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Beech tree stress, soil conditions and drought at Burnham Beeches

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Contents

1 Introduction

1.1 In December 2018, A J Moffat & Associates were instructed by Dr Helen Read, City of London Corporation to carry out a review, based on peer reviewed scientific literature, of soil-related factors that had the potential to affect the future condition of the pollarded beech (*Fagus sylvatica*) trees at Burnham Beeches SAC. Such factors include the possible influence of climate change, atmospheric pollution, visitor pressure and existing management practices, notably haloing. The list of issues and questions to be addressed in this report are appended as Annex 1.

1.2 Burnham Beeches SAC is a site of considerable ecological importance and it is also significant from a heritage and recreational perspective. Management of the site is therefore complex, because there is a need to balance intervention such that all these objectives can be satisfied. The site is particularly notable for the veteran beech and oak trees present.

1.3 There were 426 living ancient pollards recorded at Burnham Beeches in 2007 (Read et al 2007). However, a significant number of ancient pollards have been lost over the past century (Fay, 2014). This report looks at possible soil and interrelated climatic and other environmental factors that could underlie tree health and condition.

1.4 The review was carried out by Dr Andy Moffat during December 2018 and January 2019. Relevant literature was sought using Google Scholar, ResearchGate and search engines supported by the library of the University of Reading where Dr Moffat holds a Visiting Professorship. 'Grey' literature was kindly supplied by Dr Read and by Dr David Lonsdale. In addition, a site visit was undertaken on 5th December 2018, accompanied by Dr Helen Read for some of the time.

1.5 This report describes the results of the review. It also discusses the implications of its findings for current and future management of the Burnham Beeches site.

2. The Burnham Beeches site

2.1 The geology of the Burnham Plateau is primarily characterised by Thames river terrace gravels overlying Tertiary Reading Beds clays and sands.

2.2 Soils are acidic or very acidic, derived from very stony fluvially-derived Quaternary sediments, overlain by a variable but normally thin layer of Drift. This is largely derived from loessial deposits which covered much of southern England from the late Devensian Stage (Catt, 1978). Read (2010) also identified the occurrence of ironpan and peaty soils in certain places, demonstrating restricted drainage. Jarvis et al. (1984) mapped the soils at a scale of 1:250,000 as belonging to the Essendon Association (714d), an association of flinty soils over river terrace gravels. Unfortunately, a detailed map of the soils of the Burnham Beeches SAC does not exist. Nevertheless, a synthesis of available evidence, coupled with observations of the soil during the reconnaissance visit on 5th December, suggests that the bulk of the site is underlain by well-drained extremely stony soils. Observations of fallen trees, together with root systems exposed at the disused quarry near the centre of the site, suggests that tree roots are capable of rooting into the gravelly subsoil to depths of at least one metre.

2.3 No assessment of soil fertility has been undertaken in this study but soil chemical analysis, undertaken as part of Natural England's Long Term Monitoring Network programme (Shepherd, 2017) identified soil pH between 3.5 and 4.2, and soil carbon to nitrogen ratios between 19.4 and 25.2[1]. Coupled with indications from understory vegetation, these data suggest that the site is comparatively infertile.

2.4 Chalk occurs at depth in the south-western part of the site (Read, 2010). On soils developed directly on chalk, trees benefit from the ability of water to move up through the chalk to supply tree roots in summer months (Wilson et al., 2008). However, the presence of chalk below a significant thickness of fluvial deposits is unlikely to have a direct influence on the trees growing at the site.

2.5 Annual climate statistics from Heathrow airport, 15.6 km away from the City of London Corporation offices at Burnham Beeches, are given in Table 2.1.

2.6 A recent report by Air Quality Consultants (2018) suggests that the Burnham Beeches site received an estimated annual mean background NO_2 concentration of 9.3-11.1 µg m^{-3} in 2015 and measured background NH_3 concentration of 0.821 µg m^{-3} in 2017. In 2001, mean annual SO_2 deposition was estimated[2] as 3.41 µg m^{-3}. No site data for ground-level ozone are available.

[1] http://publications.naturalengland.org.uk/file/5156654487699456
[2] https://uk-air.defra.gov.uk/data/laqm-background-maps?year=2001

Table 2.1. Summary climatic statistics for Heathrow (mean values from 1981-2010)

	Max temp (deg C)	Min. temp (deg C)	Days of air frost (days)	Sunshine (hours)	Rainfall (mm)	Days of rainfall >= 1 mm (days)	Monthly mean wind speed at 10m (knots)
Jan	8.1	2.3	7.5	61.5	55.2	11.1	7.6
Feb	8.4	2.1	8.3	77.9	40.9	8.5	7.2
Mar	11.3	3.9	3.8	114.6	41.6	9.3	7.4
Apr	14.2	5.5	1.3	168.7	43.7	9.1	6.8
May	17.9	8.7	0.0	198.5	49.4	8.8	6.7
Jun	21.0	11.7	0.0	204.3	45.1	8.2	6.4
Jul	23.5	13.9	0.0	212.0	44.5	7.7	6.6
Aug	23.2	13.7	0.0	204.7	49.5	7.5	6.2
Sep	19.9	11.4	0.0	149.3	49.1	8.1	6.1
Oct	15.5	8.4	0.4	116.5	68.5	10.8	6.5
Nov	11.1	4.9	3.5	72.6	59.0	10.3	6.5
Dec	8.3	2.7	7.7	52.0	55.2	10.2	6.9
Annual	15.2	7.5	32.6	1632.6	601.7	109.5	6.7

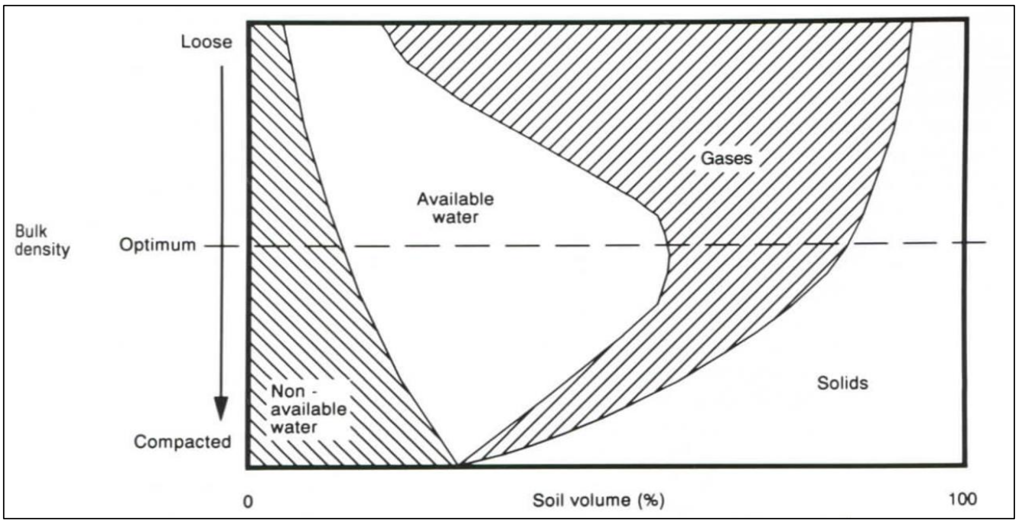
3. Environmental concerns

Soil degradation

3.1 Annex AM1 identifies that **soil compaction** is an issue that requires investigation. Concerns about compaction in relation to veteran tree health gave been reported in recent literature on veteran tree management (Read, 2000; Ancient Tree Forum, 2016). Soil compaction was identified by Fay (2014) as a likely cause of deterioration of veteran tree health and condition at Burnham Beeches, and was related tentatively to visitor numbers.

3.2 Soil compaction is defined as "the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby, increasing the bulk density" (SSSA, 2008). Compaction is therefore an undesirable process as increased bulk density can hinder root penetration, and reduced porosity can decrease plant-available water (Figure 3.1.) and induce drought. Compaction can also hinder water transmission through the soil, and therefore lead to periodic waterlogging and anaerobic conditions, which can lead to root death in the growing season if prolonged. Such combined physical degradation will also have implications for chemical and biological soil functioning, and for tree nutrient uptake.

Figure 3.1. Composition of soil at different degrees of compaction (from Moffat and McNeill, 1994). 'Available water' refers to that which can be taken up by plants; 'unavailable water' is strongly held by the soil matrix (e.g. by capillary action)



3.3 Soils become compacted when they are subjected to loads for which their soil strength (see Annex AM2) are unable to withstand. This usually occurs in wet conditions when soil strength is low. Vehicular traffic, plant and heavy equipment are the usual causal agents of compaction but poor agricultural practice, such as ploughing in inappropriate conditions, is responsible in farm systems. Farm stock can also cause compaction locally, notably in wet soil conditions. In semi-natural habitats, mountain bikers, hikers and pedestrians are implicated in many reports which refer to soil compaction, and also soil erosion (e.g. Martin et al., 2018). At Burnham Beeches, the effect of heavy pedestrian pressure is exemplified by soil poaching around the fence line surrounding the Druids oak at Burnham Beeches, noted at the time of the site visit. There is probably some soil compaction associated with this soil damage.

3.4 The extent of compaction at Burnham Beeches has not been established in this or previous studies. One reason is that measurements of 'penetration resistance', a proxy for compaction, and soil bulk density are extremely difficult to perform in stony soils. However, the fact that soils are dominantly of this type has positive benefits when considering susceptibility to compaction. Several authors (e.g. Ravina and Magier, 1984; Poesen and Lavee, 1994; Gargiulo et al., 2016) have shown that in stony soils, the stones interlock and provide significant soil strength, even when wet. Hence it is unlikely that the stony *subsoils* at Burnham Beeches are susceptible to soil compaction exerted by pedestrians or stock.

3.5 Jarvis et al. (1984) report that stony soils are covered by thin silty drift in the Burnham Beeches area and limited observations taken during the site visit suggested that less stony topsoils are thin (perhaps less than 20 cm) over much of the Burnham Beeches site. These materials may be susceptible to compaction in localities where pedestrian pressure is significant and at times when the soil is wet. Nevertheless, the soil within blocks of woodland will also benefit from the presence of tree roots as it is well known that roots can positively increase soil strength (Coppin and Richards, 1990; Gray and Sotir, 1996; Norris et al., 2008; Stokes et al., 2009), especially in surface soil horizons (Meijer et al., 2018). And these areas are generally considered as of lesser risk of pedestrian pressure. Perhaps the areas and soils at greatest risk are those where significant haloing has taken place in recent years, such as that north-east of the Druids Oak and north of Lord Mayors Drive. In this area woody vegetation has been removed from the vicinity of beech pollards and herbaceous vegetation is the dominant type around the trees. This vegetation will not provide the level of support to soil strength that woody vegetation will, and only the root system of the pollards will do so. In addition, allowing full access to these trees probably results in greater pedestrian pressure. Implications for future management are discussed in Section 4.

3.6 There is visible and photographic evidence at Burnham Beeches that some 'desire lines' across the woodland have suffered soil degradation in the form of **soil erosion**, whereupon organic and/or mineral topsoil horizons have been removed. The reconnaissance visit on 5th December was useful in demonstrating the occurrence of these, relatively small areas. Areas of bare soil appeared to be result of intensive use by visitors to the site rather than by water erosion. No attempt was taken to map these areas and relate them to beech pollard positions but the overall impression was gained that they occurred in localised areas and were not an endemic threat to the veteran trees. Nevertheless, bare soil is generally undesirable as it is at much greater risk of further damage, and some areas also occur close to some pollards (Figure 3.2). Some form of monitoring and management may be required (see Section 4).

Climate change

3.7 The UK climate has been changing markedly over the last few decades (see, for example Jenkins et al., 2008). The average UK temperature over the last decade (2008-2017) has been 0.8 °C warmer than the 1961-1990 average, whilst the UK has also seen 8% more rainfall and 6% more sunshine[3]. Of course, there are regional differences and southern England has increased in average temperature more than the north. In this region over the period 1961 to 2006, rainfall has decreased during summer months but increased in the autumn (Jenkins et

[3] https://www.metoffice.gov.uk/news/releases/2018/state-of-the-climate-2017

al., 2008). In addition to changes in average climatic indices, there has also been an increase in the frequency and severity of extreme climate conditions such as storms and heatwaves (Met Office, National Climate Information Centre, 2018).

Figure 3.2. Bare soil exposed at Egypt, March 2016 (photo: H. Read).

3.8 To help plan for future climate change, since 2002 climate projections have been published on behalf of the UK Government. The latest were published in November 2018[4]. Using the Forestry Commission Ecological Site Classification (ESC) model based on the previous set of projections (UKCP08), two important climatic indices for tree species suitability (Accumulated Temperature and Moisture Deficit) have been calculated and are shown in Table 3.1. They suggest that in the next 30-60 years, the Burnham Beeches site is expected to become considerably warmer and less able to supply water for plant (and tree) growth.

3.9 The consequences of climate change for trees, woodland and forests have been analysed and discussed recently by Read et al. (2011) and for the Burnham Beeches site by Berry and Paterson (2009). Effects on tree growth, health, biodiversity, susceptibility to pests and diseases and broader ecosystem functioning have been identified (Broadmeadow et al., 2011). Trees and woodlands possess some resilience to changes in the environment, but many climate scientists point to likely climatic changes which exceed those experienced in preceding centuries. There has been increasing concern over recent years as to the potential impacts of predicted climate change on beech populations in Britain, particularly within the natural range in southern England (Broadmeadow et al., 2005; Wilson, 2011).

[4] https://www.metoffice.gov.uk/research/collaboration/ukcp

Table 3.1. Climate indices relevant to tree suitability and projected changes by 2050 and 2080 for Burnham Beeches generated by ESC v.4[5]

Date	Accumulated Temperature (day degrees >5 °C)	Change from baseline (%)	Soil Moisture Deficit (mm)	Change from baseline (%)
Baseline (1961-90)	1814		197	
2050	2714	50	244	24
2080	3000	65	289	47

3.10 A number of research studies have examined the resilience, or vulnerability, of beech to the kinds of changes predicted in Table 3.1. Indeed, European research (e.g. Rennenberg et al., 2004; Leuschner, 2009; Köcher et al., 2009) suggests that beech has a reputation for being 'particularly vulnerable to drought' (Zimmermann et al., 2015). Nevertheless, other studies suggest that this definition is too simplistic. Zimmermann et al. (2015) found that beech was no more susceptible to drought than other species such as ash, oak and sycamore over one drought season. However, this species was negatively affected when more than one dry summer occurred in succession. These authors also suggested that high summer temperatures could act negatively on beech vitality, and concluded that beech was likely to decline in mixed woodlands over the next decades. In the UK, mature beech decline and even mortality have been associated with recent droughts (e.g. Peterken and Mountford, 1996).

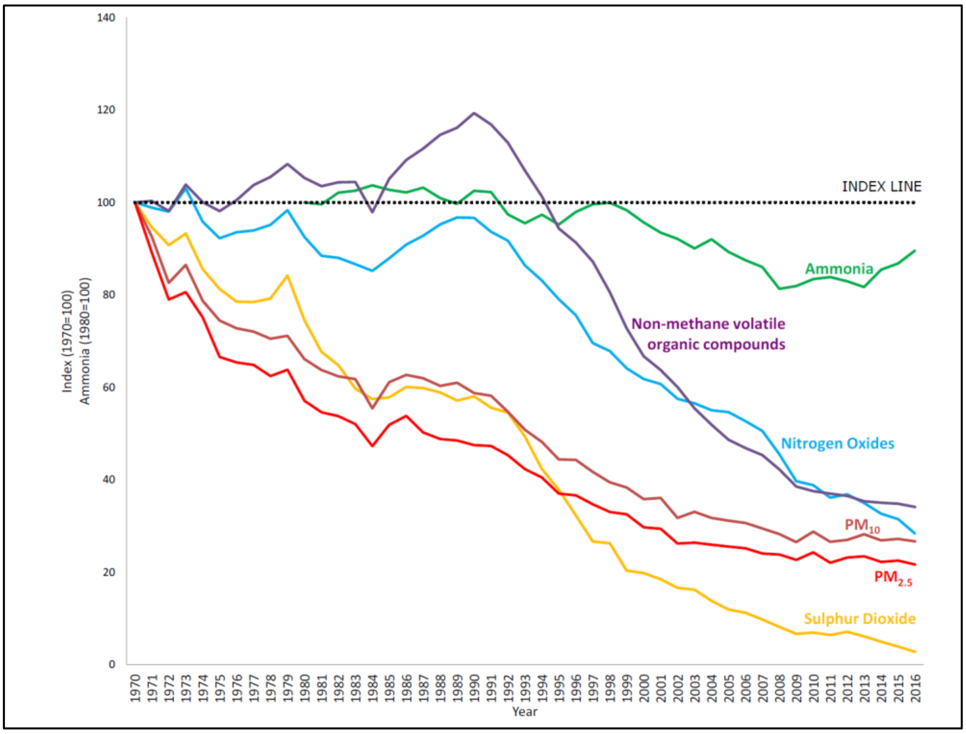
3.11 Natural England and RSBP (2014) suggest that 'beech dominated wood pasture in the south of England will be increasingly vulnerable to drought, particularly on freely-draining soils and soils subject to seasonal waterlogging'. The Forestry Commission Ecological Site Classification (ESC) model referred to above was used to predict the suitability of beech at the Burnham Beeches site in 2050 and 2080 based on the projected changes in Accumulated Temperature and Soil Moisture Deficit shown in Table 3.1. Using the 'high emissions' scenario, based upon the assumption that greenhouse gas emission rates will not be abated significantly from current levels, ESC shows that beech is predicted to become ecologically 'marginal' in 2050 and 'unsuitable' in 2080. 'Marginal' is defined in ESC literature as having 'significantly reduced growth' and a 'high risk of check or absolute failure', whilst 'Unsuitable' species 'will usually fail to establish extensive tree cover'[6]. ESC was designed to aid in species selection for new plantings, and not for assessment of veteran tree vulnerability so these predictions must be considered carefully. In addition, several authors have pointed to the inability of these kinds of model to account for microclimate (e.g. Riitters et al., 1997; Thomas et al., 2019). Because much of the Burnham Beeches site has a northerly aspect, the beech there may be more resilient to drought, as discussed by Clements (2001) for the Chiltern Hills in general. Nevertheless, the findings complement the literature reviewed above and point to a significant risk to beech in years to come. The extent to which this risk might be mitigated by appropriate management will be discussed in Section 4.

[5] http://www.forestdss.org.uk/geoforestdss
[6] http://www.forestdss.org.uk/geoforestdss/esc4.pdf

Atmospheric pollution

3.12 Government statistics (Defra, 2018a) (Figure 3.3) identify that at national scale, SO_2 and NO_2 deposition has fallen dramatically over the last half century. The data for Burnham Beeches suggests that the levels for NO_2 remain comparatively high today, though Air Quality Consultants (2018) haves estimated that these will fall below critical levels in future decades. There are national emission reduction commitments for overall UK emissions of these pollutants which should result in their further reduction over the next decades (Defra, 2018b).

Figure 3.3. Trends in UK sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia and particulate matter (PM10, PM2.5) emissions 1970 – 2016 (from Defra, 2018a)



3.13 Ozone (O_3) is a pollutant which is normally formed when other pollutants, including nitrogen dioxide and Volatile Organic Compounds (VOCs), react in sunlight. It has well-known detrimental effects on susceptible vegetation, including beech (Šrámek et al., 2012), though others (e.g. Royal Society, 2008) have suggested that climax species such as beech and oak are less susceptible than pioneering species such as birch and poplar. Ozone in general decreases tree growth, reduces leaf area and accelerates leaf ageing and abscission (Morrissey et al., 2007).

3.14 Unlike the pollutants discussed above, ground-level ozone concentrations are projected to rise in future decades, the result of a predicted reduction in NOx concentrations in urban areas. Climate change is also expected to significantly influence future O_3 concentrations, because these are strongly dependent on biogeochemical and physical processes, most of which are affected by climatic factors such as temperature, rainfall and humidity (Royal Society, 2008).

3.15 The role of atmospheric pollution on beech health and growth in southern Britain was studied in the 1990s (e.g. Ling et al., 1993). SO_2 was the pollutant most closely linked to indices of ill-health, but mainly in urban areas; the role of ozone was not studied. However, Power et al. (1995) suggested ozone was a probable driver of poor beech health in southern Britain, in association with drought, and beech woodlands were considered as of 'high risk of ozone impacts' by Morrissey et al. (2007). It is considered likely that this pollutant poses the greatest risk to beech health at Burnham Beeches in future years and symptoms have already been observed in younger trees (H. Read, pers. comm).

Modern management methods

3.16 The Ancient Tree Forum (2016) suggests that 'halo clearance' or 'haloing' should be undertaken to clear vegetation around veteran trees to reduce competition for light, and Read et al. (2007) and Read (2010) describe how this has been applied at Burnham Beeches. Removal of vegetation allows more radiation to reach the tree's foliage, and thus promote photosynthesis. It also prevents physical abrasion, especially from woody scrub and tree saplings. Alexander et al. (2010) studied the impact of halo clearance on beech and oak at Windsor Forest. They concluded that it had been very successful especially where the halo size was larger and where groups of trees were involved rather than single trees. Veteran oak benefited most but clear benefits were also noted for some of the veteran beech. Other practitioners report improved crown size, though also identify that exposure of veteran trees through rapid vegetation clearance can be detrimental to tree health[7]. Certainly. 'thinning shock' is often recognized in forest stands subject to thinning (Harrington and Reukema , 1983; Dore et al., 2012) though this is usually a temporary phenomenon.

3.17 The logic behind haloing for tree crown development seems evident, but concerns have been raised that this practice might promote greater demand of soil moisture resources. This could challenge tree physiology especially during periods of drought. Certainly, it is understood that isolated single trees in the landscape have a much higher water use than trees in forests on account of their larger canopy and greater exposure (Nisbet, 2005). There have been no known studies to explore the specific issue for veteran trees in the field. From principles of forest hydrology, haloing will increase the radiation energy load on the veteran tree, thus increasing water demand on the tree. It will increase air movement around tree – probably also increasing water loss in general, but possibly also increasing heat transfer away from illuminated canopy section in hot dry days – which might be a small advantage. On the beneficial side it will reduce water uptake from soil by adjacent 'competing' vegetation, and will reduce canopy interception losses too, so more water will get through to the soil, aiding soil moisture recharge for take up by the veteran tree (Bréda et al., 1995; Aussenac, 2000; Ganatsios et al., 2010). Unfortunately, the science behind tree drought resilience is somewhat confused and contradictory but the recent review by Grote et al. (2016) suggests that some shade is important in providing cooling and reducing radiation, of particular importance in hot periods with clear skies.

3.18 Some research on silvicultural thinning in forests may be helpful to explore this issue further. Park et al. (2018) suggest that thinning effects can differ depending on the site water availability and capacity of tree species to adjust to sudden changes in environmental

7 https://vimeo.com/117586109

conditions. Their study, on a pine species, showed that heavy thinning (40% removal) in a mature stand resulted in greater water efficiency within the remaining trees. However, in another pine forest, D'Amato et al. (2013) found that lower-density stands exhibited greater resistance and resilience to drought at younger ages (49 years), yet exhibited lower resistance and resilience at older ages (76 years), relative to higher-density stands. They attributed this reversal to significantly greater tree sizes attained within the lower-density stands through stand development, which in turn increased tree-level water demand during later droughts.

3.19 The nature of understorey vegetation, and its relative competing demand for water will be affected by a number of factors including soil conditions (e.g. chemistry, fertility), microclimate (especially shade) beneath the tree canopy, and management regime (e.g. degree of browsing or artificial removal). In general, water demand and rainfall interception will be proportional to leaf area. Interception of rainfall is also related to plant height and canopy formation. For example, heather and bracken are well known for intercepting up to 20% of annual rainfall. Table 3.2, from Nisbet (2005), gives further details.

Table 3.2. Typical range of annual evaporation losses (mm) for different land covers receiving 1000 mm annual rainfall

Land cover	Transpiration	Interception	Total evaporation
Conifers	300–350	250–450	550–800
Broadleaves	300–390	100–250	400–640
Grass	400–600	–	400–600
Heather	200–420	160–190	360–610
Bracken	400–600	200	600–800
Arable*	370–430	–	370–430

*assumes no irrigation

4. Management options

Planning for future climate change

4.1 The vulnerability of beech to a climate which is warmer and drier during the growing season has been under discussion for several decades, and the ESC projections of suitability at 2050 and 2080 are not encouraging. Nevertheless, there remain a substantial number of ancient beech pollards at Burnham Beeches and therefore a responsibility to maintain them for as long as possible. Appropriate attention to soil degradation through compaction and erosion is one management approach. Careful application of halo clearance is another. Both these interventions comply well with the first two 'Adaptation Principles' for nature elaborated by Scottish Natural Heritage (2016):

1. **Reduce other pressures** – on ecosystems, habitats and species, e.g. pollution, unsustainable use, grazing, habitat fragmentation and invasive non-native species.
2. **Make space for natural processes** – including geomorphological, water and soil processes, and species interactions.

4.2 The full list is given in Annex AM3.

4.3 Despite the climate projections discussed above, the place of beech at Burnham Beeches can be optimised by 'succession planning' and the application of silvicultural best practice applied to younger trees. This includes prevention of soil compaction and erosion, reduction of vegetation competition and management of browsing, and appropriate monitoring for health and nutrient status.

Soil amelioration

4.4 In section 3, the likelihood of widespread soil compaction at Burnham Beeches was discussed, and largely discounted. However, localised soil compaction was acknowledged as a possibility, notably where woody vegetation had been cleared and visitor pressure was high. Traditionally, compaction has been dealt with by forms of mechanical cultivation such as subsoiling, 'deep ripping' (Foot and Sinnett, 2014) and 'complete cultivation' (Sinnett, 2014). However, these interventions are generally unsuitable for soil around established trees because they disrupt and partly destroy root systems. Instead, a technology often advocated to deal with soil decompaction in association with veteran tree management[8], namely air injection, has been developed. Such technologies include Terravent™, Terralift™ and the Air Spade™.

4.5 Air injection techniques and equipment have been the subject of considerable research (e.g. Smiley et al., 1990; Hodge, 1993; Smiley, 2001; Fite et al., 2011; Hascher and Wells, 2007) in the urban environment. In summary, almost all these studies found that air injection produced little or no decrease in soil bulk density (a measure of decompaction). Fite et al. (2011) concluded that results were very dependent on location and soil type, although 'injections have seldom improved soil physical properties'. Recompaction appears to occur

[8] https://www.treerescue.org.uk/the-rescue-process

rapidly after treatment on many soil types but Fite et al. (2011) found that the addition of mulch helped to hold open the newly-loosened soil structure at two sites tested. Nevertheless, in another study examining the role of air injection in a compacted soil, no increase in tree fine root growth was found after treatment (Hascher and Well, 2007). Unfortunately, no studies have been found that deal specifically with the use of air injection in gravelly soils, but it is unlikely that this soil type will perform especially differently from those which have been studied.

4.6 Taken together, the research to date suggests that air injection is not a reliable technology to recommend for relieving soil compaction at Burnham Beeches. Natural processes, for example, wetting and drying and freeze-thaw cycles, the addition of organic matter through leaf fall and the activities of soil fauna, can relieve soil compaction over time, provided the cause of compaction is identified and removed. However, as discussed in Sections 3.4 and 3.5, the extent of damaging soil compaction is considered to be relatively small.

4.7 If compaction risk remains a concern, it is better to consider management strategies for avoidance rather than seeking a solution to remedy it after it has taken place. These could include fencing to reduce pedestrian (and stock) pressure on the soil around particularly important specimens, and/or the use of mulch placed under tree canopies for the same purpose. Scharenbroch and Watson (2014) found that wood chips and compost top dressings improved tree growth and soil bulk density in compacted urban soils they studied. Similarly, Flores Fernández et al. (2019) demonstrated that mulch aided the recovery of soil structure of a compacted forest soil in Germany. Mulching also increases fine root growth in the surface horizons, and enhances soil biological functioning. It is important to apply mulch to an appropriate thickness (between 5 cm to 7.5 cm maximum), to facilitate rainfall percolation and oxygen diffusion into the underlying soil. Mulching is clearly a management intervention which moves beyond natural litter accumulation beneath trees, but it appears to fit with the ethos of the Adaptation Principles listed in Annex AM3. Mulch will also provide nutrients available for uptake by the tree, and help to counter any deficiencies due to inherent soil infertility, the effects of atmospheric pollution and nutrient removal by vegetation. The RHS website gives further guidance on the practice of mulching[9].

4.8 The risk of further compaction and soil erosion should also be addressed by management of pedestrian routes through the Burnham Beeches site at sensitive locations whilst understorey vegetation is re-established. Bare soil is very prone to further damage, and a grass sward should be established as soon as possible, possibly using seed gathered from suitable locations on site to prevent introduction of 'alien' species. The grass species in the seed mixture for this purpose must be shade-tolerant.

Halo clearance

4.9 Unfortunately there have been no specific studies on pollard hydrology at Burnham Beeches and the studies discussed in Section 3 do not define a robust picture of the water balance associated with halo clearance of veteran trees. Indeed, those available suggest that the effects of thinning, or vegetation clearance around individual trees, are likely to depend on the particular site and silvicultural conditions at the tree. In general, however, the overall

[9] https://www.rhs.org.uk/advice/profile?pid=323

message appears to be one in support of halo clearance, whilst retaining a forest cover in close proximity to the haloed trees wherever possible. This suggests that the degree of clearance achieved in the area north-east of the Druids Oak and north of Lord Mayors Drive, known as 'The Paddocks', is excessive, and counter-productive to optimal soil-tree hydrology, now and in the future. In addition, removal of woody roots in the proximity of specimen pollards as part of halo clearance will reduce soil strength and increase the risk of soil compaction and erosion.

Monitoring

4.10 Monitoring of ancient beech pollards, and those expected to succeed them, is an important management strategy to increase the likelihood of their persistence at Burnham Beeches. Tree monitoring is already undertaken for purposes of assessing human health and safety risk, e.g. to prevent injury from falling boughs or branches[10], but is focused on areas where visitor usage is greatest (e.g. adjoining roads, car parks and primary paths). Some monitoring of maiden beech trees also takes place following prescribed guidance (Anonymous, undated). Other forms of monitoring could include annual measurement of tree crown condition using methodologies promoted by ICP Forests[11,12]. Examination of the tree to identify 'damaging agents'[11], if necessary in conjunction with a qualified forest pathologist, will help to ascribe cause to the tree conditions found. Ozone damage can be identified by comparison with photos of known symptoms[13].

4.11 Periodic sampling of tree foliage can also be undertaken in order to establish tree nutrient levels, and therefore whether soil amelioration using compost or artificial fertilisers might be necessary. Guidance on how to do this is provided by Forest Research, based in Farnham, Surrey[14]. Measurements of tree growth (e.g. diameter at breast height, or annual tree height increment), common indicators of health and condition, are extremely difficult in veteran trees compared to those in commercial forestry. However, photographs taken annually from the same position may reveal whether a tree is succeeding or struggling over time.

4.12 There is no feature of above-ground tree growth that can be linked reliably to soil compaction *per se*, but it may become manifested in reduced tree growth or poor nutritional characteristics. However, these phenomena can arise as a result of many other drivers including annual climatic conditions or the impact of pests and diseases.

4.13 In conclusion, if consistent monitoring of ancient pollards proves impossible, it may be better to instigate or continue an annual monitoring programme on a representative sample of maiden beech trees. Such a programme should, over time, help to identify the response of beech to the impact of environmental, biological drivers and management at the Burnham Beeches site.

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[10] For example, as described by the National Tree Safety Group (2011)

[11] http://icp-forests.net/page/icp-forests-manual

[12] http://www.icp-forests.org/pdf/manual/2016/ICP_Manual_2017_02_part04.pdf

[13] See, for example, http://www.ozoneinjury.org/index.php?option=com_content&view=article&id=50:genus-fagus&catid=3:photos-of-ozone-induced-visible-injury&Itemid=52

[14] https://www.forestresearch.gov.uk/services/plant-tree-soil-and-water-testing/foliar-analysis/

5. Recommendations

5.1 Possible changes to current management practices have been discussed in the body of this report, but the following recommendations have been brought together below:

- Soil compaction and erosion should be prevented by appropriate pedestrian management, and application of mulch under the canopy of important and/or ailing trees;
- Where possible, a grass sward should be established in areas of bare soil in proximity to veteran trees to prevent further soil compaction and erosion;
- Halo clearance should remain as a management option to promote longevity of veteran trees, but it should be undertaken with care and restricted to removal of woody vegetation within the existing canopy of the trees and the immediate zone around the tree crown;
- A monitoring regime should be strengthened to understand the condition and health of beech trees through time and in relation to microclimate. The extent and condition of the remaining areas of bare soil should also be noted from time to time;
- Research on the water relations of pollarded beech trees at Burnham Beeches could be usefully undertaken, possibly in conjunction with a local university.

6. Conclusions

6.1 A review of relevant literature in relation to soil, climate and related environmental pressures on the pollarded beech trees at Burnham Beeches has been carried out.

6.2 A synthesis of this literature has identified that a range of simple management options could do much to reduce the impact of visitor pressure and environmental change on veteran tree health and longevity.

6.3 Nevertheless, predicted changes in climate and pollution climate are likely to further challenge the health of the beech at Burnham Beeches. Monitoring tree health will help to identify if and when further management intervention is necessary.

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Annex AM1

Literature Review – Beech tree stress, soil conditions and drought

1. Explore the relationships between soil compaction, changes in the chemical and physical structure of the soil and tree health/condition in relation to mature beech trees.
2. Explore the potential impact of beech trees growing in woodland vs wood pasture conditions regarding dry/drought conditions
3. Provide recommendations for detecting problems in the trees.
4. Provide recommendations for ameliorating soil conditions.
5. Link the findings to the impact of other stressors such as drought, flooding and air pollution.

Specific questions to try and address:

- Do the gravel soils of Burnham Beeches get compacted or is the apparent compaction due to erosion of the humus and leaf litter layer?
- How does the impact of soil compaction manifest itself in beech trees?
- How do gravel soils differ from chalky soils in terms of root growth & hence tree growth?
- Are trees growing in open grown situations at higher risk of drought stress than those within woodland?
- How does drought stress inter-relate with relation to soil type, aspect, vegetation type (grassland, heathland) etc.
- In drought conditions are there any ways we can 'help' rooting conditions of trees growing on gravel soils?
- What are the best ways to ameliorate soil compaction to assist root growth with veteran trees?
- Are these compatible with trees in 'natural' (i.e. wood pasture within a nature reserve) situations rather than urban parks?
- Are aeration methods applicable on gravel soils? What do they actually do for the trees?

Annex AM2

Glossary of terms

Air injection. The process of injecting air or nitrogen gas into the soil at high pressure in order to create fracturing of soil structural units and reduce bulk density. Note that there is little evidence that this is routinely achieved over timeframes measured in years.

Haloing. The removal of trees and shrubs from around an old tree in a series of small steps in order to give it more light without exposing it to a sudden increase in light and heat that may be caused by large scale clearance of neighbouring vegetation (Read et al., 2007).

Soil compaction. The soil compaction can be defined as “the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby, increasing the bulk density” (SSSA, 2008).

Soil strength (cone index, penetration resistance). A transient localized soil property that is a combined measure of a given pedon’s, horizon’s, or other soil subunit’s solid phase adhesive and cohesive status. This property is most easily affected by changes in soil water content and bulk density, although other factors including texture, mineralogy, cementation, cation composition, and organic matter content also affect it (SSSA, 2008).

Annex AM3

SNH Adaptation principles

1. Reduce other pressures on ecosystems, habitats and species – e.g. pollution, unsustainable use, grazing, habitat fragmentation and invasive non-native species.

2. Make space for natural processes including geomorphological, water and soil processes, and species interactions.

3. Enhance opportunities for species to disperse by reducing fragmentation and increasing the amount of habitat available.

4. Improve habitat management where activities such as grazing, burning or drainage cause declines in diversity or size of species populations, or where modifying management or increasing habitat diversity could improve resilience to climate change.

5. Enhance habitat diversity, e.g. by varying grazing or plant cutting management on grassland or moorland, or creating new habitats on farms.

6. Take an adaptive approach to land and conservation management e.g. by changing objectives and management measures in response to new information.

7. Plan for habitat change where assessments indicate losses of habitats or species are inevitable, for example as a result of sea-level rise.

8. Consider translocation of species in circumstances where assessments indicate the likely loss of a species despite new management measures, and where there are suitable areas for nature to adapt.

ANNEX AM4

Qualifications and Experience

Dr Andy Moffat has been engaged in research and advisory work on trees since joining the Forestry Commission Research Division in 1985. He has a BSc (Hons) in Geography and Soil Science and a PhD in Geography.

Dr Moffat began his career as a soil surveyor in the Soil Survey of England and Wales, and was engaged on mapping soils in south-east England. He began his research career with the Forestry Commission studying the interaction of trees in urban and peri-urban environments, and aspects of trees and air pollution. He was a contributor to Urban Forestry Practice, published by the Forestry Commission, and several other government guidance documents. Subsequently, he has led research projects on a variety of subjects relevant to arboricultural policy and practice, notably in the areas of trees and soil contamination, air pollution, tree rooting, trees, drought and moisture abstraction, soil shrinkage and species suitability. He has recently been involved in the areas of climate change impacts and ecosystem services. Dr Moffat has published widely, and is the author of some 75 peer reviewed papers, 40 Government publications, 45 books, book chapters and published conference proceedings, 65 out-reach, trade and other publications and 40 contract reports. During his time with the Forestry Commission, he had a close working relationship with both forestry and arboricultural practitioners, and with arboricultural policy advisors to government (in the Department for Communities and Local Government).

In 2013, Dr Moffat set up his own consultancy company, specialising in trees and the built environment. He works closely with arboricultural practices, notably Martin Dobson Associates, and delivers workshops on soil and climate change issues on behalf of the Arboricultural Association and the Royal Forestry Society. He is a Fellow of the Royal Geographical Association and of the British Society of Soil Science, and is a Member of the Institute of Chartered Foresters. He enjoys Chartered Consultancy status from the latter.