	V12
Other Damage	Present or historical damage to the tree (>45cm above ground level). **0** indicates absence **1** indicates presence	V19	V13
Overall Tree Condition Category (PTRP Condition Category)	An important indicator of the overall health of the tree. A tree must display most of the characteristics indicated to be given that rating. **Good** = Full canopy, minimal to no mechanical damage to trunk, no branch dieback over 5cm (2”) in diameter, no suckering (root or water sprouts), form is characteristic of species. **Fair** = Thinning canopy, new growth in medium to low amounts, tree may be stunted, significant mechanical damage to trunk (new or old), insect/disease is visibly affecting the tree, form not representative of species, premature fall colouring on foliage, needs training pruning. *continues*	V20	V14

Variables collected * denotes an additional variable, not further described in the Planted Tree Re-inventory Protocol.	**Further information** * denotes a modification from original Planted Tree Re-inventory Protocol, subsequently described	**This research's variable ID**	**PTRP variable number**
Overall Tree Condition Category (PTRP Condition Category) *continued*	**Poor** = Tree is declining, visible dead branches over 5cm (2") in diameter in canopy, significant dieback of other branches in inner and outer canopy, severe mechanical damage to trunk usually including decay from damage, new foliage is small, stunted or minimum amount of new growth, needs priority pruning of dead wood. **Sprouts** = Only a stump of a tree is present, with one or more water sprouts of 45cm (18") or greater in height growing from the remaining stump and root system. **Dead =** Standing dead tree, no signs of life with new foliage, bark may be beginning to peel. **Stump** = Only a stump of a tree is present, with no water sprouts greater than 45cm ***Absent** = There is no evidence of the tree in the planting location *In the original PTRP, trees that have obviously been replaced (are the incorrect species, much smaller than they should be given the planting date, etc.) are categorised as 'Absent;. In this research, notes of if a tree was the 'incorrect species in location' or 'suspected replacement' tree (of which there were very few) notes on this were made separately to the condition variable, and as opposed to recording such a tree as 'absent'. In this research, the condition of such replacement trees was recorded as above.	V20	V14
*Consolidated Tree Condition Category	As above, but combining **Dead** and **Stumps** categories with trees which were known to have been planted but which were **absent** on the day of the survey to form the new category: **Stumps / Dead Standing / Died or Removed** = Either only a stump of a tree is present, with no water sprouts greater than 45cm, or a standing dead tree, with no signs of life with new foliage, bark may be beginning to peel, or a tree which was **absent** on the day of survey but believed to be planted and therefore is presumed to have died or been removed.	V21	
Interference Variables:	**Presence indicates a current conflict with specified infrastructure types.** Specified infrastructure: Utilities, Buildings, Fences, Signs, Lighting, Pedestrian Traffic, Road Traffic, *Hedges, *Other Vegetation **0** indicates absence **1** indicates presence	V22–30	V15–21
Ground Cover Type (At Base)	**Predominant ground covering type adjacent to stem at the base of the tree** (in the approximate 15cm circumference around the tree stem) **Soil** = Bare soil, exposed dirt; includes very old mulch where so few mulch pieces are visible that it no longer serves a purpose as mulch. **Organic mulch** = Organic (biodegradable in the short term) mulching material, such as bark or wood chips, shredded wood waste, even sawdust or intentionally placed leaves or pine needles. **Inorganic mulch** = Inorganic (manmade and non-biodegradable in the short term) mulching material, such as rubber or plastic pellets. **Grass** = Turf grass. **Perennial** = Perennial plants, flowers, shrubs; live more than one growing season; most bushes are perennial plants. **Annual** = Annual plants or flowers; only live one growing season; examples include most food plants, begonias, petunias, most geranium flowers. **Gravel** = Small pebbles, gravel, or landscaping rocks. **Weeds** = Weeds, nuisance plants, grass, etc. greater than 30cm (1ft) high. **Pavement** = Pavement, cement, asphalt, paving stones, etc.; may be broken and cracked but should still be in large, identifiable pieces to qualify as pavement (small, gravel-sized pieces would be gravel). Pavement, cement, asphalt, paving stones, etc.; may be broken and cracked but should still be in large, identifiable pieces to qualify as pavement (small, gravel-sized pieces would be gravel). *continues*	V31	V22

Variables collected * denotes an additional variable, not further described in the Planted Tree Re-inventory Protocol.	**Further information** * denotes a modification from original Planted Tree Re-inventory Protocol, subsequently described	**This research's variable ID**	**PTRP variable number**
Ground Cover Type (At Base) *continued*	**Other, permeable*** = Any other ground covering not mentioned above that is permeable (water would run through the substance and reach the soil below). *Other permeable was also used if two permeable surface types were in equal distribution (i.e. a tree planted exactly at the edge of a hedge and turf) **Other, impermeable** = Any other ground covering not mentioned above that is impermeable (water runs off in the direction of gravity or pools on the top but does not reach the soil immediately below).	V31	V22
Ground Cover Type (Under Canopy)	**Predominant ground covering type under the canopy** (before dripline) Categorised as per Ground Cover Type At Base.	V32	V23
Planting Area Type	The Planting Area Type is a name for the contiguous, permeable physical place within which the tree is planted. **Tree Lawn** = Tree is planted in the strip of permeable surface (usually grass) between the sidewalk and the street. **Median** = Tree is planted in a median, or strip of land between two or more lanes of traffic. **Shoulder** = tree is planted in a large road shoulder, either sloping up or down from street level; generally, for trees planted in the right-of way of wide, busy streets or roads in more rural areas. **Tree grate** = Tree is planted in a pit along a street or sidewalk and planting area is covered by a metal tree grate. **Tree pit** = Tree is planted in a relatively small pit-like area, bordered by pavement or similar in close proximity on all four sides, but without a tree grate accompanying the pit. **Bumpout** = Tree is located in a bumpout or cutout along the sidewalk or street, bordered by pavement or similar in close proximity on three sides; common where on-street parking occurs. **Front yard** = Tree is located in the front yard of a house or building, between the building and the sidewalk or street. **Side yard** = Tree is located on the side of a house or building, between two buildings. **Open area** = Tree is located in a larger, park-like open area (e.g., a grassy open area near a pond or the middle of a small pocket park).	V33	V24
Planting Area Relative to Road	**Planting height of tree relative to nearest road.** **Above, Even, Below** *Where encountered, private driveways were not counted as roads	V34	V25
Planting Area Width	**Narrowest dimension of the planting area in a direction perpendicular to an edge of the planting area.** Measured in metres. *Measured with surveyor's tape or measuring tape if ground flat, distances 5m–25m estimated by foot paces to the nearest 0.5m.	V35	V26
Planting Area Length	**Longest dimension of the planting area in a direction perpendicular to an edge of the planting area** Measured in metres. *Measured with surveyor's tape or measuring tape if ground flat, distances 5m–25m estimated by foot paces to the nearest 0.5m.	V36	V27
*Planting Area	**Area of the contiguous permeable space where the tree is planted** (metres squared). *This was calculated afterwards by measured width and length multiplication for relatively square planting areas, or by creating polygons on Google Earth after the surveys for irregular planting areas. Planting areas over 1000m^2 were recorded as >1000.	V37	

Variables collected * denotes an additional variable, not further described in the Planted Tree Re-inventory Protocol.	**Further information** * denotes a modification from original Planted Tree Re-inventory Protocol, subsequently described	**This research's variable ID**	**PTRP variable number**
Kerb Presence	**A kerb or barrier at the edge of a planting area.** **0** indicates absence **1** indicates presence.	V38	V28
Number of Trees 10m radius (of measured T)	**Number of other trees (excluding the focal tree) in 10m radius** Common sense / "anything that one would call a tree is a "tree" used to distinguish trees from hedges. (e.g. some hedges which were encountered which were over 2m but clearly maintained as hedges and therefore not included in this variable, likewise small hedges, whips and sprouts were not counted).	V39	V29
Number of Trees 20m radius (of measured T)	**Number of other trees (excluding the focal tree) in 10m radius** As previous variable.	V40	V30
Number of Trees in same planting area (as measured T)	**Number of other trees (excluding the focal tree) in stated area** (planting area as specified in previous variable) As previous variable.	V41	V31
Distance To Road	**Distance to nearest road.** Measured in metres between the trunk of the tree and the edge of the nearest road. *Measured with surveyor's tape or measuring tape if ground flat, distances 5m–25m estimated by foot paces to the nearest 0.5m.	V42	V32
Distance To Building	**Distance to nearest building.** Measured in metres between the trunk of the tree and the edge of the nearest road. *Measured with surveyor's tape or measuring tape if ground flat, distances 5m–25m estimated by foot paces to the nearest 0.5m. This variable was not recorded where it was too intrusive on private for a lone worker to collect without prior notification of the resident.	V43	V33
Maintenance Variables: Pruning Mulching Staking *Tree Guard *Stem Guard *Water Bag *Water Pipe	**The set of 'Management Variables' in the PTRP includes maintenance practices evident on the tree.** Recorded as correct, incorrect or none (e.g. if no stake was present, or no pruning was done). See main body text results section for descriptions. *These have been re-termed 'Maintenance Variables' in this research. Water bags are included as a management variable in the context of UK tree planting (as opposed to a community/householder variable as in the PTRP); water pipes were added separately. Waterbags were recorded as correct if they were full, or there were signs of recent use, or damp soil underneath; and incorrect if they were improperly installed and thus damaging the tree or bone dry inside. Waterpipes were recorded as correct if they were undamaged and not blocked; and incorrect if they were damaged and unusable or blocked. Separate variables for if Tree Guards (around main stem and most often stake) and Stem Guards (at base/root collar of tree) were present/maintained correctly; as with staking, they were categorised as incorrect if they were damaging the tree in a way that compromised the integrity of the cambium layer. See main body text results section for descriptions.	V44–50	V34–37
*Guying	**Visible evidence of guying wires (installed at the time of planting) now damaging the tree.** **0** indicates absence **1** indicates presence	V51	
Trash/Debris	**Rubbish in the planting area near the base of the tree or in the canopy itself.** (*Trash termed rubbish in this research). **0** indicates absence **1** indicates presence	V52	V41

Variables collected * denotes an additional variable, not further described in the Planted Tree Re-inventory Protocol.	**Further information** * denotes a modification from original Planted Tree Re-inventory Protocol, subsequently described	**This research's variable ID**	**PTRP variable number**
*Road Congestion	**Describes road congestion in the area close to the measured tree at the time of survey.** Measured on a scale from 0–5. **0** = Parking not permitted **1** = Free parking (driveways & minimal signs of cars parked regularly on road **2** = Easy parking (road wide enough to accommodate cars parked on them & allow straightforward traffic flow **3** = Limited parking available (some cars parked on road & driveways; traffic flow restricted in places) **4** = Clear shortage of parking (cars have 2 or more wheels up on pavement, traffic flow difficult) **5** = Major shortage of parking (cars parked on most of pavements, often too close to street trees)	V53	
*Compaction 1	**Visible evidence of Compaction at the time of the survey** (e.g. tyre marks). **0** indicates absence **1** indicates presence	V54	
*Compaction 2	**Visible evidence of whole site clearance/levelling at the time of development** (Google Earth/Google Street View). **0** indicates absence **1** indicates presence	V55	
*Possible site compaction	Combination of variables Compaction 1 and Compaction 2. **0** indicates absence **1** indicates presence	V56	
*Reinstated Soil 1	**Visible evidence of Reinstated Soil at the time of the survey** (e.g. copious building rubble in soil at planting location). **0** indicates absence **1** indicates presence	V57	
*Reinstated Soil 2	**Visible evidence of whole site clearance/levelling at the time of development** (Google Earth/Google Street View). **0** indicates absence **1** indicates presence	V58	
*Possible poor soil quality	Combination of variables Reinstated Soil 1 and Reinstated Soil 2. **0** indicates absence **1** indicates presence	V59	
*Waterlogging	**Visible evidence of waterlogging at the time of the survey**. **0** indicates absence **1** indicates presence	V60	
*Contamination	**Visible evidence of contamination on the ground close to the stem at the time of the survey.** **0** indicates absence **1** indicates presence	V61	
Bench, Birdfeeder, Yard Art	*Variables described in the PTRP which were not incorporated as presence/absence variables in the survey collection method. Notes of such items were made in the notes column of the data.	Not rec-orded	V38–40

Appendix 2: Sites with trees which were not planted

Table 13. Planting Delivery

Development-led (Site ref.)	Expected number of trees	Absent Trees	Planting delivery	Grant Led (Site ref.)	Expected number of trees	Absent Trees	Planting delivery
1.A	20	5	75%	1.G	20	1	95%
1.B	20	2	90%	1.K	20	2	90%
1.C	20	4	80%	2.G	7	3	57%
1.D	20	4	80%	2.H	11	7	36%
1.E	20	11	45%	2.J	11	8	27%
1.F	20	1	95%	2.N	10	1	90%
2.A	20	1	95%				
2.B	17	4	76%				
2.E	20	19	5%				
2.F	20	6	70%				
3.A	20	5	75%				
3.C	20	7	65%				
3.D	15	3	80%				
3.E	20	5	75%				
3.F	20	1	95%				
4.A	20	6	70%				
4.C	22	2	91%				
4.D	34	14	59%				
4.E	20	1	95%				
4.F	20	10	50%				
Total Development-led	488*	111	77%			22	

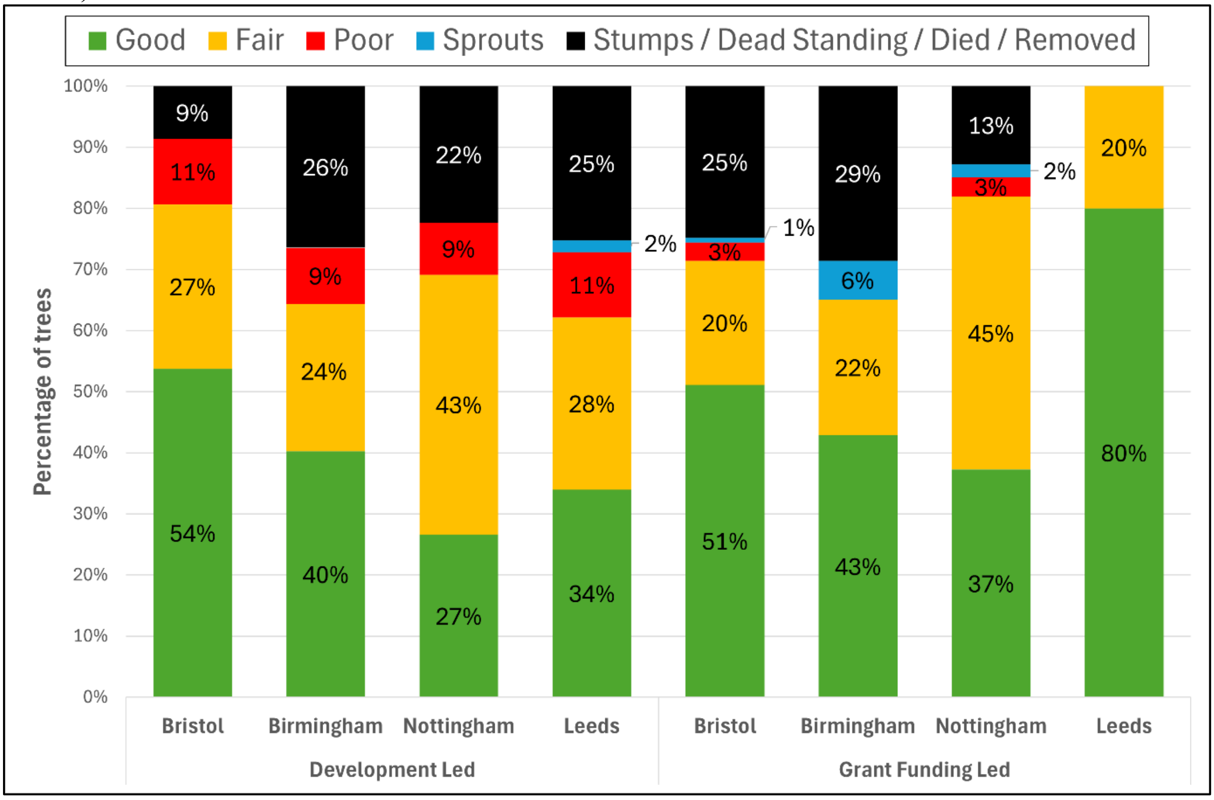
*Four development sites with 100% planting delivery (of 20 trees) are not listed in this table.

Below average delivery highlighted grey (46% of development-funded sites exhibited under average delivery of trees on their proposals)

Appendix 3: Tree condition by city and funding source

Figure 30. Tree condition by city and funding source

(Total observation *n*=687: Bristol grant-funding-led *n*=133, Birmingham grant-funding-led *n*=63, Nottingham grant-funding-led *n*=94, Leeds grant-funding-led *n*=20; Bristol development-led *n*=226, Birmingham development-led *n*=150, Nottingham development-led *n*=188, Leeds development-led *n*=123)



***Leeds grant-funding-led is based on only one sampled site.**

Some categories were removed from analysis due to low observation numbers, resulting in the following contingency tables being used for the chi-squared test of independence for this segment of data analysis:

Table 14. Development-led tree planting with sprouts category removed

	Bristol	Birmingham	Nottingham	Leeds	Row Total
Good	50	35	25	35	145
Fair	25	21	40	29	115
Poor	10	8	8	11	37
Stumps / Dead Standing / Died / Removed	8	23	21	26	78
Development Led Total	93	87	94	101	375

Table 15. Grant-funding-led tree planting with sprouts, poor and Leeds categories removed.

	Bristol	Birmingham	Nottingham	Row total
Good	68	27	35	130
Fair	27	14	42	83
Stumps / Dead Standing / Died / Removed	33	18	12	63
Grant Funding Led Total	128	59	89	276

Appendix 4: DBH, diameter at 1m, caliper, height and height to canopy

Table 16. Grant-funding-led DBH, diameter at 1m, caliper, height and height to canopy summary statistics

Grant-funding-led									
DBH (cm)		Diameter at 1m (cm)		Caliper (cm)		Total height (m)		Height to crown (m)	
Mean	7.8	Mean	8.9	Mean	11.5	Mean	4.90	Mean	1.29
Standard Error	0.3679	Standard Error	0.4410	Standard Error	0.5640	Standard Error	0.1259	Standard Error	0.0414
Median	5.5	Median	6.6	Median	8.9	Median	4.45	Median	1.45
Mode	5.3	Mode	5.7	Mode	6.5	Mode	4.10	Mode	1.80
Standard Deviation	5.5423	Standard Deviation	5.9654	Standard Deviation	7.5034	Standard Deviation	1.9869	Standard Deviation	0.6514
Sample Variance	30.7168	Sample Variance	35.5863	Sample Variance	56.3003	Sample Variance	3.9476	Sample Variance	0.4243
Kurtosis	3.6102	Kurtosis	2.8803	Kurtosis	1.9731	Kurtosis	1.7910	Kurtosis	-0.1054
Skewness	1.8197	Skewness	1.6876	Skewness	1.4543	Skewness	1.1470	Skewness	-0.3706
Range	33	Range	32.5	Range	38.2	Range	12.3	Range	3.6
Minimum	1.2	Minimum	2	Minimum	2	Minimum	0.9	Minimum	0
Maximum	34.2	Maximum	34.5	Maximum	40.2	Maximum	13.2	Maximum	3.6
Count	227	Count	183	Count	177	Count	249	Count	247

Table 17. Development-led DBH, diameter at 1m, caliper, height and height to canopy summary statistics

Development-led									
DBH (cm)		Diameter at 1m (cm)		Caliper (cm)		Total height (m)		Height to crown (m)	
Mean	6.5	Mean	7.2	Mean	9.4	Mean	4.99	Mean	1.43
Standard Error	0.1913	Standard Error	0.2063	Standard Error	0.2628	Standard Error	0.0895	Standard Error	0.0352
Median	5.7	Median	6.3	Median	8.2	Median	4.80	Median	1.55
Mode	4.3	Mode	5.8	Mode	7.4	Mode	5.00	Mode	1.70
Standard Deviation	3.2694	Standard Deviation	3.4152	Standard Deviation	4.3975	Standard Deviation	1.5469	Standard Deviation	0.5975
Sample Variance	10.6888	Sample Variance	11.6636	Sample Variance	19.3381	Sample Variance	2.3927	Sample Variance	0.3570
Kurtosis	1.6884	Kurtosis	1.8656	Kurtosis	2.1127	Kurtosis	2.8142	Kurtosis	0.4588
Skewness	1.2024	Skewness	1.2678	Skewness	1.3811	Skewness	1.0684	Skewness	-0.5286
Range	17.9	Range	18.7	Range	23.9	Range	11.4	Range	3.25
Minimum	0.3	Minimum	1.7	Minimum	2.2	Minimum	0.2	Minimum	0
Maximum	18.2	Maximum	20.4	Maximum	26.1	Maximum	11.6	Maximum	3.25
Count	292	Count	274	Count	280	Count	299	Count	288

Appendix 5: Planting area surface areas

Figure 31. Grant-funding-led planting area surface area
Grant funding led, pla
nted trees, *n*=310

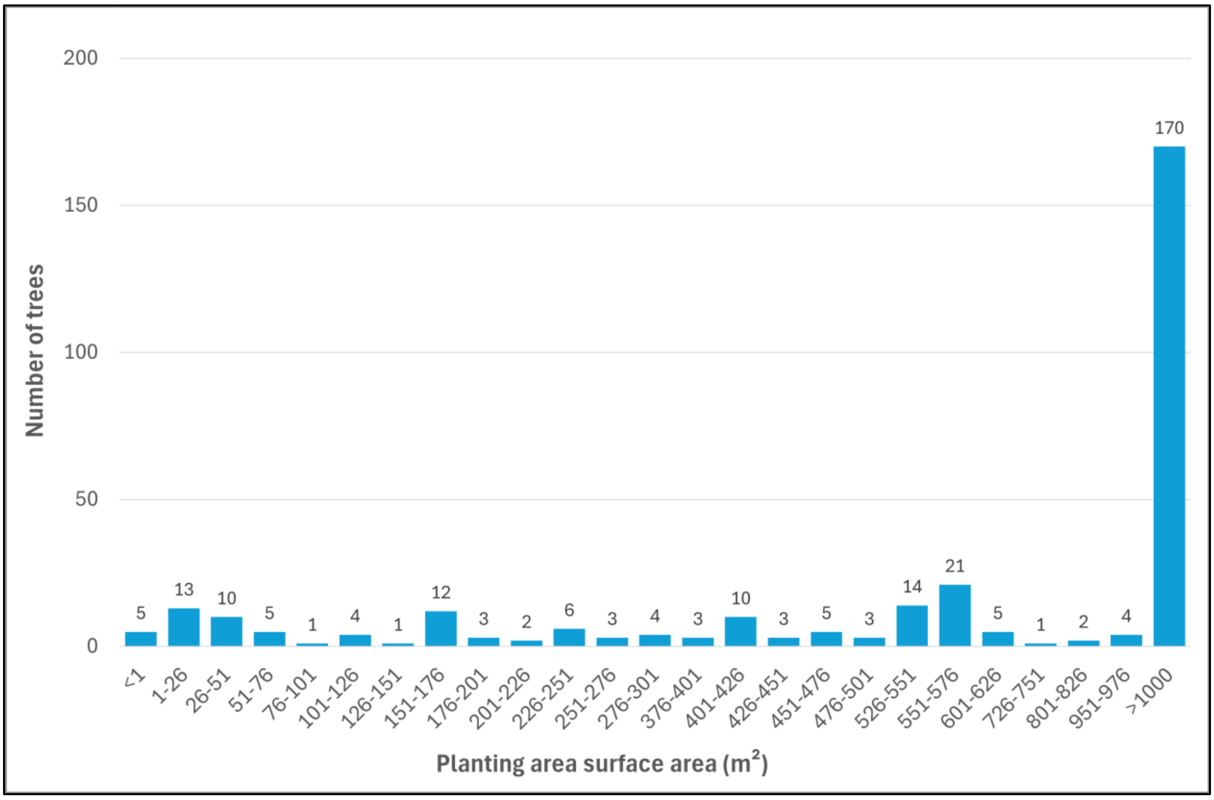
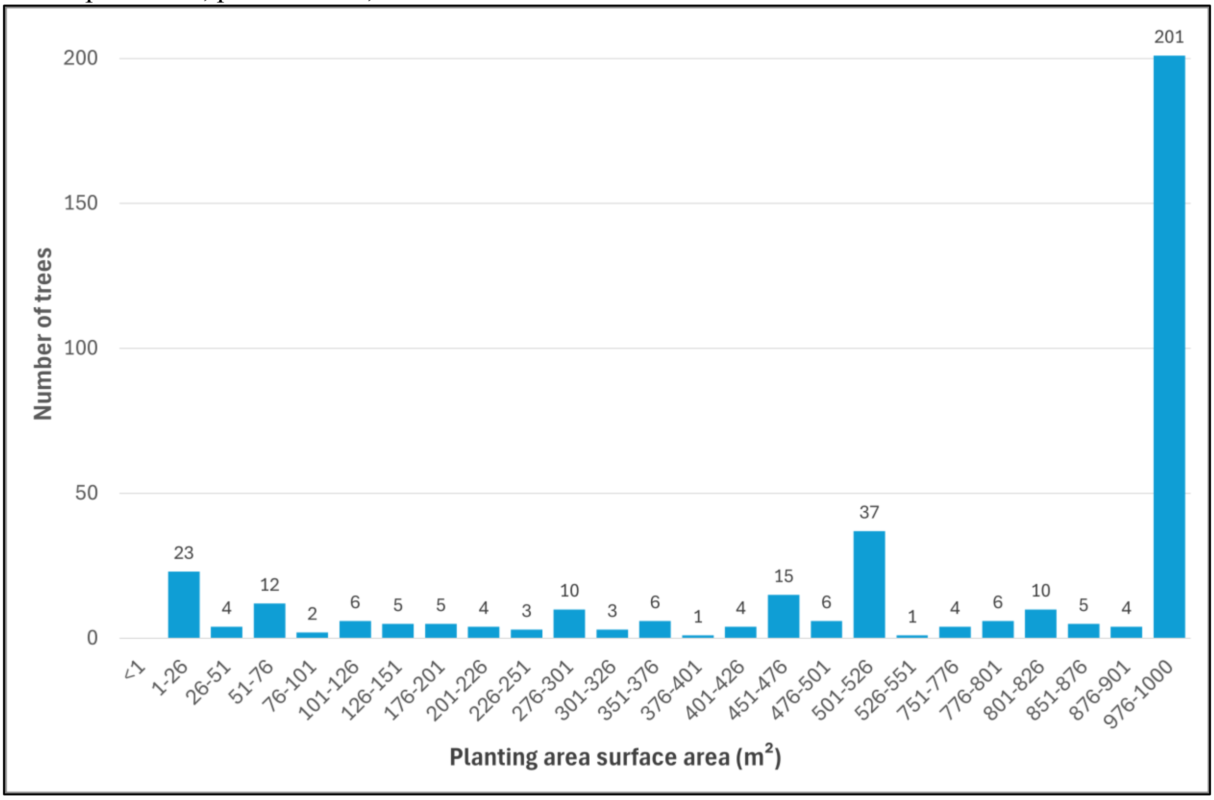


Figure 32. Development-led planting area surface area
Development led, planted trees, *n*=377



Appendix 6: Exposure

Table 18. Exposure by funding source

	Fully exposed canopy	Four sides exposed	Three sides exposed	Two sides exposed	One side exposed	No sides exposed	Grand Total
Development-led	86%	8%	1%	2%	3%	0%	100%
Grant-funding-led	91%	6%	1%	0%	1%	0%	100%
Grand Total	88%	7%	1%	1%	2%	0%	100%

Appendix 7: Proximity to other trees

Figure 33. Number of trees within 10m

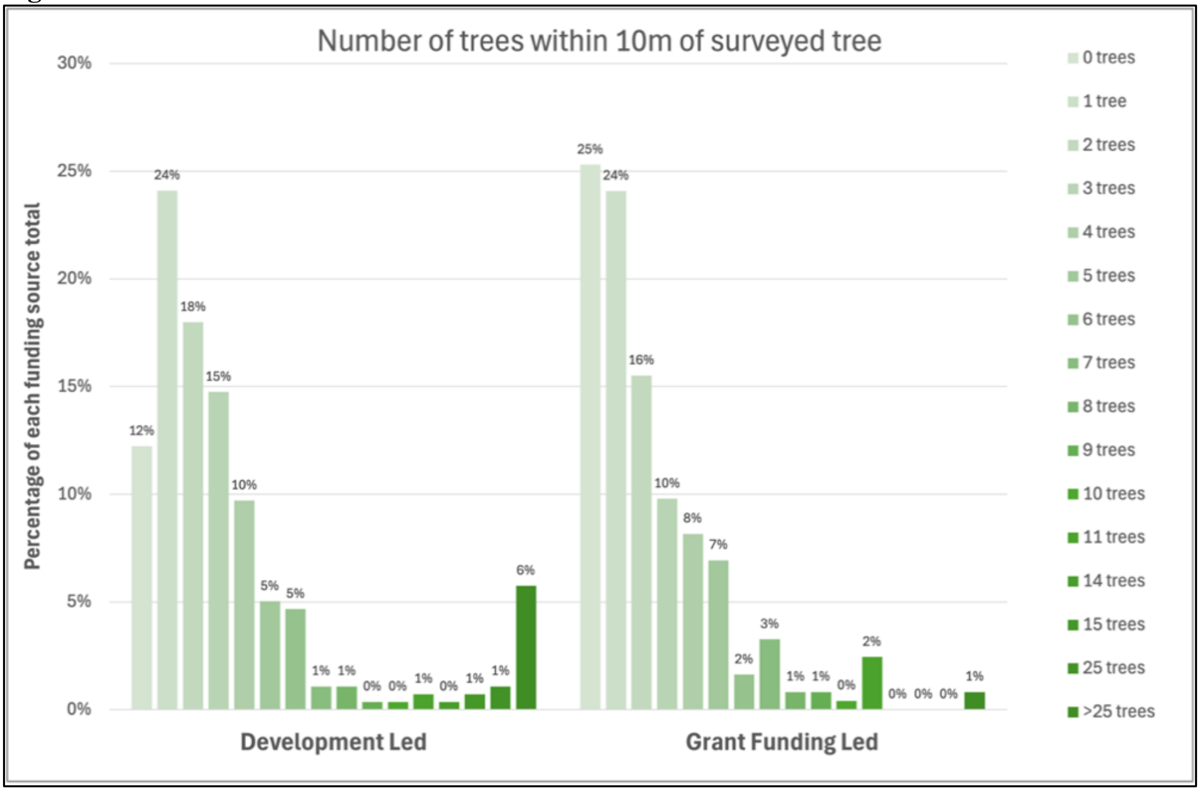


Figure 34. Number of trees within 20m

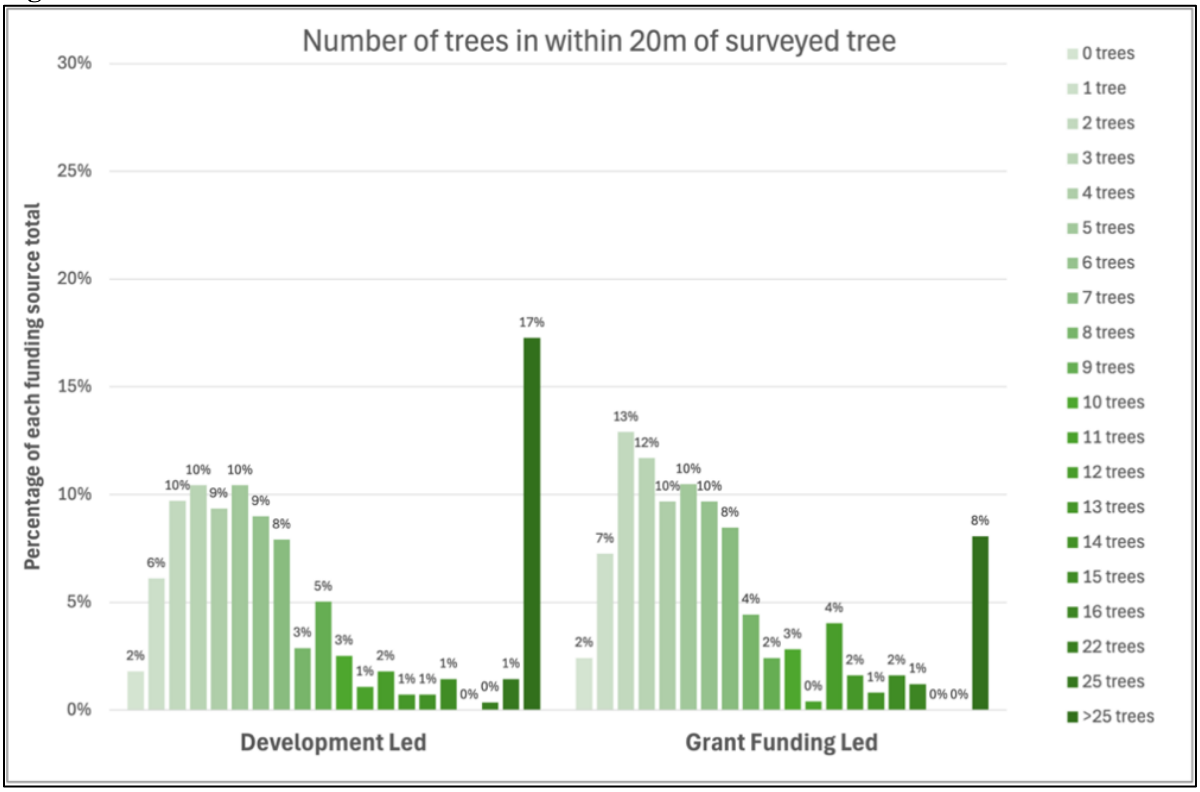
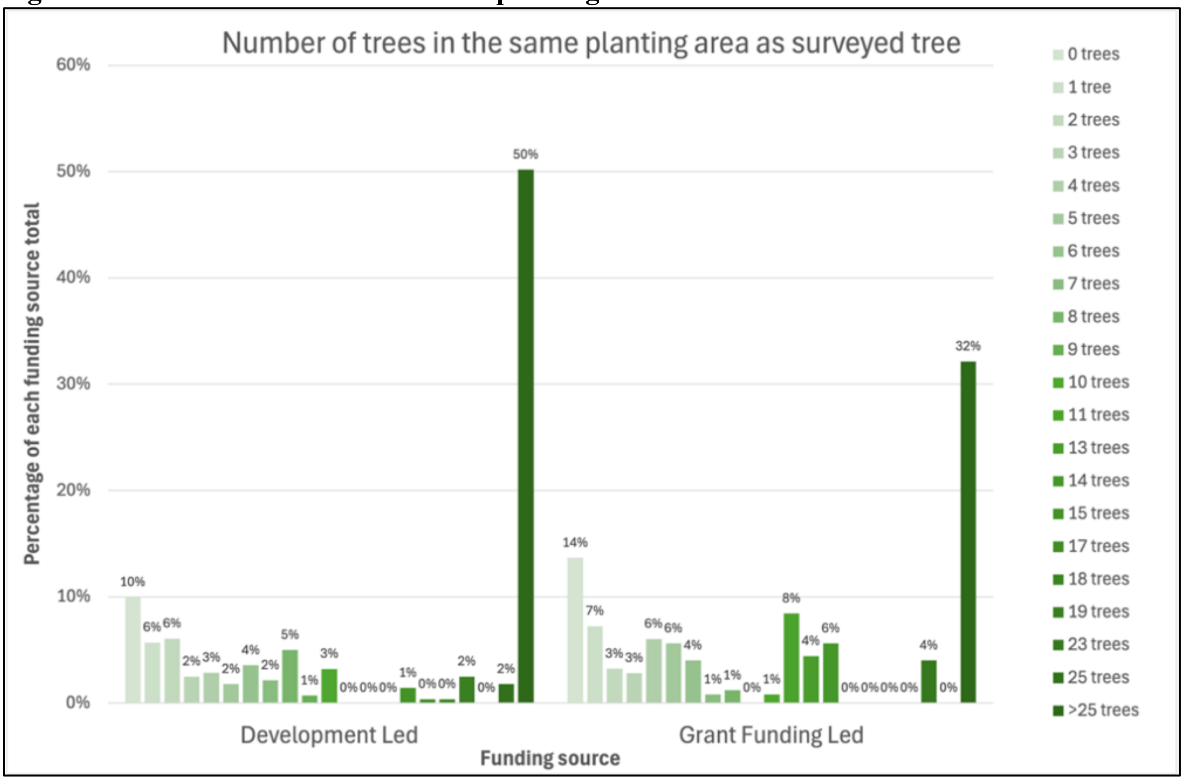


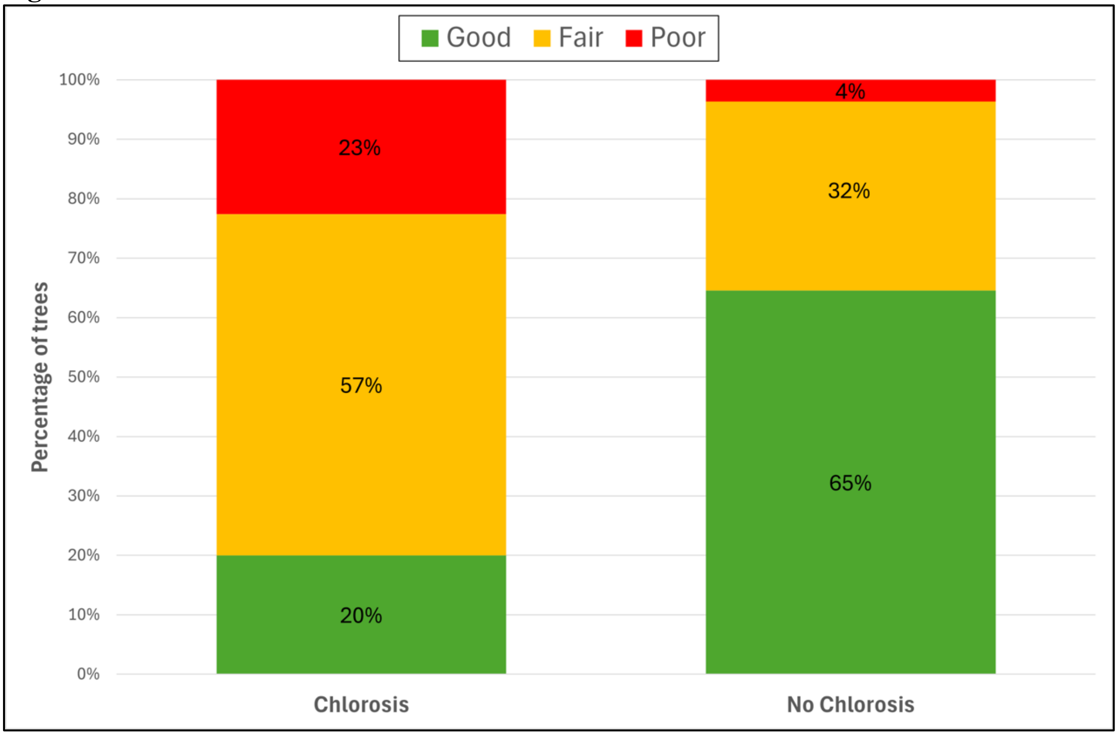
Figure 35. Number of trees in the same planting area



Appendix 8: Stress indicators and condition

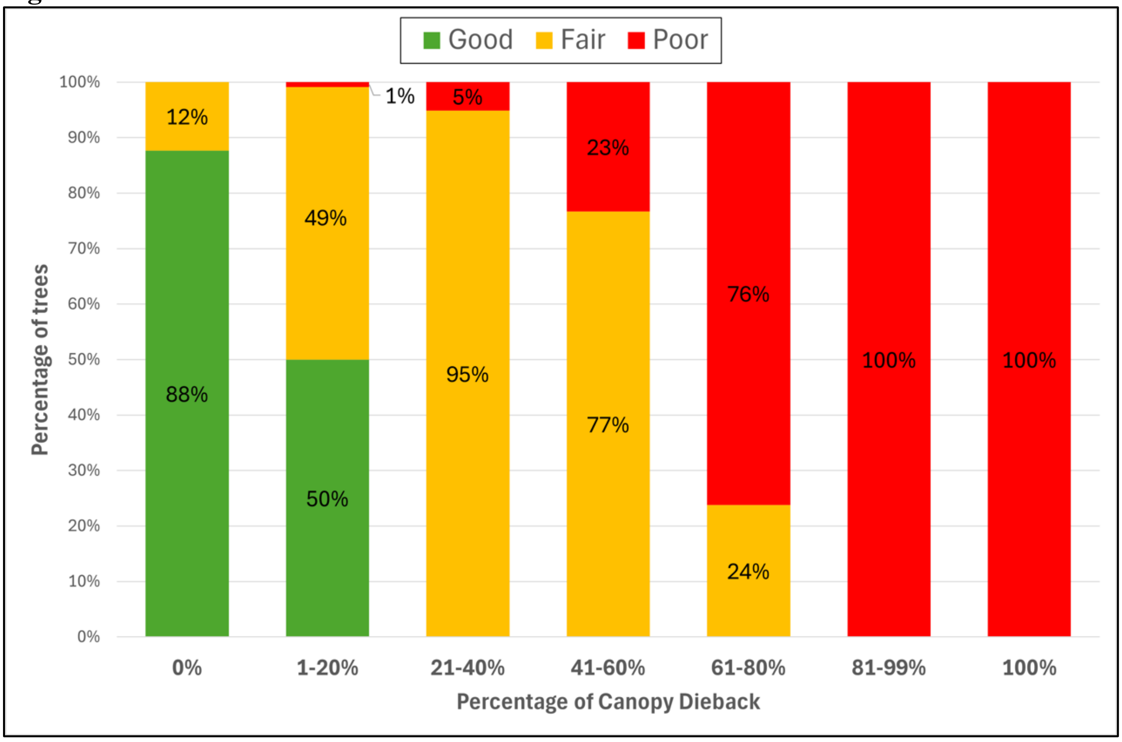
Chlorosis was found to have a significant relationship with condition outcome ($p<0.01$). Trees with chlorosis were significantly less likely to be found in good condition and more likely to be in fair or poor condition.

Figure 36. Chlorosis and condition outcome



Dieback was found to vary significantly with condition outcome.

Figure 37. Dieback and condition outcome



Appendix 9: Mortality rates

Table 19. Average annual mortality rates with 2G (100% mortality) included.

	City	Development Led average mortality rate	Grant Funding Led average mortality rate	City Average
1.A	Bristol	2.0%		
1.B	Bristol	3.4%		
1.C	Bristol	3.3%		
1.D	Bristol	0.0%		
1.E	Bristol	1.8%		
1.F	Bristol	0.0%		
1.G	Bristol		0.0%	
1.H	Bristol		2.5%	
1.I	Bristol		2.1%	
1.J	Bristol		0.0%	
1.K	Bristol		1.6%	
1.L	Bristol		1.5%	
1.M	Bristol		14.5%	
Bristol		**1.7%**	**3.2%**	**2.5%**
2.A	Birmingham	9.8%		
2.B	Birmingham	0.0%		
2.C	Birmingham	10.4%		
2.D	Birmingham	5.6%		
2.E	Birmingham	0.0%		
2.F	Birmingham	0.0%		
2.G	Birmingham		100.0%	
2.H	Birmingham		0.0%	
2.I	Birmingham		5.7%	
2.J	Birmingham		0.0%	
2.K	Birmingham		1.1%	
2.L	Birmingham		2.3%	
2.M	Birmingham		5.2%	
2.N	Birmingham		4.7%	
2.O	Birmingham		5.2%	
Birmingham		**4.3%**	**13.8%**	**10.0%**
3.A	Nottingham	5.6%		
3.B	Nottingham	21.2%		
3.C	Nottingham	3.0%		
3.D	Nottingham	0.0%		
3.E	Nottingham	4.7%		
3.F	Nottingham	1.5%		
3.G	Nottingham		4.2%	
3.H	Nottingham		0.0%	
3.I	Nottingham		0.0%	
3.J	Nottingham		0.0%	
3.K	Nottingham		0.0%	
3.L	Nottingham		0.0%	
3.M	Nottingham		15.6%	
Nottingham		**6.0%**	**2.8%**	**4.3%**
4.A	Leeds	0.1%		
4.B	Leeds	0.0%		
4.C	Leeds	20.8%		
4.D	Leeds	0.1%		
4.E	Leeds	8.0%		
4.F	Leeds	7.6%		
4.G	Leeds		0.0%	
Leeds		**6.1%**	**0.0%**	**5.2%**
All cities funding source Average		**4.5%**	**6.9%**	
All planted trees average				5.7%

Table 20. Average annual mortality rates with 2G (100% mortality) excluded.

	City	Development Led average mortality rate	Grant Funding Led average mortality rate	City Average
1.A	Bristol	2.0%		
1.B	Bristol	3.4%		
1.C	Bristol	3.3%		
1.D	Bristol	0.0%		
1.E	Bristol	1.8%		
1.F	Bristol	0.0%		
1.G	Bristol		0.0%	
1.H	Bristol		2.5%	
1.I	Bristol		2.1%	
1.J	Bristol		0.0%	
1.K	Bristol		1.6%	
1.L	Bristol		1.5%	
1.M	Bristol		14.5%	
Bristol		**1.7%**	**3.2%**	**2.5%**
2.A	Birmingham	9.8%		
2.B	Birmingham	0.0%		
2.C	Birmingham	10.4%		
2.D	Birmingham	5.6%		
2.E	Birmingham	0.0%		
2.F	Birmingham	0.0%		
2.H	Birmingham		0.0%	
2.I	Birmingham		5.7%	
2.J	Birmingham		0.0%	
2.K	Birmingham		1.1%	
2.L	Birmingham		2.3%	
2.M	Birmingham		5.2%	
2.N	Birmingham		4.7%	
2.O	Birmingham		5.2%	
Birmingham		**4.3%**	**3.0%**	**3.6%**
3.A	Nottingham	5.6%		
3.B	Nottingham	21.2%		
3.C	Nottingham	3.0%		
3.D	Nottingham	0.0%		
3.E	Nottingham	4.7%		
3.F	Nottingham	1.5%		
3.G	Nottingham		4.2%	
3.H	Nottingham		0.0%	
3.I	Nottingham		0.0%	
3.J	Nottingham		0.0%	
3.K	Nottingham		0.0%	
3.L	Nottingham		0.0%	
3.M	Nottingham		15.6%	
Nottingham		**6.0%**	**2.8%**	**4.3%**
4.A	Leeds	0.1%		
4.B	Leeds	0.0%		
4.C	Leeds	20.8%		
4.D	Leeds	0.1%		
4.E	Leeds	8.0%		
4.F	Leeds	7.6%		
4.G	Leeds		0.0%	
Leeds		**6.1%**	**0.0%**	**5.2%**
All cities funding source Average		**4.5%**	**2.9%**	
All planted trees average				3.7%

Appendix 10: Unscathed trees

Figure 38. Number of trees remaining after filtering for certain conditions

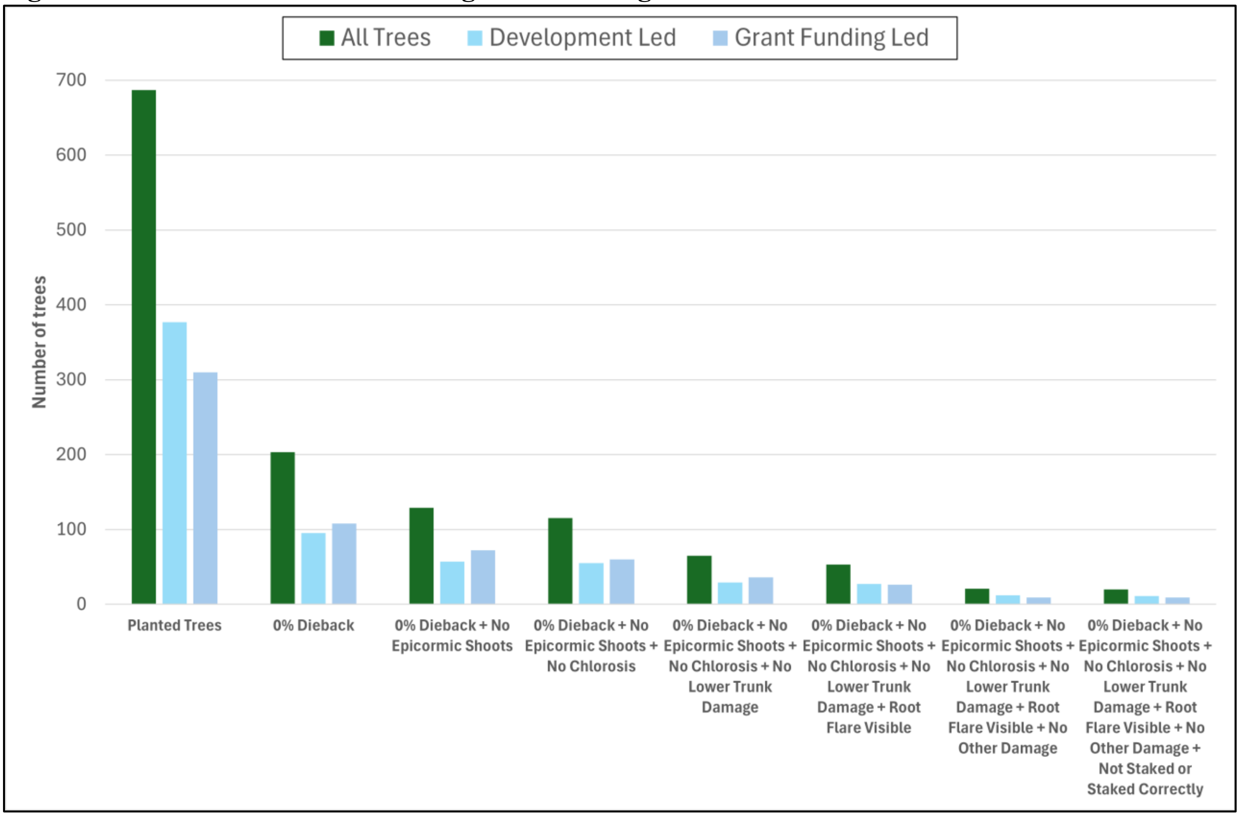


Table 21. Number and % of trees remaining after filtering for certain conditions

Unscathed trees	Development-led	Grant-funding-led	All trees	Development-led	Grant-funding-led	All trees
Planted Trees	377	310	687	377	310	687
0% Dieback	95	108	203	25%	35%	30%
0% Dieback + No Epicormic Shoots	57	72	129	15%	23%	19%
0% Dieback + No Epicormic Shoots + No Chlorosis	55	60	115	15%	19%	17%
0% Dieback + No Epicormic Shoots + No Chlorosis + No Lower Trunk Damage	29	36	65	8%	12%	9%
0% Dieback + No Epicormic Shoots + No Chlorosis + No Lower Trunk Damage + Root Flare Visible	27	26	53	7%	8%	8%
0% Dieback + No Epicormic Shoots + No Chlorosis + No Lower Trunk Damage + Root Flare Visible + No Other Damage	12	9	21	3%	3%	3%
0% Dieback + No Epicormic Shoots + No Chlorosis + No Lower Trunk Damage + Root Flare Visible + No Other Damage + Staked Correctly or Not Staked	11	9	20	3%	3%	3%

Appendix 11: Photographs of significance

Red borders signify less positive outcomes, black are neutral, and green are more positive outcomes.

Figure 39. Dieback
Various stages of dieback; Left to Right: 100%, 40–60%, 60–80%. 1–20%, (from images)

Figure 40. Lower trunk damage
Omnipresent in turfed areas in which trees are planted. Light guards are ineffective at prevention.

Figure 41. Stake negligence
Trees left on the stake too long, more prevalent at development sites.

Figure 42. Other damage
Left to Right: Ripped branches (common). Incorrect spacer installation leading to damage. Poor stake placement. Abandoned cable ties.

Figure 43. Strimmer damage – some instances where it was absolutely certain that the Lower Trunk Damage was caused by strimmers.
Left to Right: Stakes do not prevent strimmer damage effectively. It is omnipresent in maintained turfed areas in which trees are planted.

Figure 44. Animal damage and vandalism
Left to Right: Animal damage (×2). Vandalism (x3).

Figure 45. Poor soil; weed killer non-preventative to tree strimming
Left to Right: Desiccated soil with tar. Severe lack of moisture. Even when waterpipes are present. Weed killer does not discourage strimmer use close to trees (x2).

Figure 46. Improper planting or planting maintenance
Left to Right: Incorrectly tied trees. Inappropriate mesh use. Stem guard leaves not opened properly at installation, also now buried, overgrown and immovable. Nursery stakes and ties left on. Buried and overgrown strimmer guards.

Figure 47. Training and method detail
Left to Right: Survey training day, comparing protocols (the original PTRP and the adapted version which Birmingham Tree People used in their 2023 surveys). Ensuring DBH tape is not stretched. Measuring over the kerb edge for distance to road. Correctly staked trees may still exhibit chafing.

Figure 48. The "unscathed"
Left to Right: Big Tree Plant (BTP), planted 2012–13, Height 8.5m, DBH 27.9cm. BTP, planted 2012–13, Height 9.8m, DBH 22cm. BTP, planted 2014–15, Height 7.7m, DBH 15.3cm. Urban Tree Challenge Fund, planted 2019–20, Height 3.9m, DBH 4.1cm. Development-led, planted 2020–2012, Height 4.7m, DBH 6.2cm. (location identifying features have been blacked out)

Figure 49. Birds nest and biodiversity
Left to Right: Pigeon's nest. Wasp fly. Aphids and ants (very common). Slugs. Ladybug larvae. Not pictured but also found were ants' nests in the root area of dry stem guards.

Figure 50. Interaction with the public and stakeholders through the project
(some location identifying features, members of the public and a minor have been blacked out.)
Left to Right: Neighbour prunes dead branch during interaction. Father and son pose after talking about tree care (child blacked out in photo). Neighbour shows researcher (now dead and removed) tree locations. Attending Tree People conference in Birmingham (documenting issues raised). Delivering preliminary results presentation at Arboricultural Association Conference 2024.

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