The current status of ancient pollard beech trees at Burnham Beeches and evaluation of recent restoration techniques

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SUMMARY: Recent studies on ancient beech pollards at Burnham Beeches have included assessments of their current condition and evaluation of the responses of the trees to restoration pollarding, both in terms of new growth after cutting and the health of the branches. The trees show positive responses to cuts and the death rate of the trees has been slowed. The length of stub left at time of cutting is positively correlated with the number of branches arising from it; a longer stub also increases the chance that a cluster of new shoots will arise. Trees that had been cut in the 1950s have produced more new shoots than those not cut for approximately 200 years. Other impacts on tree growth after recent restoration cutting are discussed.

Introduction

The ancient beech pollards at Burnham Beeches have been admired by visitors for decades and indeed were one of the reasons that the area was purchased by the City of London in 1880 to save it from development (Corporation of London, 1993). The old pollarded trees, mostly beech but some oak, are very variable in character and are thought to be predominantly approximately 400 years old (Read et al., 1996). Burnham Beeches was a wooded common and the trees were probably cut for local fuel, and were pollarded to enable regrowth because the land around them was grazed with a mixture of different livestock. The pollards have been cut many times creating trees with very knobbly bollings that, along with the decaying wood in the centre of many of them, make them valuable for wildlife. Burnham Beeches is now a SAC, and is one of the most important nature reserves in Europe for species that require continuity of decaying wood habitat.

A forester in the 1930s estimated that the numbers of pollards at Burnham Beeches was then 1,795 but believed that there may have been up to 3,000 previously (Le Sueur, 1931). In 1990 550 pollards were reported (Read et al., 1991) but several have been ‘discovered’ since and this figure should probably be about 574. The majority of the pollards were beech but both native oaks were also pollarded; in 1990 oaks made up 15% of the pollards. Cutting ceased approximately 200 years ago and grazing had stopped by the Second World War. This change in management has resulted in lapsed pollards with decaying and hollow bollings bearing large, heavy branches (themselves often the size of mature beech trees) drawn up very tall and with little foliage lower down. This may have been exacerbated by the trimming of lower branches to enhance their exceptional appearance and for safety reasons. The top-heavy nature of the trees and lack of lower branches has resulted in many trees falling over and loss of large branches with no chance of regrowth around the break. In addition, some especially giant trees have died standing for no apparent reason. In the 1950s and 1960s some attempts were made to recut some pollards. The work was not very sympathetic and many trees were cut either very hard, or cut to a standard or even height above the bolling.

In the late 1980s the biological value of these trees started to be appreciated and there was increased awareness of the problems of lack of continuity. Small scale experimental work was carried out in Burnham Beeches and elsewhere in Britain to investigate the possibility of active work to keep such trees alive as long as possible, and to start a new generation. This type of work has led to a new discipline of ‘environmental arboriculture’ (Fay, 2002). In Burnham Beeches the experimental work started on young beech trees and progressed to a small number of older trees. This 'restoration' of ancient pollards is a new science and many of the techniques were carried out on a 'trial and error' basis. All the old pollards in Burnham Beeches were tagged and recorded in detail in 1990 and the situation was reviewed in 1999. The resulting internal report (Read, 2000) proposed increased action for future years. The fact that uncut trees were declining at a rate of 10 trees per year meant that by 2046 there would be no old pollards left at Burnham Beeches. In summary, this report concluded that a few trees had died after cutting but largely due to factors other than the cutting itself. The short-term success rate of cut trees was very good; the long-term success rate cannot be judged without waiting more years than it is desirable to wait. Thus, the decision was made to increase the work programme following these principles:

- Trees suffering from lack of light caused by surrounding tree growth (largely holly or birch) were haloed (i.e. a small clearing made around the tree to avoid dramatic changes in light/humidity).

- Top heavy trees in reasonable health were cut to reduce the weight on the bolling and bring down the height, while retaining lower live branches. The aim was to carry this out in a series of steps, eventually reducing the tree as close to the original bolling as possible. For some trees this might be close to the original cutting point, for others it might be much higher. The amount of canopy removed from each tree initially was highly variable but 'typically' in the region of 25-30%.

- Trees unlikely to respond to cutting because of having very small crowns or being unstable were not cut.

- Any other work that seemed likely to help the survival rate of the trees was carried out, for example moving paths away from roots, mulching with wood chip, replacing old support cables between branches and using props.

- Difficult decisions had to be made where letting light to old pollards would have entailed felling a number of mature maiden trees. The decision in these cases involved evaluating the number of mature trees needing to be felled relative to the number of ancient pollards that this would benefit and their overall health. In a small number of cases the decision was made to do nothing.

Over time the methods have been adapted on the basis of a visual assessment of how the trees have responded. There have also been variations due to the style of the individual tree surgeon doing the cutting, which has been considered positive; should one method fail then not all the trees have been subjected to it. A small number of trees have also been tip pruned rather than removing a larger proportion of the canopy.

Between 1996 and 2007 some 375 trees were cut (this does not include those where only haloing or other management work was done), with 6 trees being cut twice. Trees were mostly cut in winter (January to March) with a few cut in mid summer.

Previous studies evaluating the success of restoration pollarding

Small-scale studies on the pollarding work at Burnham Beeches have been carried out previously. Frater (1995), summarised in Read et al. (1996), looked at growth responses in ancient pollards cut during the first phase of restoration in comparison with some not yet cut. Only one tree out of 11 showed growth of new shoots from the cut stubs but the cut trees had significantly greater growth of retained branches (4 times more) relative to uncut trees, as determined by distances between terminal bud scars. For young pollards cut for the first time, a significant positive relationship was found between the diameter of the cut surface and the distance from it of new shoots which suggests that leaving a long stub might be beneficial.

Pfetscher and Denne (1995) assessed the regrowth after restoration pollarding of beech trees at Burnham Beeches and Savernake Forest. They concluded that survival rate was far greater when stubs left exceeded 0.3m in length. They reported a low survival rate of trees after cutting at Burnham Beeches (22 out of 49 trees) but the mortality was exaggerated. Only 22 of the trees they studied had been cut and of these 18 (81%) are still alive in 2009 (some of those not cut had also died). This can be seen by reference to photographs, comments and data given in the original report (Pfetscher, 1994).

Work at Epping Forest (Dagley & Burman, 1996) on lapsed beech pollards indicated that only 60 trees survived out of 202 trees cut, although many were cut for safety reasons and were already dying or in very poor condition. Here the majority of branches were removed; single sap risers were left on some trees but this did not provide any particular benefit. There was no indication that stub length was a significant factor in branch survival.

A physiological review (Lonsdale, 1995) considered that restoration pollarding is more drastic to the tree than traditional pollarding and that large sized cuts should be avoided where possible. Twigs and branches should be retained around the circumference of the tree and cutting in a drought year or even the year after should be avoided.

Guidelines/comments about cutting old trees (not specifically pollards) are summarised in Table 1.

Despite authors suggesting that the factors in the table might be important (stub length, stub diameter, method of cutting etc.), these have only previously been investigated in detail on small numbers of trees (see Table 6 for more details). Studies have also varied in their definition of success or failure. Some used mortality rates and others the production of new branches as a result of the cutting work. It should be noted that for beech the response of the tree may be for the retained branches to grow well, either putting on large amounts of extension growth or producing new side branches. However the tree may not produce new shoots on or near the branch that was actually cut.

The present study was initiated with the intention of clarifying some of these aspects as well as reporting on the overall success rate of the work at Burnham Beeches in the last 20 years.

Methods

This study was carried out on old pollards at Burnham Beeches that had been cut traditionally in the past. New pollards have been created but the responses of

Table 1. Guidelines for cutting old trees (from Read, 2000 & 2006).

Aspect	Response
Species of tree:	Some easier than others, beech is one of the least responsive.
Time of year:	Avoid spring and autumn, cut in winter and mid summer.
Amount of crown to remove:	Leave some limbs intact (the actual number of branches depends on the species). Reduce trees gently (i.e. do not remove too much canopy at a time since removing all the canopy will almost certainly kill the tree).
Light reaching the tree:	No over-shadowing branches but don't increase light suddenly. Trees need enough light but not too much.
Length of stub:	Avoid flush cuts. Leave the branch collar; as a rough guide leave 10 times the diameter of the branch above the bolling.
Cutting in two or more stages:	May be necessary but dependent on the form of the tree.
Type of cut:	No conclusion regarding what type of cut might be best (slanted or rough jagged cuts).
Cutting tool to use:	No conclusion regarding whether axes are better than saws.
Weather conditions when pollarding:	Avoid drought years and beware of frost hollows.
Balance:	Make sure the tree is not unbalanced after cutting.
Regional differences:	Humid areas e.g. west of Britain may be better.
Growth of lower branches:	Some debate about whether excessive growth of lower branches will divert energy from the top of the tree.
Age of tree and length of time since last cut:	The older the tree and the longer since the last cut the less likely the tree is to respond well.
Trees with burrs:	May respond better.

Table 2. The number of trees assessed and the years in which they were cut.

Date of cutting	Reference date	Number of trees recorded
Before 1993	<1993	9*
Winter 1997/98	1998	10
Winter 1998/99	1999	10
Jan-Feb 2000	2000	11
Jan 2001	2001	11
Jan 2002	2002	10
Jan 2003	2003	10
Jan 2004	2004	1**
Jan 2005	2005	4***
Total		76

*Only 9 trees were available that had been cut prior to 1993.
**Only 1 beech was cut this year as it was exceptionally dry & it was tip-pruned rather than the normal reduction.
***Only 4 very urgent trees were cut (i.e. those for which there were concerns over stability) since this was a drought year.

those trees have not been reported on here although they are tagged and recorded. The work reported on here was been carried out in three parts.

i) Tree health assessments
As part of a wider study of the health of beech trees at Burnham Beeches during 2005-2006, 70 beech pollards were selected for assessment in a stratified random way (using the 4-figure unique identifier number for each old pollard) to ensure that all four major areas of Burnham Beeches with pollards were included. Methods followed Roloff (1985), expanded by Gadsdon (2007), and consisted of one assessment in summer (crown thinness, amounts of mast and biotic damage) and one in winter (canopy architecture and twig structure) for each tree. All characteristics were scored using the standard values that range between 0 (healthy tree) and 4 (dead tree). Values for each measure were then combined to give a mean score for each tree.

ii) Survey of the condition of the ancient pollards
Every old pollard (573) still alive was surveyed during winter 2006-7 using the Specialist Survey Method for old trees (Fay & De Berker, 1996) to gain information about the condition and habitat value of trees. Some additional information was recorded including extent of squirrel damage and also canopy architecture and twig structure for both new and retained branches on each tree where possible. These were subsequently used to give an idea of the healthiest and poorest growth on each tree. Finally an individual tree management plan was drawn up for each tree based on its response to previous cuts as well as its current shape and stability.

iii) Assessing the response of the trees to cutting
A sample of 76 trees that have been restoration pollarded since 1988 were assessed to examine their responses. Approximately 10 trees (9 for years prior to 1993, and 11 in 2000 and 2001) were selected for each year that tree management was undertaken. The sample was taken from those trees for which tree health assessments had been made, with additional trees added using random identifiers, where necessary (Table 2).

Each tree was examined from all sides using binoculars and a rough estimate made of the number of branches cut and those retained. Five branches were selected from those that had been cut. (If fewer

Table 3. Scoring system used for assessing the responses of pollards to cutting.

Length of stub		Diameter of stub	
Field assessment	**Recorded score**	**Field assessment**	**Recorded score**
Very short	1	Wrist sized	1
Short	2	Arm sized	2
Medium	3	Leg sized	3
Long	4	Waist sized	4

Distance of shoots from cut		Length longest new branch	
Field assessment	**Recorded score**	**Field assessment**	**Recorded score**
On cut surface	1	0 – 0.5m	1
Just below – up to 0.25m	2	0.5 – 1.0m	2
Up to 0.5m below	3	1 – 5m	3
>0.5m	4	>5m	4

Table 4. Causes of beech pollard death.

Cause of death	Number of trees
Major branch loss (either entire top at one time or more gradual loss of branches)	41
Fallen whole	35
Died standing (more or less whole)	32
Died standing after major limb loss	29
Felled (inadvertently)	1
Unknown	3

than five had been cut, all were recorded, if more than five had been cut then those selected were branches that could be seen easily, represented the range of different branch types and/or cutting methods used on that tree, and were distributed around the tree.)

For each branch selected, the length of stub (i.e. the distance between the cut and the next branch) and the diameter of the stub were estimated using scores of 1 to 4. Each branch was checked for regrowth and the number of new shoots, the distance down from the cut (using a 4-point score) and the length of the longest new branch arising (which varied with the number of years since cutting) were recorded (see Table 3 for details). A general note was made of any points of interest, for example, if the branch showed dieback, signs of healing over or obvious squirrel damage.

The results were combined using Excel spreadsheets with information gathered on some of the trees previously, including the girth, estimated percentage of canopy removed during cutting, whether climbing spikes were used, if tears were left, and who cut the tree. Some information was not available for trees cut in earlier years.

Statistical analysis was carried out using non parametric tests using FC stats v.1.1g (Wheater & Cook, 2003) and Statview v.5.0.1. For Spearman Rank Correlation Coefficients, r_s values stated were adjusted for ties. Since trees were excluded if they were missing relevant data, the numbers of trees and/or branches varies between different analyses.

Table 5. Cause of death for cut pollards.

Cause of death	Number of trees
Death after cutting work	13*
Fallen or death following major branch loss after clearance but before any cutting work	10
Other trees falling into them	5
Surrounded by rhododendrons (lack of water?)	3
Flooded by stream blockage	1
Compaction by cars	1
Cleared round and then signs of drought stress	1

*7 were cut after major limb loss in order to stabilise the tree; 3 suffered lack of light several years after cutting despite clearance at the time; 1 fell (it was a very tall tree with heavy branches and no easy lower cutting point); 1 was also a very tall tree that had both major limb loss and suffered lack of light; 1 was generally looking in poor health.

Results

Survey of the condition of the ancient pollards

Of the total 574 ancient pollards that have been recorded and tagged since 1990, 151 (including 10 oaks) are now dead (Table 4). Heavy branches appear to be the major reason for tree death and/or failure of

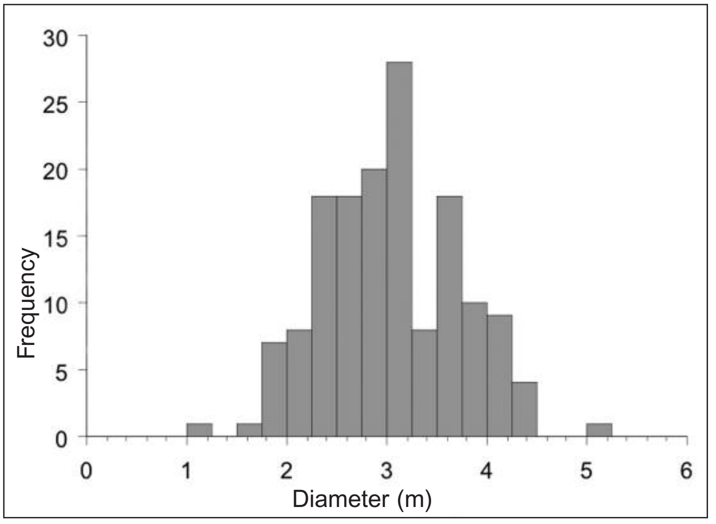

Figure 1. Plot showing the girth of beech pollards at Burnham Beeches.

trees to grow following major limb loss. Of the dead trees, 34 died subsequent to restoration cutting (Table 5).

A relatively small number of pollards died as a direct result of the cutting (even fewer than Table 5 initially suggests).

Of the trees alive 18% were oak, a slightly higher proportion than the 15% recorded in 1990 probably due to the higher rate of mortality of beech trees. The girths of the beech trees are illustrated in Figure 1 (those with complete trunks).

The graph shows no evidence of cohorts of recruitment as pollards. The one very small tree is probably an accidental pollard (i.e. not cut as a pollard but created by storm damage). A small number of trees reach an exceptionally large girth. Currently the largest is 5.11m; one which fell in 1978 had a girth of 8.5m when measured in 1936 and the largest ever recorded was 9.1m in 1878.

Table 7. Response of pollards to cutting.

Response to cutting	Number of trees
0	19
0.5	17
1	72
1.5	39
2	49
2.5	13
3	51
3.5	0
4	17

The potential habitat value of the trees has been confirmed by the survey as shown in Table 6.

Trees with abundant epicormic growth often respond better to cutting. Epicormic growth was recorded for beech at the base of 48 trees, the trunks of 37 trees and the crowns of 153 trees.

Grey squirrel damage may have a negative impact on the trees by killing branches that have grown as a response to cutting and there is concern about the consequence of this on the long term survival of trees. (231 beech trees had obvious signs of squirrel damage, with 58 having extensive damage.)

The trees were scored regarding their response to cutting where 0 is a decline after cutting, 0.5 and above a positive response with 4 being the best. Trees were only assessed if they were alive so scores of below 0 were not obtained. The results are shown in Table 7.

The majority of the trees showed a positive response to cutting, although few were recorded in category 4. For 87 trees it was estimated that the end point of restoration pruning had been reached, i.e. no further reduction in height of canopy was required. The remaining trees were estimated to require up to 6 different operations to reach the end point.

Table 6. Habitat features recorded on pollards.

Habitat feature		Number of trees	Total number
Major cavities	Top of trunk	285	
	Mid trunk	174	
	Base	352	
Hollows in crown		394	1322
Holes 5-15cm diameter		414	2166
Water pockets		61	73
Split limbs	1 split limb	74	
	2 split limbs	2	
Sap run		14	192
Dead wood in crown (>15cm diameter)		315	1790m**
Bark dead, attached, missing >30x30cm	Base	68	
	Trunk	141	
	Crown	192	
Major rot (<30x15cm)		318	
Extensive rot (>30x15)		55	
Rot type	White	266	
	Red	36	
	Black	34	
	Wood mould*	61	

*The end product of various different rot types.
**Total length of dead wood in metres.

Table 8. Tree health assessment results for pollards.

	Retained branches	New growth	Overall health
Health score	1.63	0.73	1.28
Minimum value	0.25	0.07	0.45
Maximum value	3.00	3.00	3.00
No. scoring 3 for canopy or twig structure (winter assessment)	47 out of 93 trees	3 out of 73* trees	
No. scoring 3 for crown thinness (summer assessment)	17 out of 70 trees	0 out of 41* trees	

*Not all trees surveyed had new growth to be assessed.

Tree health assessments

The results of assessments on the growth of retained branches and that of new growth as a response to cutting are shown in Table 8 for the random sample of pollards. The difference is significant when compared using a paired *t* test: $t = 11.81$, $P<0.0001$, 74 d.f.

Since canopy architecture had previously been found to be the best single indicator of health for the trees in Burnham Beeches (Read, 2006) this is perhaps the most important factor. 50% of trees scored 3 (the poorest health score) for canopy architecture or twig structure on their old growth but only 4% did so on their new growth. Interestingly the mean score for the retained branches of the pollards (1.63) was very similar to that of the maiden trees (mean of 1.59). The results for canopy architecture for all trees surveyed are given in Table 9.

Responses of the trees to cutting

Of the 76 trees examined, 34 (45%) trees had one or more branches with new regrowth resulting from the cutting and a further 5 had possible regrowth resulting from cutting. Of the 343 cut branches examined, 84 branches clearly had regrowth (24.5%) and a further 5 possibly had regrowth. Many trees showed good extension growth after cutting but not necessarily new branches arising from stubs or cut surfaces. This is very difficult to record in a systematic way and has not been included in the results. Very few aspects studied were found to be significant in terms of successful growth of new shoots from branches cut during restoration pollarding. Significant results are discussed below.

Table 9. Canopy architecture scores.

Branch score	Number of trees with retained branches	Number of trees with new branches
0-0.5	6	110
1-1.5	21	77
2-2.5	74	30
3	226	7

Trees cut in the 1950s

Many of the trees in Burnham Beeches were cut during the 1950s and these can be recognised by the shape of the branches; unfortunately the exact number is unknown. Using the data on the response of the branches gathered a comparison between branches clearly cut previously and those that were thought not to have been cut for 200 years was made. The result was significant for both the number of branches and the proportion of branches responding (Mann-Whitney *U* test: $U>199$, $P<0.01$, $n_{nosuccess}=60$, $n_{success}=12$). For those cut in the 1950s a mean of 2.08 branches per tree produced new shoots, whereas for those not cut the mean was 0.93. Branches cut previously therefore respond twice as well as those not cut previously, highlighting the value of keeping trees in a regular cutting cycle.

Stub length, new shoots and clusters of shoots

There was a significantly greater chance of new shoots on longer stubs (Mann-Whitney *U* test: $U = 6458$, $P=0.014$, $n_{nosuccess}=178$, $n_{success}=88$). There was a significant relationship difference between the length of stub and the number of new shoots ($r_s = 0.167$, $P=0.0067$, $n=341$). Stub length however only explains a very small amount of the variation seen in the responses (co-efficient of determination $R^2 = 2.8\%$). Some branches produced clusters of branches rather than just a single shoot at one location. Although 1 cluster was taken to be equivalent to 1 shoot for the above analysis, the presence of clusters was also significantly higher when the stubs are longer (Mann-Whitney *U* test: $U=3084$, $P<0.0001$, $n_{nosuccess}=223$, $n_{success}=43$). Longer stubs therefore increase the chance that the branch will respond to cutting by producing new shoots and also increase the

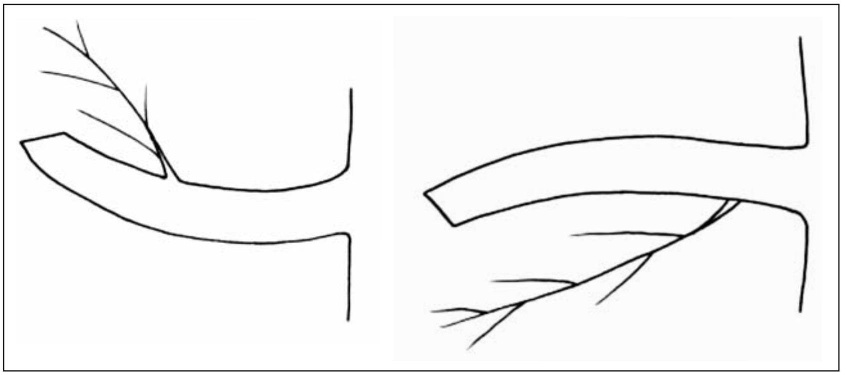

Figure 2. Left: Retained branch is above cut branch – generally good survival. Right: Retained branch is below, die back of cut branch leads to instability of new growth.

chance that a cluster of branches will arise rather than just a single shoot.

Notes on branch structure and position of cut

91 branches from 43 trees showed signs of dieback (or total death) from the cut point. Only 9 branches from 7 trees showed clear signs of healing over. 20 branches from 15 trees showed clear signs of squirrel damage. The consequences of dieback and squirrel damage after cutting means that there can be problems as a result of the cutting, notably when a heavy 'lever arm' is created by a retained branch left underneath the stub. Dieback then makes this growing branch heavier than its support (see Figure 2). A similar problem is sometimes created when the cut is made very close to a retained branch. Good growth from the base of the retained branch may occur but sometimes this situation is detrimental as the decay from the cut extends into the retained branch which keeps on growing and a heavy lever arm develops.

Summary of significant characteristics

Table 10 summarises the aspects examined and their significance. It is reassuring that the tree surgeon does not have a significant impact on the response of the tree and helpful to know that neither the location nor the year in which the tree was cut are important. It is also interesting that the length of new shoots recorded was not significantly related to the date of cutting, thus growth on trees cut longer ago was not significantly greater than in trees cut in very recent years.

Table 10. Summary of results.

Aspect examined	Test used	Significance (*P*)
Tree girth	Spearman's rank correlation coefficient	>0.87
Tree health (of old growth)	Spearman's rank correlation coefficient	>0.24
Amount of canopy removed in restoration	Spearman's rank correlation coefficient	>0.17
Climbing spikes used	Mann-Whitney U	>0.28
Jagged cuts & tears left	Mann-Whitney U	>0.27
Trees cut in 1950s	Mann-Whitney U	<0.009*
The person doing the restoration cutting	Kruskal-Wallis	>0.561
Location of the tree	Kruskal-Wallis	>0.78
Year that it was restoration cut	Kruskal-Wallis	>0.35
Stub length and chance of new shoots	Mann-Whitney U	0.01*
Stub length and number of new shoots	Spearman's rank correlation coefficient	0.007*
Stub length and presence of clusters of shoots	Mann-Whitney U	<0.0001*
Stub diameter and chance of new shoots	Mann-Whitney U	0.138
Stub diameter and number of new shoots	Mann-Whitney U	0.66
Stub diameter and presence of clusters of shoots	Spearman's rank correlation coefficient	0.11
Distance down stub that new shoots arise	Spearman's rank correlation coefficient	0.04*
Stub length and date of cutting	Spearman's rank correlation coefficient	0.09*

*statistically significant <0.05

Table 11. Summary of significant results from all previous studies.

Aspect	Site	Species	Study	Comments
Frequency of cutting or length of lapse				
Branches cut on trees previously cut in 1950s are more likely to produce new shoots than those not cut in 1950s.	Burnham Beeches	Beech	This study	
Cut trees grow better than uncut trees (young & old pollards).	Burnham Beeches	Beech	Frater 1995	
Stub length				
The longer the stub the greater the chance that a new shoot will grow.	Burnham Beeches	Beech	This study	
The longer the stub the further down it new shoots arise.	Burnham Beeches	Beech	This study	
The longer the stub the more new shoots likely to arise.	Burnham Beeches	Beech	Pfetscher & Denne 1995	Some trees erroneously included in analysis.*
The longer the stub the greater the chance that a cluster of branches will arise.	Burnham Beeches	Beech	This study	
The longer the stub the greater the mean diameter of new shoots.	Burnham Beeches	Beech	Pfetscher & Denne 1995	Some trees erroneously included in analysis.*
The longer the stub the greater the total regrowth.	Burnham Beeches	Beech	Pfetscher & Denne 1995	Some trees erroneously included in analysis.*
Stub diameter				
The larger the stub diameter the further away from the cut the new shoots arise.	Burnham Beeches	Beech	Frater 1995	On newly created pollards.
The greater the stub diameter the more shoots per cut.	Savernake	Beech	Pfetscher & Denne 1995	n = 8 trees, one very vigorous.
Amount of canopy removed				
The more cut branches on the tree the more new shoots per cut.	Savernake	Beech	Pfetscher & Denne 1995	n = 8 trees, one very vigorous.
Tree location				
Significant difference in tree survival after cutting depending on location within the forest.	Epping Forest	Beech	Dagley & Burman 1996	Tested but not significant in current study.
Bolling size and condition				
Trees with larger bollings responded by stronger branch growth.	Knebworth	Hornbeam	Warrington & Brookes 1998	V. large sample size (n = 500)
Trees with loose bark responded less well.	Knebworth	Hornbeam	Warrington & Brookes 1998	V. large sample size (n = 500)
Trees with bollings that were not ‘whole’ responded less well.	Knebworth	Hornbeam	Warrington & Brookes 1998	V. large sample size (n = 500)
Health of tree (measured as canopy characteristics)				
Health of new growth after cutting is better than the retained growth.	Burnham Beeches	Beech	Read 2006	Many trees were same as those in this study.

*See introduction for details

Discussion

The beech pollards have generally not responded by growing many new shoots as a direct result of the cutting, however some have new shoots and the retained branches are generally growing well; the health of the trees, determined by aspects of branch structure, is also significantly better after cutting. The health of new growth on the pollards is generally better than that on uncut maiden trees. A major impact of cutting is also to improve stability. Although a small number of trees have died the mortality rate is now lower than prior to the start of the restoration work giving hope that it is helping the trees survive better. If the trees were not cut the loss through catastrophic failure of branches and trunk due to the increased weight on the bolling would lead to a greater mortality rate. Restoration work is acting in a rejuvenating way, like pollarding, so that the death of the tree simply through 'old age', and being unable to put on a complete ring of wood across the whole tree, becomes less likely.

The death rate between the first two tree surveys in 1990 and 1999 was 8.5 trees per year. Between 1999 and 2007 the death rate was 6.4 trees per year suggesting that the death rate slowed as a result of the active management work. It is unlikely that the change in death rate was caused by the death of only the poorest trees.

For a species not renowned for epicormic growth it seems that Burnham Beeches has a relatively large number of trees with at least some. Damage from grey squirrels may promote epicormic growth, or the genetic composition of the trees may be different to those seen elsewhere in Britain.

Table 11 summarises all the significant findings from various studies, including work on other tree species from other sites, on the responses of trees to restoration pollarding.

The current study has confirmed previous suggestions that the length of the stub is important and that longer stubs give the best chance for more new branches to grow after cutting. This technique was advocated in an early paper on restoration pollarding for oak and hornbeam (Mitchell, 1989). It has been proposed that dormant buds may have a better chance of growing through the younger, thinner bark that is found towards the ends of the stubs (Mitchell,1989). The other relatively consistent result is that the longer the stub, the further down the length the new shoots occur. A minority of trees produce new adventitious growth from the cut surface which should not be expected to be a regular response in beech unless the tree shows clear indications of it from previous work. Thus methods to promote the growth of dormant buds and techniques to encourage the growth of retained branches are the most important; especially as the long term survival of the epicormic growth from the cut surfaces is yet to be proven.

One key aspect that this study has not confirmed is that the diameter of the branch is important. Cutting larger branches may have a long term impact on the stability of the tree because the wood decays and produces larger hollows but in the short term they are no less likely to produce new branches than smaller ones.

When working on beech trees, techniques should be used to encourage growth from the cut stems where possible (i.e. leaving long stubs). Another key aim should be to shape the tree such that retained branches can put on new growth. This is because a relatively low number of branches produce new shoots after cutting. Thus retained branches are important to maintain stability and encourage the tree to produce better growth lower in the crown for long term continuity. Leaving long stubs when cutting is contrary to the British standard practice which recommends cutting back to the branch collar. The difference when dealing with ancient pollards is that wound sizes may be too large for the trees to callous over before decay sets in. Leaving a long stub may reduce the chance of decay travelling into the main stem or other major branches. The combination of the fact that a greater number of shoots arise from the stub as well as the cone of decay not reaching into other major limbs makes this type of cutting more appropriate when restoring ancient (particularly pollarded) trees. Anecdotally it appears that where ever possible the retained branch on a stub should be upper most, not underneath and that cutting close to a retained branch should be avoided, thus making a longer stub.

Making coronet cuts, jagged cut surfaces and tears may be desirable for other reasons (see Fay, 2003 for more information) but evidence from the current study suggests that these methods may not be particularly important in encouraging regrowth from restoration cut beech pollards. These techniques may yet prove important on younger trees or those of other species. Most such techniques have only been tried in recent years so it is possible that more time is needed to see clear responses. The principle of trying to mimic natural breaks when cutting limbs stems from anecdotal experience following the 1987 storms. Those trees (in particular beech) where large limbs had been lost produced more new shoots from around the broken surface and below than if those limbs were ‘tidied up’.

Cutting large diameter branches causes a much larger cone of drying out within the tree and it is generally recommended that this is avoided. However, some very large diameter branches have been cut at Burnham Beeches and this study has not found any particular cause for concern about these in the short term (providing long stubs are retained) and there is no indication here that the largest diameter stubs are responding any less well than smaller ones. However, the chances of the trees healing these large wounds is negligible, especially as the sapwood in beech does not live longer than 30 years (Lonsdale, pers comm), a younger age than many of the branches cut. Thus the long term implications of cutting such large branches will need to be carefully assessed in the future.

Trees cut after a shorter lapse in cutting appear to respond better, this is perhaps fundamental to the practice of pollarding (although cutting trees every year is not recommended). Once new pollards are started it is important that they be continued. Long lapses mean that the trees are less likely to respond and this is true for the old pollards as well. The higher success rate of trees last cut in the 1950s is also interesting. Of course this study does not record how many trees were cut during this period and died; clearly only the survivors are still alive to be studied. However this confirms the statement in Read (2000) that the length of time since a tree was last cut can be important.

Weather conditions at Burnham Beeches and predictions of the impacts of climate change are of concern. The responses of trees cut during and after periods of low rainfall need to be explored further, including an exploration of the physiological response of a tree in drought conditions to a reduced canopy. General studies on how beech trees respond to drought may be helpful when considering the responses of trees to pollarding. Further research on the impact of reducing canopy size on transpiration rates and therefore tree response to reduction of water is recommended.

Conclusions

There is now some confidence that cutting is a suitable treatment for these trees; it should keep them alive for longer and the new growth is of better health than the retained growth. Loss of trees not undergoing restoration pollarding appears to be higher and they are poorer in overall health. The challenge is to continue to manage these trees, promoting good quality and securely attached branches and working to stabilise the trees, reducing their centres of gravity and the lever arm effect of longer branches. More work is needed to evaluate what encourages extension growth after cutting since this forms the major part of new tree growth. Further study is also essential to evaluate other cutting techniques such as retrenchment pruning (Fay, 2003) which aims to encourage the tree to produce a lower crown via removal of very small amounts essentially managing the hormone balance and natural fracture techniques (here equivalent to the tip pruning which has only be carried out on one tree at Burnham Beeches). In some cases the retrenchment pruning is showing very good results whilst in others (even between trees of the same species) there has been no increase in the thickness of the lower crown.

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