Burnham Beeches NNR

Population Analysis (*Fagus sylvatica* and *Quercus* sp.) 2010 & 2012

On behalf of

The Corporation of London
Helen Read - Conservation Officer
Open Spaces Department
Burnham Beeches NNR & Stoke Common
Hawthorn Lane
Farnham Common
Buckinghamshire SL2 3TE

Prepared by
Vikki Bengtsson *(Ecologist)*, Ola Bengtsson *(Ecologist)*
Reviewed by
Paul Muir *(Arboricultural Consultant)*

March 2013

Summary

The aim of this analysis is to provide an assessment of the population structure of *Fagus sylvatica* and *Quercus* sp. trees within Burnham Beeches. An understanding of the population structure is required in order to understand future management requirements and to secure the future generation of ancient trees and the habitats they provide.

Burnham Beeches is a woodland of approximately 220ha. A total of 187 plots from three different areas were surveyed for the beech and oak population covering an area of 204ha. All trees over 5cm in girth were measured and given a subjective age class. In addition a percentage cover of regeneration was recorded for both species in Area 1 and Area 2. In Area 3, number of seedlings and saplings were recorded. There was a strong correlation between girth and subjective age class. Oak regeneration was only recorded from Area 3 in 11% of the plots. Beech was found to be regenerating in 58% of the plots in Area 1 and 2, and 18% in Area 3. The beech tree data was analysed using subjective age class, girth class and calculated age classes.

The beech population is generally weighted towards the young and semi-mature age classes. There does not, however, appear to be a significant age gap in the population other than perhaps within the next 50 years, which is how long it is likely to take for the existing mature beech trees to become trees of nature conservation value. This gap suggests that there was a period that ended around a hundred years ago, when recruitment of beech was poor. This is probably related to grazing, when grazing stopped, recruitment improved and reflects the population structure we see today.

The oak population is heavily weighted towards the mature age class in Area 1 and 2, which suggests that there has been very little regeneration over a substantial period of time, (possibly over at least the last century) in these areas, leaving a significant gap in the population. In Area 3 the situation is brighter, however favouring oak needs to be a key management strategy if species associated with ancient oak trees are to be sustained at Burnham Beeches.

Models of the population of beech trees suggest that the mortality rate of the ancient pollarded beech trees needs to be reduced from 1.7% to 1.3% (preferably even less). This will help reduce the likelihood of a gap in the population and give time for the mature trees to develop veteran habitat features. An aim should also be to keep the mortality rate of the mature beech trees to 2% or less. Any work veteranising or pollarding trees within the beech population should be aimed primarily at the young and semi-mature age classes.

It would be useful to set up a monitoring programme to establish the actual mortality rates for the different age classes of trees and to find out at what age maidens, pollards and veteranised trees become interesting for wildlife. It would also be useful to undertake a further study of beech and oak trees to determine a more accurate picture of the relationship between girth and age at the site.

1.0 Introduction

1.1 Instruction

1.1.1 This analysis is the subsequent stage to a recent project involving the collection of data related to the tree population of oak and beech undertaken in 2009/2010. This first analysis was complemented by further field work in 2012 in a third area of Burnham Beeches resulting in the entire site being studied.

1.1.2 An official order from The Corporation of London was provided to Treework Environmental Practice on 16th July 2010. This was complemented by an additional order to Pro Natura in April 2012.

1.1.3 Discussions regarding analysis of the original data took place in the summer and autumn of 2010. Pro Natura, as subcontractors to Treework Environmental Practice, undertook to carry out the analysis during the winter of 2010/2011. Vikki Bengtsson, Ola Bengtsson and Heidi Paltto undertook the analysis on the instruction of Paul Muir (Treework Environmental Practice). Pro Natura undertook the additional analysis in 2012/2013.

1.2 Scope

1.2.1 The purpose of the current analysis is to provide an understanding and assessment of the population structure of *Fagus sylvatica* and *Quercus* sp. trees within Burnham Beeches. An understanding of the population structure is required in order to understand future management requirements and to secure the future generation of ancient trees and the saproxylic habitats they provide.

1.2.2 Information regarding the numbers of trees within each age or life-stage category was analysed in order to determine whether there are any gaps in the population structure and thus to inform management decisions regarding operations that may be required to address any gaps. An over-riding management objective is assumed to be to ensure that sufficient transition / recruitment veteran trees are available within the population of *Fagus sylvatica* and *Quercus sp.* at Burnham Beeches to give confidence that these will adequately replace the current population of ancient pollards as these are lost. Data for other tree species has not been collected. For more details of the background to this project and the method for the data collection, see Muir, 2009 and sections 2.1 and 2.2.

2.0 Method

2.1 Introduction

2.1.1 Burnham Beeches is a diverse woodland of approximately 220ha. The site was first divided into two relatively homogeneous areas containing trees with relatively similar characteristics covering an area of approximately 150ha. Area 1 is described as old wood pasture with old pollards, in-filled with secondary woodland and new pollards. Area 2 is described as ancient woodland (not wood pasture), former coppices, both outgrown trees and maiden trees. Data was collected from Areas 1 & 2 in the first survey in 2010. The complementary data collection took place in Area 3 (54ha) in 2012 which covers the areas of heathland and mire. This third area has a much lower tree cover, but was thought to contain more young oak and which was why this area was subsequently surveyed in 2012.

2.1.2 The field work and data collection was carried out according to the method and training course provided by Paul Muir, Treework Environmental Practice with some minor modifications as described below. See Muir, (2009) for a full and detailed description of the background and description of the method.

2.2 Amendments to and brief description of the data collection method

2.2.1 The type of sample plots chosen were circular areas of 5m radius ($78.5m^2$) centred about a randomly generated grid reference (easting and northing) point. A map showing the location of each of the plots and the sample areas is presented in Appendix A. The sample plot grid references were generated randomly using an excel spreadsheet (090507 Random Sample Plot Generator.xls). These are listed in Appendix B. The sample plot centres were located on site with the use of a hand-held GPS device. The sample plot centres were marked with a survey pole or cane placed at the appropriate grid reference.

2.2.2 Data was collected from a total of 189 plots, 40 from Area 1, 40 from Area 2 and 109 from Area 3. The data was entered into a database.

2.2.3 Vitality was only recorded if it was considered to be "poor" in the first survey (Area 1 & 2). When Area 3 was surveyed, vitality was recorded for all trees on a scale of 1 to 3 (where 1 is good vitality, 2 is poor vitality and 3 is dead).

2.2.4 Multi-stemmed trees were assessed to be those which have a natural multi-stemmed form rather than those which had been coppiced.

2.2.5 Squirrel damage was not recorded consistently.

2.2.6 Data for the tagged ancient trees and dead ancient trees is available for the population of trees across the whole site (although in principle only found in Area 1 and very few in Area 3). Consequently these were not recorded if found within a sample plot.

2.2.7 Trees with a girth larger than 5cm (rather than 5cm in diameter according to the method) and without any height restriction (4m was specified in the original method) were recorded as young trees rather than natural regeneration. Trees smaller than 5cms in girth were recorded as regeneration in the survey of Area 1 & Area 2. Some additional samples were collected in order to establish a correlation between percentage cover and number of saplings. This was only done in a few squares in areas considered to be representative of locations where there is regeneration (although this proved difficult to correlate, see also section 3.2.2).

2.2.8 When Area 3 was surveyed more specific data was collected in relation to seedlings and saplings. The total number of seedlings was recorded and a seedling for this study was defined as a tree up to and including two years of age. The total number of saplings was also recorded and a sapling for this study was defined as a tree over two years of age and up to 5cms in girth. The method was modified to allow potential analysis of the seedling/sapling data, which had proven difficult with a percentage cover bands.

2.2.9 The amount of natural regeneration (Area 1 & 2, seedlings and saplings for Area 3), and the following data for each tree within the sample plot was collected:

- Species: Beech, Oak
- Age Class: Seedlings (number Area 3 only), Saplings (number Area 3 only), Young, Semi Mature, Mature (no other age classes were recorded)
- Tree Form: Blank (single stemmed maidens), Pollard, Coppice, Multi-stemmed
- Girth: Measurement of stem circumference in cm at 1.5m above ground level
- Basal Girth: Measurement of circumference of base just above buttress swelling in cm (Multi-stemmed and Coppice trees only)
- Vitality: Low (when applicable for Areas 1 & 2), 1, 2 or 3 for Area 3.
- Veteran Features: High, Moderate, Low, None (Semi-mature, Mature trees only)
- Natural regeneration (Areas 1 & 2 only) as percentage bands as follows 0-10% (10), 11-25% (25), 26-50% (50), 51-75% (75), 76-100% (100).

2.3 Analysis

2.3.1 A t-test was carried out to see if there was a significant difference in the data from Area 1 and Area 2 in order to establish whether the data could be analysed as one data set or whether it should be analysed as two separate data sets. The data set from Area 3 was analysed in the same way to see if the data sets could be combined.

2.3.2 Beech data and oak data were analysed separately. The coppice and multi-stemmed trees were included in the analysis as a single stem (the number of individual stems associated with each stool/tree was not recorded).

2.3.3 The data was analysed according to subjective age class (see Muir, 2009 for more details) and actual girth class. The difference in girth was tested with two-sided permutation tests for independent samples with the statistical software SPSS 17.0 (Polar Engineering and Consulting 2008).

2.3.4 An attempt was made to estimate the age of each beech tree using John White's method (1998) and data from a few beech trees where rings have been counted and measured. Several different figures were tested from John White's paper and compared with the data from the trees which have had ring counts. The formula using a core age of 120 years and an annual increment of 2mm was found to have the best fit (the calculated age according to White, 1998 which matched most closely the trees where the age had been calculated with ring counts) and was used for the various analyses. This was not done for the oak data, because there are no actual ring counts available.

2.3.5 Using the *calculated* ages a mean age per *subjective* age class was calculated along with the range for each class for beech.

2.3.6 Actual annual mortality rates for the ancient pollard population (oak and beech separately) were calculated over different time periods using data collected in 2007 (Read *et al*, 2007). These rates were used as a basis for testing several scenarios for the different age classes of beech trees to see where any potential gaps may occur in the future and what mortality rate is sustainable. This latter test was not possible for oak due to the lack of tree ring data.

2.3.7 For the analysis of the natural regeneration data from Area 1 & Area 2, the upper percentage for each percentage band was used to calculate a mean percentage cover for the plots (i.e. 25% was used for the band 11 – 25%). This data had to be presented separately because of the difference in the measurements (percentage cover as opposed to actual numbers of trees). From all three areas, the percentage of plots with regeneration has been presented.

2.3.8 A model based on different scenarios to try and plot the development of the beech population at Burnham Beeches was developed. A presentation of the situation for the mature oaks over time was also presented. For more details of this see section 3.4.

3.0 Results

3.1 Results for the whole dataset

3.1.1 A t-test which was carried out to compare the data collected from Area 1 and Area 2 for beech and oak and all age classes showed that there was no significant difference between the two areas (95% confidence level[1]). For oak, there were too few records for trees in the age classes other than mature to make it possible to do a t-test for Area 1 and Area 2.

[1] **Confidence interval** - A calculated interval around the mean value where the true mean will lie with a specified likelihood. This likelihood is commonly set to 95% i.e. the true mean of the population will be within the interval shown with a 95% certainty.

Tree species and age class	*p* values[2] (n = 40)
Young beech	0.29
Semi-mature beech	0.06
Mature beech	0.91
Mature oak	0.29

Table 1 – *p values from the t-test to compare data from Area 1 and Area 2. Within the oak population only mature oaks were tested and thus there is only a p value for mature oaks. There was no significant difference between Area 1 and Area 2 with a 95% confidence level.*

3.1.2 As a result of the t-test analysis the data from Area 1 and Area 2 were thus combined and analysed as a single data set. This means that there are a greater number of samples (n = 40 + 40) increasing the statistical precision.

3.1.3 Following the field work in 2012, another t-test was carried out to compare the combined data from Area 1 and 2 for beech and oak with the data collected from Area 3. The test showed that there is a significant difference between the two areas (95% confidence level[3]). The two datasets were thus kept separate in the subsequent analyses.

Tree species and age class	*p* values
Young beech	0.003
Semi-mature beech	0.0004
Mature beech	0.00001
Young oak	0.00001
Semi-mature oak	0.00001
Mature oak	0.16

Table 2 – *p values from the t-test of the number of trees in respective subjective age classes per plot. The values from Area 1 and 2 (n = 80) combined were compared with the values from Area 3 (n = 109). There was a significant difference between the two areas with a 95% confidence level.*

3.1.4 There was a strong correlation between measured girth and subjective age class. Only the data from Area 1 and 2 was used in this analysis. The median[4] girth of young beech trees was 10cm, the median girth of semi-mature beech trees was 29cm; and the median girth of mature beech trees was 138cm (Figure 1). The

2 **P-value** the p-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true. One often "rejects the null hypothesis" when the p-value is less than 0.05 or 0.01 corresponding respectively to a 5% or 1% chance of rejecting the null hypothesis when it is true. If you have a p-value greater than 0.05 in this analysis then you can assume that there is no statistical difference between the two datasets compared.

3 **Confidence interval** - A calculated interval around the mean value where the true mean will lie with a specified likelihood. This likelihood is commonly set to 95% i.e. the true mean of the population will be within the interval shown with a 95% certainty.

4 **Median** value gives a more correct picture of the truth when the values in the population are asymmetrically distributed and is used when analysing for any correlations.

difference in girth differed significantly between mature and semi-mature trees ($p<0.001$), and between semi-mature and young trees ($p<0.001$).

3.1.5 Veteran features were recorded for semi-mature and mature trees. The numbers of trees which had veteran features were so few (20 in total) that it has not been possible to do any form of correlation analysis on this data. This is perhaps a reflection on the fact that there seems to have been a period that ended around a hundred years ago, when recruitment of beech was poor. This is probably related to grazing, when grazing stopped, recruitment improved and reflects the population structure we see today. Work by Fritz et al, 2008 showed that beech trees of more than 180 years old were more likely to have red data book lichens and mosses. There is very little other research data in this area, regarding the age at which beech trees develop saproxylic habitats and become interesting for nature conservation.

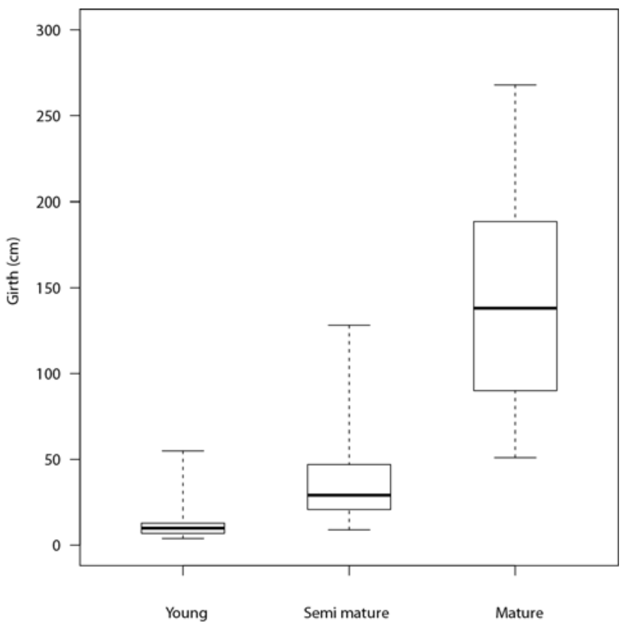

Figure 1 – *Girth of beech trees for young (n=211 trees), semi mature (n=110 trees) and mature stems (n=55 trees) in Burnham beeches (the line in the box shows the median value; the box includes values between the 25% and 75% quantiles, and the bars show the minimum and maximum values). The median girth differs significantly between the three groups of trees (between mature and semi-mature trees: $p<0.001$; between semi-mature and young trees: $p<0.001$).*

3.2 Results for beech

3.2.1 Beech regeneration was recorded from 55% of all plots from Area 1 and 60% of all plots from Area 2 (58% combined). The mean percentage cover of beech regeneration in those plots which contained regeneration was 16% (based on the upper level in the bands of percentage cover) for Area 1 and Area 2 combined. Due to the fact that these figures were an estimate it was not considered useful to convert these to a figure reflecting the "middle" of each band, rather to stick to the upper limit of the percentage cover band actually recorded. This does however mean that these results are likely to represent an overestimate of the cover of regeneration. The important figure here however, is that regeneration occurred in 58% of all plots from Area 1 and 2 combined.

3.2.2 Data was collected slightly differently from Area 3 (which may allow further analysis at a later date). However it is possible to compare the percentage of plots which have regeneration and for Area 3 this figure was 18% (20 out of 109 plots).

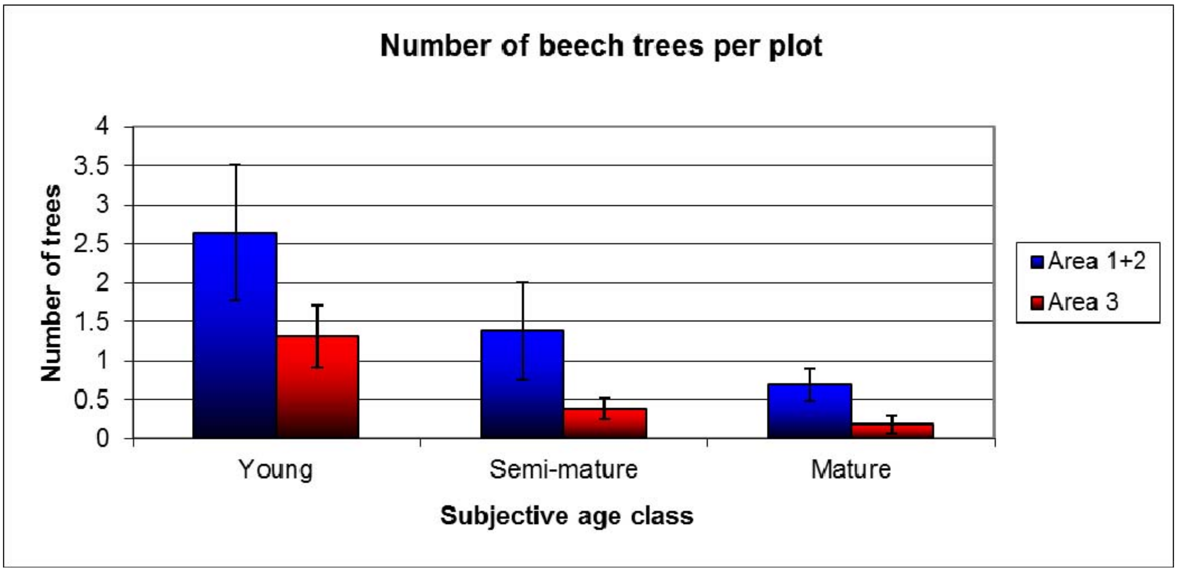

Figure 2 – *Mean number of beech trees per plot in the subjective age classes with confidence intervals (95%) for all three areas.*

3.2.3 Figure 2 shows the mean number of beech trees per plot in the young, semi-mature and mature subjective age classes with confidence intervals. The confidence interval at plot level also gives an indication of the accuracy of the data set based on the number of sample plots. This population structure is probably what could be expected when regular regeneration has occurred over a relatively long period of time.

3.2.4 The mean number of beech trees in the sample plots for each subjective age class was scaled up to give an understanding of the resource for the whole sample area in tables 3 and 4 (Area 1 and 2 – 150ha, Area 3 – 54ha). The confidence interval is a reflection on the variation of the data at plot level. If this value was scaled up in the same way it may lead to an overestimation of the variation across the whole sample area. The ratio confidence interval/mean value will however give a rough idea of the magnitude of the variation and the interval at either side of the mean value, if scaled up, should be seen as a worst case scenario. This data shows that for beech, Areas 1 and 2 are much more important.

	Young	Semi-mature	Mature
Calculated total number of beech (150 ha) based on mean values from sample plots	50450	26370	13200
Confidence interval/mean (%) at plot level	33	45	30

Table 3 – *The calculated number of beech trees in each subjective age class based on mean values from the sample plots (combined Area 1 and Area 2).*

	Young	Semi-mature	Mature
Calculated additional number of beech (54 ha) based on mean values from sample plots	9071	2754	1246
Confidence interval/mean (%) at plot level	30	35	61

Table 4 – *The calculated number of beech trees in each subjective age class based on mean values from the sample plots (Area 3 only).*

3.2.5 The beech trees (from Area 1 and 2) were divided up into 20cm girth classes and this data is presented in figure 3 for both areas. This shows that there are a lot more trees in the smallest girth bracket and gives a slightly different picture compared to when only three subjective age classes were used.

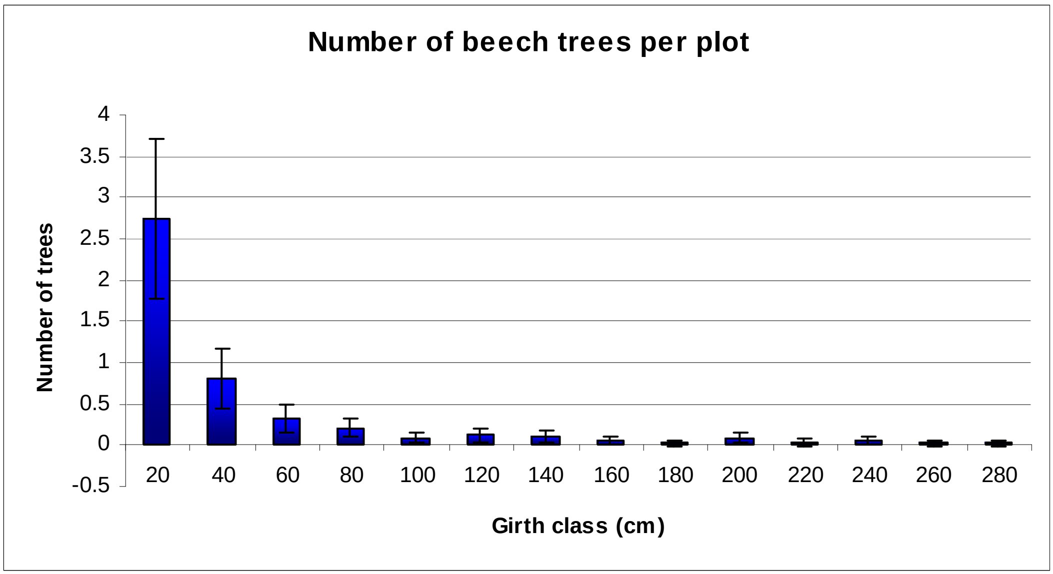

Figure 3 – *Mean number of beech trees per plot (from Area 1 and 2) divided up into 20cm girth classes with confidence intervals.*

3.2.6 There are a small number of beech trees which have had the annual rings counted from Burnham Beeches. Unfortunately the trees have grown under different conditions, some with richer soils, others more exposed and on poorer soils. This means that there is variation in the annual ring counts. In addition the point at which beech trees reach maturity at Burnham Beeches is also unknown (so called Core Age according to White, 1998).

3.2.7 It was felt however, that it was worth attempting to age the beech trees measured in this study to get an idea of the spread of the population and to see if this presented any other variation in the population structure. Generally speaking the annual increment for the beech trees measured from Burnham Beeches is 1.5 – 2.0mm. The growing conditions for these trees could be described either as in woodland or on poor soils (or both!) according to the categories referenced in White, (1998). Given the unknown core age for these trees, the following scenarios were considered: Core ages of 60 and 120 years and annual increments of between 1.5mm and 2.0mm The combination of a core age of 120 years and an annual increment of 2mm gave the "best fit" when compared with the trees for which actual age and girth data was available (Appendix D). This was used as the basis for the calculations in section 3.4. Only data from Area 1 and 2 for beech was used in these analyses due to the fact that the amount of beech from Area 3 was only a small proportion and the fact that the data could not be combined statistically.

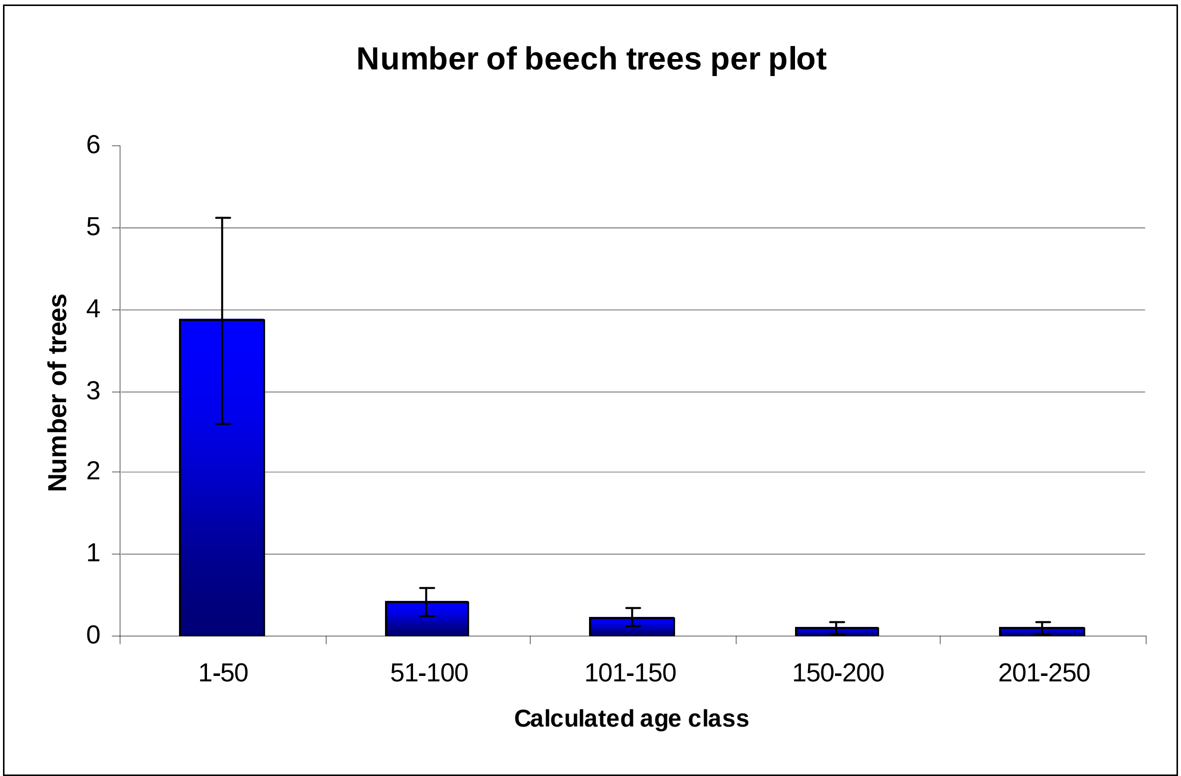

Figure 4 – *Mean number of beech trees per plot (from Area 1 and 2) divided up into age classes of fifty years (Core age 120 years, CAI – 2mm, White, 1998) with confidence intervals.*

3.2.8 Figure 4 shows that the majority of trees in the plots from Area 1 and 2 are in the age class 1 to 50 years of age. These trees are not likely to begin developing habitat for at least another 100 years (Fritz *et al*. 2008). This picture shows a less even distribution of trees in the population.

3.2.9 The beech population is generally weighted towards the younger age groups i.e. less than one hundred years (reflecting the fact that few trees had developed veteran features). There does not, however, appear to be a significant age gap in the population other than perhaps within the next 50 years, which is how long it is likely to take for the existing mature beech trees to become trees of nature conservation value. This gap suggests that there was a period that ended around a hundred years ago, when recruitment of beech was poor. This is probably related to grazing, when grazing stopped, recruitment improved and reflects the population structure we see today.

3.2.10 The calculated ages for each tree have been used in conjunction with the subjective age class to calculate the mean tree age and the span of years within each subjective age class. It is hoped that by using both sets of data the uncertainties associated with the calculated ages can be minimised. See more section 3.4.

3.3 Results for oak

3.3.1 Oak regeneration was not recorded from a single plot in either Area 1 or Area 2. It was however recorded from 11% of the plots in Area 3 (only saplings, no seedlings were recorded).

3.3.2 Figure 5 shows the mean number of oak trees per plot in the young, semi-mature and mature subjective age classes with 95% confidence intervals. The confidence interval at plot level also gives an indication of the accuracy of the data set based on the number of sample plots. This picture shows an opposite pattern to that found for beech in Areas 1 and 2. It suggests that there has been very little oak regeneration over a substantial period of time, possibly at least a century in Areas 1 and 2. It also shows that there is a gap in the population structure between young and mature trees. The picture in Area 3 is quite different and shows a population structure that is more sustainable, although without aging data, it is more difficult to interpret.

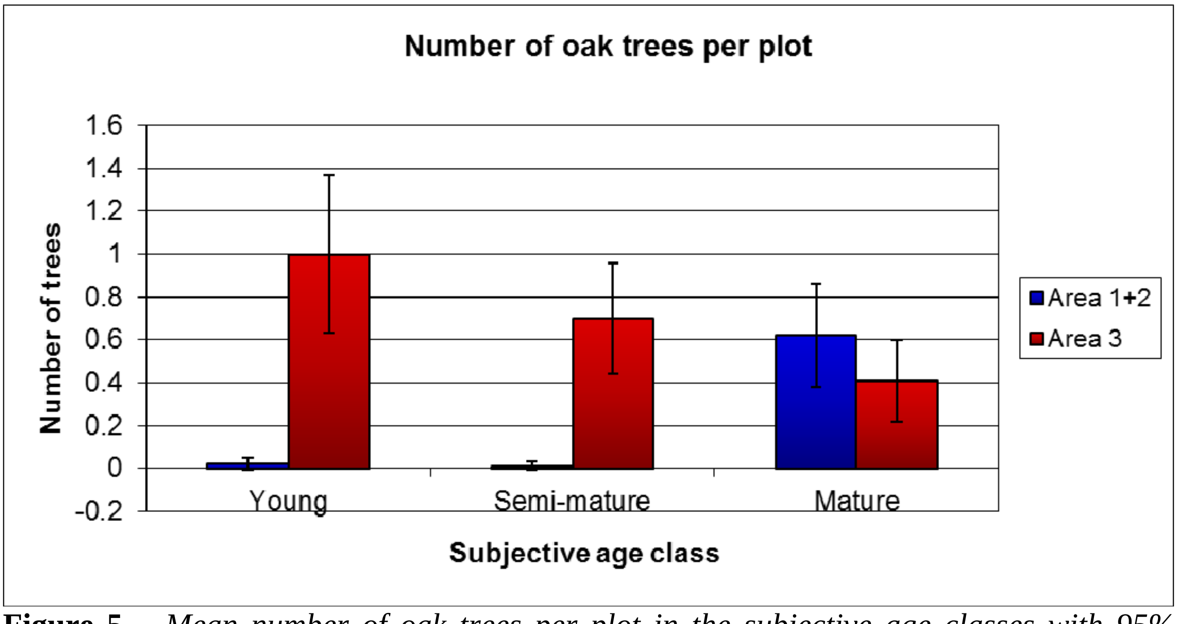

Figure 5 – *Mean number of oak trees per plot in the subjective age classes with 95% confidence intervals for all three areas.*

3.3.3 The mean number of oak trees in the sample plots for each subjective age class was scaled up to give an understanding of the resource of the whole sample area in tables 5 and 6 (Area 1 and 2 – 150ha, Area 3 – 54ha). The confidence interval is a reflection on the variation of the data at plot level. If this value was scaled up in the same way it may lead to an overestimation of the variation across the whole sample area. The ratio confidence interval/mean value will, however give a rough idea of the magnitude of the variation and the interval at either side of the mean value, if scaled up, should be seen as a worst case scenario. This data suggests that for mature oak, Areas 1, 2 and 3 are important, whereas for the young and semi-mature oaks, Area 3 is likely crucial for the long term survival of oak.

3.3.4 As very few oaks in the age classes young and semi-mature were recorded from Areas 1 and 2, the mean values scaled up to site level suffer from very poor statistical precision (indicated by a confidence level/mean ratio of + or – 150 or 200%).

	Young	Semi-mature	Mature
Calculated total number of oaks (150 ha) based on mean values	382	191	11847
Confidence interval/mean (%) at plot level	150	200	39

Table 5 – *The calculated number of oak trees in each subjective age class based on mean values from the sample plots (combined Area 1 and Area 2).*

	Young	Semi-mature	Mature
Calculated number of oak in area 3 (54 ha) based on mean values from sample plots	6924	4848	2837
Confidence interval/mean (%) at plot level	37	37	46

Table 6 – *The calculated number of oak trees in each subjective age class based on mean values from the sample plots (Area 3 only).*

3.3.5 No ring count data is available for oak at Burnham Beeches which meant that undertaking an estimate of calculated age would have resulted in too much uncertainty.

3.4 Population modelling and mortality rates

3.4.1 The ancient pollards at Burnham Beeches have been surveyed several times over the last 20 years. They were first surveyed and tagged in 1989. Since then a survey of the whole population took place again in 1999 and in 2007. This gives a unique opportunity to be able to calculate actual mortality rates for beech and for oak.

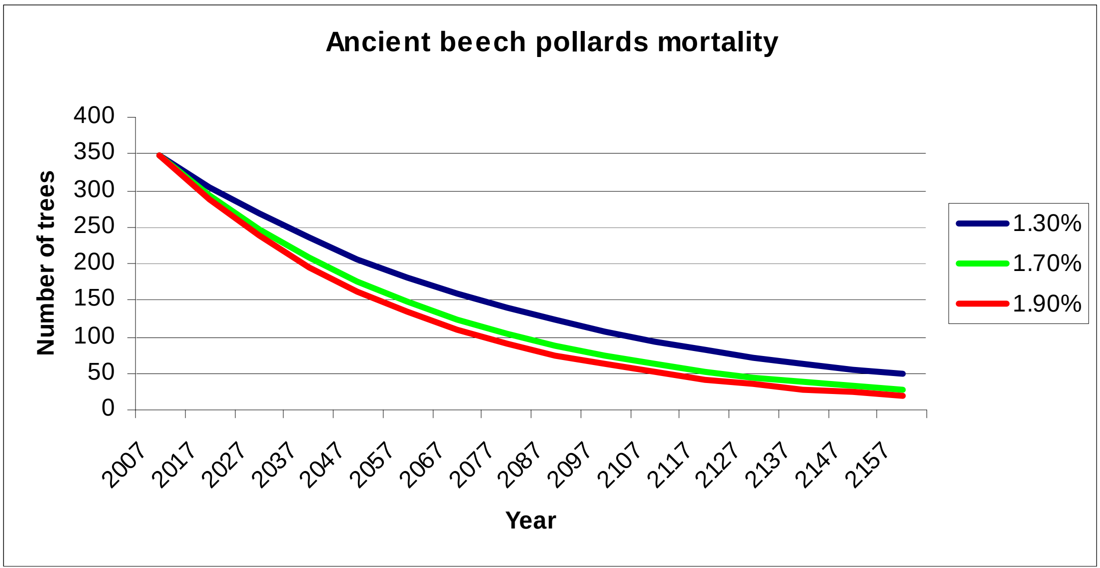

Figure 6 – *Changes in the number of living ancient beech pollards based on three different mortality rates (1.9%, 1.7% and 1.3%).*

3.4.2 Data from Read, *et al.* (2007) was used to calculate the mortality rates for beech and oak. For beech the mortality rate between 1989 and 1999 was 1.91%. Between 2000 and 2007 the mortality rate had decreased to 1.69%. The mortality rates were calculated using an exponential formula (see Appendix C). If the mortality rate remains the same as it was from the period 1999 to 2007, then by 2080 there will be less than 100 ancient pollarded beech trees remaining.

3.4.3 For oak the mortality rate between 1989 and 1999 was 0.35% pa. Between 2000 and 2007 the mortality rate for oak had increased to 1.07% (see Appendix C for formula used for these calculations). If the mortality rate remains the same as it was from the period 1999 to 2007, then by 2080 there will be less than 40 ancient pollarded oak trees remaining.

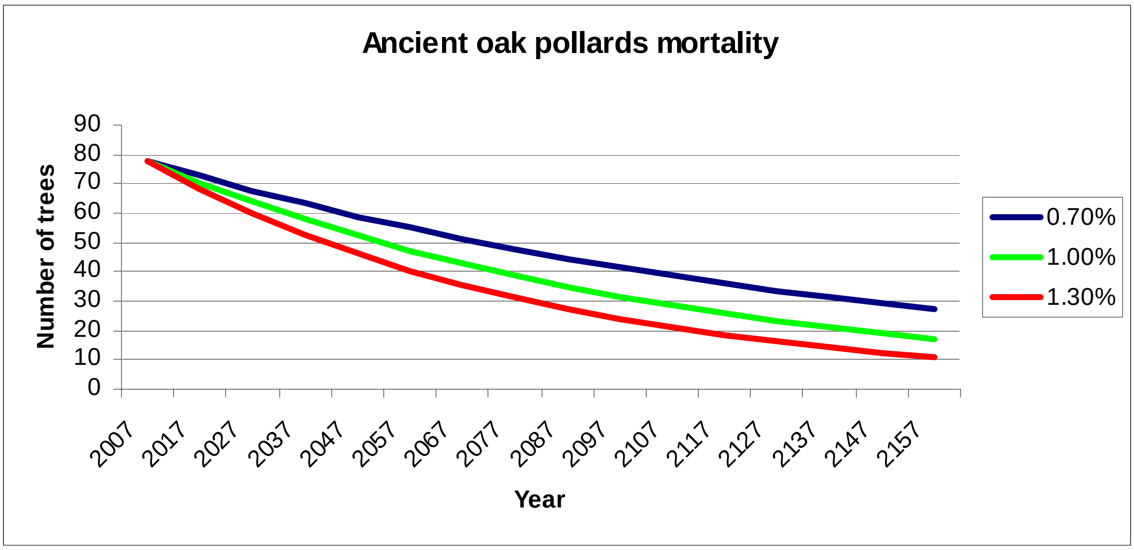

Figure 7 – *Changes in the number of living ancient oak pollards based on three different mortality rates (0.7%, 1.0% and 1.3%).*

3.4.4 In order to get an idea of how the amount of available habitat of conservation interest associated with beech (equivalent to the number of trees over 180 years of age) will vary over time, a three-scenario model was set up. This model stretches over 150 years and only includes mature trees and ancient trees. Trees in the semi-mature age class were, according to their calculated age, to a large extent too young to have any major impact on the situation over the coming 150 years and were therefore excluded.

3.4.5 The following figures and calculations were used as the basis for the purpose of modelling the population of beech trees at Burnham Beeches. Only data from Area 1 and 2 was used:

- Number of ancient beech pollards in 2011 based on the mortality rate being the same between 2007 and 2011 as it was between 1999 and 2007 and survey data from 1989-2007 (325 trees) and assumes no more are found.
- Total number of mature beech trees in Area 1 and 2 based on the calculated mean per plot (approx. 13200 trees)
- Lowest possible number of mature beech trees in Area 1 and 2 based on the calculated confidence interval of 30% at plot level (13200 x 0.7~9200)
- The mean age and age interval for the mature age class using the calculated and subjective age classes (123 years and 73-250 respectively).
- The percentage of trees with a calculated age in the lower half of the mature age class (trees with a calculated age between 73 and 177 years) and the percentage of trees in the upper half of the mature age class (trees with a calculated age between 178-250 years). Approximately two thirds (67%) of all the mature trees belonged to the lower half and one third (33%) to the upper half. To create a "worst case scenario" and to counteract a likely overestimation of trees with the largest girths, the 67% belonging to the lower half were all assumed to be 73 years of age and the remaining 33% were assumed to be 123 years of age.

- The number of mature trees with the assumed age of 73 years was then calculated (6200) along with the number of trees with an assumed age of 123 years (3000).

3.4.6 To make this model work it was important to decide on an age at which a beech tree becomes of nature conservation interest. According to Fritz *et al.* (2008) red data book lichens associated with beech do not occur in any significant numbers until the beech tree has reached an age of 180 years. It is however not known if this is true for other groups of organisms such as fungi or saproxylic invertebrates. It is likely however that older trees will contain a greater proportion of species of conservation interest also from these latter groups. In this model the definition of a beech tree of conservation value was therefore set to 180 years (best available data).

3.4.7 In the model three different scenarios were created. All scenarios had the same number of trees in the first year (6200 mature trees, aged 73 years, 3000 mature trees aged 123 years and 325 ancient beech pollards all more than 180 years of age. In the three scenarios the mortality rates varied but within each scenario it was kept constant for the whole period of 150 years. The most up to date annual mortality rate for the ancient beech pollards is known to be 1.7% (see also figure 6 for how the ancient beech population may change over time based on the different mortality rates). For the mature trees the mortality rate is unknown, which is why we have had to use a model. The different scenarios used were as follows:

- Scenario 1. Mortality rate mature trees 1% annually, ancient beech pollards 1.3% annually.
- Scenario 2. Mortality rate mature trees 2% annually, ancient beech pollards 1.7% annually.
- Scenario 3. Mortality rate mature trees 3% annually, ancient beech pollards 1.9% annually.

3.4.8 For every year the number of trees over 180 years of age was summarised and plotted into a diagram.

3.4.9 This model (just as any model used within ecology!) is based on a number of assumptions and therefore only completely valid if these assumptions are fulfilled. The model should therefore not be seen as a 100% accurate picture of the future but as a rough illustration of what the future may hold. The historical situation may not at all reflect how the population may develop in the future, given climate change, beech tree health and management which are all likely to be different. At best a model can also point out critical factors within a process.

3.4.10 The model indicates that there will be no significant input of new "old" trees within the coming decades and it is therefore crucial to reduce the mortality rate of the ancient beech pollards to a minimum over this period. After 50 to 60 years the model predicts a significant increase in mature trees reaching a phase were they will be of conservation value. Once this phase is reached there seems to be little risk of a shortage of old trees as long as the mortality rate of the mature age class is kept below 2% annually and recruitment of young beech continues.

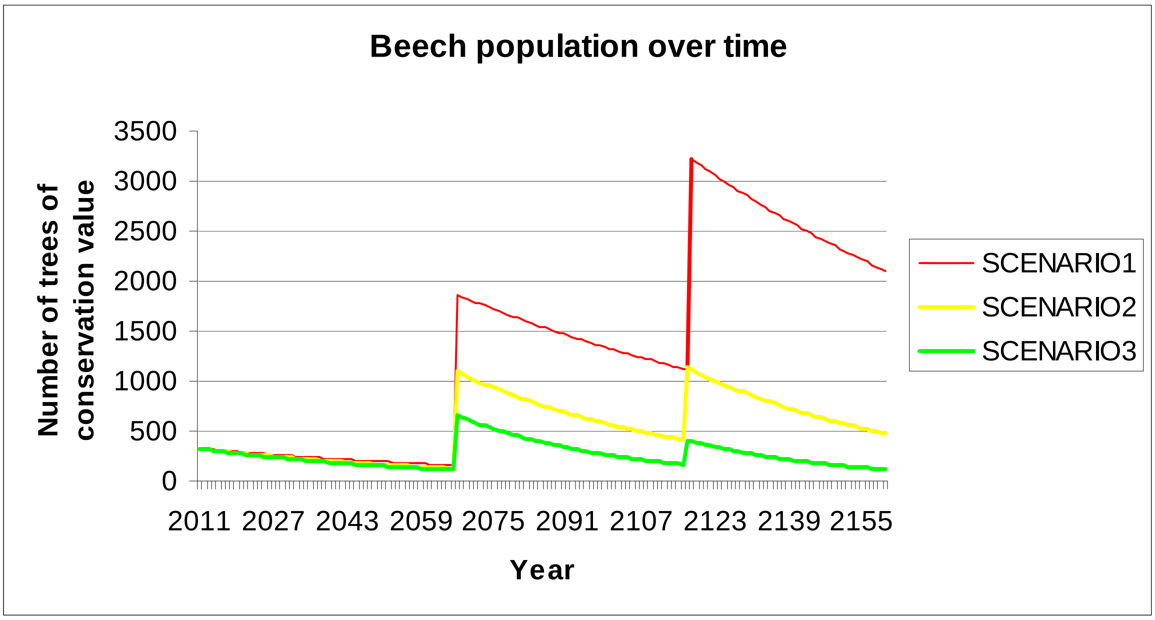

Figure 8 – *Graph showing the number of beech trees of conservation value i.e. over 180 years of age over time with different mortality rates.*

3.4.11 The sharp jumps or steps in the model are as a consequence of the fact that the mature trees were assumed to be either 73 years or 123 years. In reality the tree ages are more likely to be evenly spread out and thus the steps will be smoother. The use of specifically designed modelling databases could perhaps help provide a clearer picture.

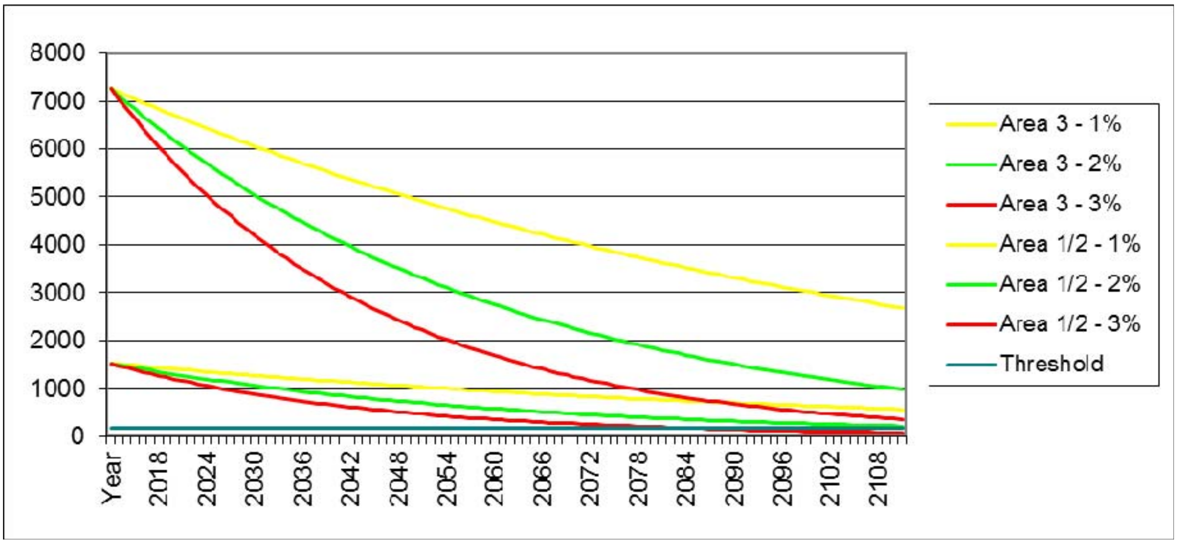

Figure 9 – *Graph showing the mortality rates of the mature oaks from Area 1 and 2, combined and Area 3. The threshold value reflects 160 hollow oaks from Bergman (2006) as the minimum for a sustainable saproxylic beetle population.*

3.4.12 Due to fact that there is no age/tree ring data from Burnham Beeches for oak, it was not possible to do a similar analysis as above for oak. However a simple analysis in figure 9, comparing the mature tree resource from Area 1 and 2 combined and Area

3 has been done. Three scenarios are presented with mortality rates of 1%, 2% and 3% using the lowest possible number of mature oaks in the two data sets where the number of mature trees have been scaled up for the whole area (see tables 5 and 6). Recruitment from young and semi-mature trees has not been included, so this is still likely to be an underestimate, although young and semi-mature trees are in essence only found in Area 3. It is also unlikely that many of semi-mature trees will reach maturity within 100 years.

3.4.13 Ranius et al 2009 identified that in Sweden 50% of oaks between 200 and 300 years contained hollows. When the oaks reached 400 years, all had hollows. From figure 9, the worst case scenario leaves 74 oaks of about 300 years old in Area 3 and 356 from Area 1 & 2. If half of these are hollow (as per Ranius et al, 2009), then there would be around about 200 oaks with hollows, of which around 30 would be in Area 3. This means that Area 3 alone is not sustainable for old oaks. The likelihood is that the mortality rate will be higher in Area 1 and 2 for oak due to the fact that many are in what is beech woodland today (Bengtsson & Fay, 2009, Bengtsson & Bengtsson, 2009) and lower in Area 3 as it is more open.

4.0 Conclusions and management recommendations

4.1 Beech

4.1.1 It is recommended that efforts to keep the ancient pollards alive are continued for as long as possible, but critically over the next fifty years (even if many may only be remnants). Ideally the mortality rate for the ancient beech pollards should be down at 1.3% pa or lower if possible. These trees are obviously the main refuge for the rare species associated with the ancient beech trees. Their importance is highlighted to an even greater extent by the very low numbers of maiden trees with veteran features.

4.1.2 It is recommended that management efforts should be aimed at ensuring the survival of the mature beech trees and improving conditions (if possible) for them so that the mortality rate does not exceed 2% pa and ideally is lower than this. If the mortality rate exceeds 2% per annum, the situation should be reviewed and management recommendations may need to be altered. With a 2% mortality rate it may be possible to have more than 1000 beech trees of conservation values within 60 to 70 years.

4.1.3 It is recommended that the veteranisation work and pollarding (not least from a historical point of view) should also be continued but that the focus for this work should primarily be on the semi-mature or young beech tree population rather than the mature trees. This is because the young and semi-mature trees make up a larger resource and will take longer to develop habitat anyway. The mature trees will hopefully begin to produce interesting wildlife habitat in the next fifty years naturally. Veteranising the mature population is unlikely to speed up the habitat production significantly enough that it makes the risk of losing the trees worth taking (see also 5.2). Thus veteranisation or felling of mature beech ought to be avoided wherever possible.

4.1.4 Area 3 could potentially be used for boosting conservation values associated with beech and if this is chosen and could potentially add 5-25% beech habitat in the long term. The conservation values will however be slightly different due to the more open nature of this part. However given that 150ha of Burnham Beeches has high quality beech habitat, which is likely sustainable, and given the other values associated with Area 3 (see below), it not considered to be a sensible management strategy to favour beech in Area 3.

4.2 Oak

4.2.1 It is recommended that efforts to keep the ancient oak pollards alive for as long as possible are continued alongside favouring the mature oak population. It is vital to try and reduce the mortality rate of the ancient oak pollards. The situation is even more critical for oak than beech. In Areas 1 and 2, there is no oak regeneration and the population is heavily skewed towards mature oaks (see figure 5). This likely reflects the fact that lack of grazing has favoured beech in these areas and the situation for oak looks bleak here. Any younger oak trees in Areas 1 & 2 should be valued and kept wherever possible.

4.2.2 In Area 3 however, there is a more sustainable oak population structure and regeneration of oak is occurring. This means that the maintenance of a sustainable population of oak in Area 3 must be a priority for management if the habitat values and species associated with ancient, hollow oaks are to be sustained at Burnham Beeches. It is however important to, for example clear around some mature oaks in Areas 1 and 2, to improve their long term survival. Favouring oak only in Area 3 may be a risky strategy (see figure 9).

4.2.3 Area 3 is primarily made up of heathland and acid grassland and these values can easily be combined with the conservation values of oak, in particular open grown oaks. A number of the best oak sites in Sweden are, for example, situated on acid soils, where the management favours both the ground flora and the trees. Removal of oak in Area 3 here to favour the grassland values may have far reaching consequences for the oak habitat values at Burnham Beeches. Favouring open grown oaks should thus be seen as compatible with heathland restoration objectives. Particularly when set in the context of the importance of this area for the long term viability of the oak population and the associated species at Burnham Beeches.

4.2.4 Burnham Beeches is an internationally important site for its old trees and thus the long term survival of the values associated with old oaks and beech trees must be seen as a priority over other, less rare habitats found here.

5.0 Future work and monitoring

5.1 Future work

5.1.1 Identification of the core age and annual increment for beech and oak at Burnham Beeches would be very useful to be able to understand the age structure better and the age at which habitat features begin to develop in veteranised, pollarded and maiden trees. It would also help to iron out many of the assumptions made in this analysis.

5.1.2 Further work needs to be undertaken in order to understand the role of the old coppice stools in the context of potential bridge habitat and where these fit in the population structure, in particular for oak. It would be useful to understand the habitat value provided specifically by the coppice stools (survey for fungi, beetles, mosses and lichens for example). It is not currently clear to the authors how they should fit into the population structure (e.g. numbers of stems related to numbers of trees, how they age and if this is different from maidens).

5.2 Monitoring

5.2.1 Permanent plots where mortality rates of beech in different age classes can be monitored and where the development of habitat features can be monitored would be very useful not just for Burnham Beeches, but other wood pasture sites.

5.2.2 Monitor the ancient pollard population mortality rate on a regular basis (at least every 5 years).

5.2.3 Monitor the trees which have been veteranised and pollarded to try and establish when the veteran features begin to develop and compare this with when it happens "naturally" or by pollarding.

5.2.4 Monitor the impact of grey squirrels on beech.

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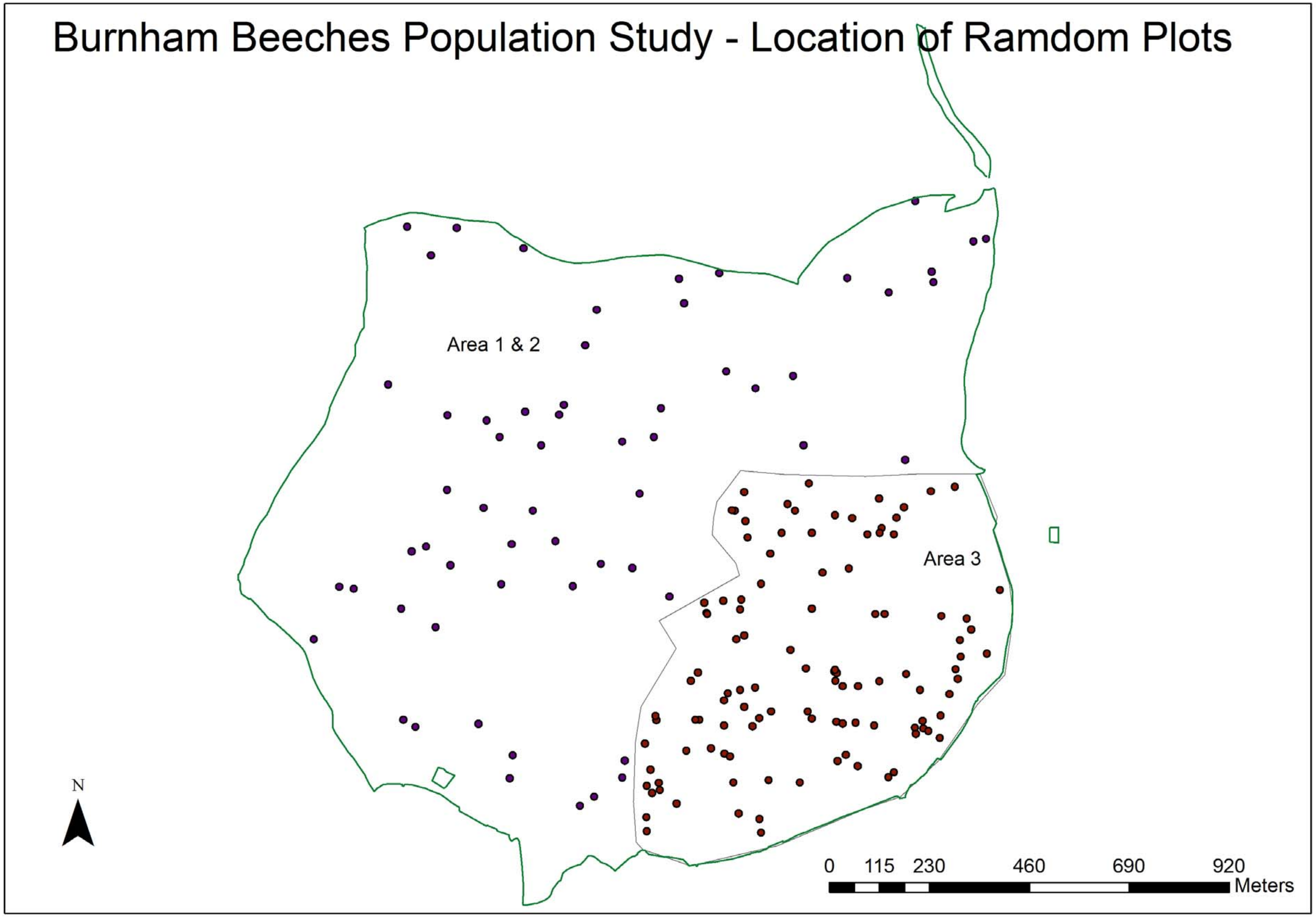
Appendix A

Map showing the sample areas and locations of the sample plots


Burnham Beeches Population Study - Location of Ramdom Plots
Area 1 & 2
Area 3
N
0
115
230
460
690
920
Meters

Appendix B

Table showing the grid references for the sample plots

Sample Point	Easting	Northing	Area
1	494475	185769	1
2	495078	184915	1
3	494432	185404	1
4	494885	185495	1
5	495644	185827	1
10	494589	185766	1
11	494856	184940	1
12	494970	184498	1
14	495807	185740	1
16	494906	184454	1
17	494530	185702	1
19	494825	185334	1
21	494921	184990	1
27	494993	184981	1
36	495583	185616	1
37	494836	185357	1
44	494467	184631	1
46	494495	184615	1
52	494639	184622	1
53	494718	184549	1
55	494911	185577	1
56	495686	185640	1
62	495488	185650	1
70	495681	185665	1
75	495621	185231	1
77	494711	184496	1
78	494976	184538	1
80	495778	185735	1
82	494873	184433	1
84	494261	184816	1
86	495024	184753	1
98	494394	185535	1
100	495495	185613	1
101	495681	185501	1
102	494805	184904	1
103	494784	184793	1
104	495074	184673	1
105	494933	184922	1
106	494866	184853	1
108	495391	185647	1

Sample Point	Easting	Northing	Area
7	495112	185592	2
8	494651	185120	2
15	494716	185036	2
18	495210	185434	2
26	494485	185019	2
33	494817	185043	2
35	494743	185718	2
38	494352	184933	2
41	494462	184888	2
43	495101	185649	2
47	494575	184988	2
49	494692	184944	2
60	494688	185284	2
61	494568	185162	2
66	495387	185264	2
67	494319	184938	2
68	494568	185333	2
83	495277	185396	2
88	494970	185272	2
95	495043	185283	2
96	495010	185152	2
99	495194	185661	2
113	495363	185424	2
115	495059	185350	2
118	494765	185113	2
121	494519	185031	2
129	494784	185264	2
147	494746	185342	2
148	494658	185322	2
156	494541	184845	2
159	495272	185516	2
166	494363	184893	2
181	495382	185552	2
182	494727	184953	2
183	494472	184801	2
184	495364	185631	2
188	494810	185290	2
190	495025	185180	2
194	495017	185215	2
197	494318	184995	2

Plot number	Easting	Northing	Area
2	495583	184499	3
4	495351	185128	3
6	495237	184415	3
7	495499	185096	3
8	495513	184708	3
9	495704	184870	3
12	495663	184611	3
13	495251	185156	3
14	495027	184374	3
15	495701	184589	3
16	495561	185142	3
17	495205	184553	3
18	495285	184634	3
20	495550	184619	3
21	495253	185089	3
24	495742	184726	3
25	495056	184469	3
27	495357	184792	3
28	495552	184875	3
29	495022	184577	3
30	495054	184485	3
31	495406	185062	3
33	495290	184945	3
34	495144	184740	3
35	495174	184566	3
36	495241	184700	3
37	495477	184709	3
39	495204	184619	3
40	495674	184605	3
41	495147	184631	3
42	495139	184631	3
43	495461	184721	3
45	495574	184875	3
46	495809	184784	3
47	495645	184600	3
49	495400	185176	3
50	495465	184537	3
51	495601	185097	3
54	495218	184546	3
55	495567	185073	3
56	495289	184371	3
57	495038	184463	3
58	495226	184486	3

Plot number	Easting	Northing	Area
59	495244	184909	3
60	495680	185158	3
61	495623	184737	3
62	495722	184690	3
63	495661	184628	3
65	495561	184720	3
66	495485	184550	3
67	495595	184510	3
68	495232	184816	3
69	495259	185052	3
71	495839	184930	3
72	495026	184479	3
73	495462	184626	3
74	495286	184403	3
75	495204	184676	3
76	495458	184743	3
77	495367	185113	3
78	495095	184438	3
80	495535	185059	3
81	495035	184517	3
83	495397	184650	3
85	495276	184706	3
86	495164	184878	3
88	495643	184613	3
89	495229	185114	3
90	495512	184525	3
91	495392	184749	3
92	495117	184560	3
93	495618	185121	3
94	495738	184748	3
95	495736	185169	3
97	495250	184661	3
98	495158	184902	3
99	495748	184815	3
101	495477	184623	3
102	495763	184865	3
103	495406	184887	3
104	495213	184692	3
105	495203	184905	3
106	495049	184630	3
107	495046	184641	3
108	495464	184739	3
109	495702	184641	3

Plot number	Easting	Northing	Area
110	495241	184886	3
111	495507	184625	3
112	495311	185015	3
113	495313	184650	3
114	495026	184407	3
115	495166	184875	3
116	495378	184487	3
117	495491	184981	3
118	495656	184700	3
119	495251	184826	3
121	495337	185062	3
123	495460	185103	3
125	495270	184616	3
126	495430	184970	3
127	495406	184634	3
129	495460	184747	3
130	495563	185062	3
132	495596	185059	3
133	495222	185114	3
134	495749	184777	3
135	495307	184492	3
139	495128	184721	3
140	495773	184840	3

Appendix C

Description of exponential formula used to calculate mortality rates.

CALCULATING THE MORTALITY RATE FROM KNOWN POPULATION OF TREES AND KNOWN TIME SPAN

Basic formula

$x(t)=a*b^{t/г}$

a = number of live trees we started with
b = growth factor (or in our case mortality rate, which is the unknown)
г = period unit over which the growth occurs (in our case mortality is measured annually and therefore r is usually = 1)
t = actual time span we have data for
x(t) = number of live trees after time span which has elapsed and over which we have surveyed.

Example:

Number of live trees counted year 1 (a): 29 900
Number of live trees counted year 2 after a period of time (x(t)): 14950
Actual time span between year 1 and 2 (t): 50 years
Period unit over which mortality is measured (г): 1 year

This leads to the following equation:
$14\,950 = 29\,900 * b^{50/1}$
from this equation "b" is calculated as: $b^{50/1} = 14950/29\,900$ ($b^{t/r} = y$)

An equation of the form $b^{t/г}=y$ is solved via the law of logarithms stating that:

$\log b^{t/r} = \log y$ or:

$t/г * \log b = \log y$ or $t/г = \log y/\log b$

In our example y = 14950/29 900

The equation can then be written:
$50/1 * \log b = \log 14950/29\,900$ or $\log b = \log 0{,}5/50$ $((\log 14950/29\,900)/50)$

On the windows advanced calculator press 0.5 then log / 50 = inv then log
Then mark the "inv" square and press log.

In our example the answer should be 0.9862327 (meaning that the annual mortality rate is (1-0,9862327) x 100 = ap 1.4%).

When calculating an exponential series in excel it is the value 0.9862327 that should be entered as step value.

Appendix D

Calculation sheets for beech according to White, 1998.

(Excel calculation sheets constructed by Paul Muir).

Treework Environmental Practice

The Wool Hall, 12 St Thomas Street, Bristol BS1 6JJ
Telephone: 0117 910 5200: Fax: 01179 926 0221

www.treeworks.co.uk • info@treeworks.co.uk