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## *Survival, height and tree stability responses of Quercus petraea, two decades after the introduction of different tree shelter types*

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# Survival, height and tree stability responses of *Quercus petraea*, two decades after the introduction of different tree shelter types

by Catherine Elizabeth Duerden, Tom Jenkins, Hugh Evans and Dylan Gwynn-Jones

**Summary:**
The long-term effects of 20 replicated tree shelter types (0.45-1.8m) were tested on sessile oak (*Quercus petraea*) saplings in mid Wales (1994-2014), against two control treatments. After 20 years shelters significantly ($p<0.05$) promoted survival in 17 of 20 treatments. Tree height was unaffected, but DBH was significantly ($p<0.05$) increased in 3 of the 20 types. Height:DBH, used as a tree stability proxy, revealed significantly ($p<0.05$) lower mean values in 12 shelter types compared to the open control. This study suggests shelters can enhance survival and result in morphological changes that may make trees more stable in the longer term.

## Introduction

Early work, starting in the late 1970s, highlighted the potential benefits of using tree shelters to improve the early growth and survival of saplings (Tuley, 1985). Shelters protected trees from herbivores and herbicides (Evans, 1984), and encouraged trees to grow taller and straighter at a faster rate (Mayhead and Boothman, 1997). As a consequence, the use of shelters rapidly gained in popularity and was adopted as an accepted forestry practice, despite the long-term effects being unknown (Evans, 1984). In the first years of production, usage rapidly grew from 100,000 in 1981/82 to 1,000,000 in 1983/84 (Tuley, 1985). Now tree shelters are commonly encountered across the UK and around the world in a broad range of projects, from woodland establishment to land reclamation, and roadside re-vegetation to community planting schemes. A wide variety of shapes, sizes, colours and materials have already been reviewed (Potter, 1991).

The microclimate within a tree shelter is different from that surrounding it, with the amount of photosynthetically active radiation typically reduced by 20-70%; daytime temperature sometimes increased by up to 10°C; $CO_2$ concentrations considerably modified and air inside the tube often saturated with water vapour (Bergez and Dupraz, 2009). It has also been found that shelter walls can collect dew, and certain designs can increase soil moisture (Campo et al., 2006).

A range of studies have documented the general influence of shelters on saplings in their first years, with most running for fewer than six years (Tuley, 1985; Braithwaite and Mayhead, 1996; Fabiao and Silva, 1996; Mayhead and Boothman, 1997; Mayhead and Price, 1998). Some papers describe responses ten years after use (see Dupraz, 1997; Ponder, 2003) but no known research has considered the longer term impacts of using tree shelters.

Sheltered trees generally display a greater survival rate than unsheltered trees (Potter, 1991). This is less significant on well-maintained sites where no animals are present (Mayhead and Price, 1998). Tree shelters have also consistently been shown to greatly increase the rate of height growth in the first years after planting, particularly before the tree emerges from the top of its shelter. This, however, is also coupled with a reduced stem diameter growth compared to unsheltered trees (Potter, 1991; Mayhead and Boothman, 1997; Mayhead and Price, 1998). Unprotected trees would typically have a tapering stem form in year 3, whereas a sheltered tree would be more columnar, particularly in taller shelters (Potter, 1991).

It has been recommended that shelters and stakes should not be removed from trees until they degrade or threaten to damage the growing tree (Potter, 1991). Evidence suggests that sessile oak trees that had their shelters (1.2m) removed three years after planting were less stable in wind (Mayhead and Price, 1998). Root growth is also commonly less in sheltered trees (Fabiao and Silva, 1996) and root dry weight was found to relate inversely to shelter height (Mayhead and Boothman, 1997).

Research to date clearly points towards shelters protecting saplings against biotic and abiotic factors during early establishment and resulting in trees that are potentially taller but less stable. However, none of the above studies has followed subsequent tree growth to >20 years after the initial introduction of shelters. Here we test 20 different types of shelter for tree survival, height, stem diameter and stability effects on sessile oak (*Quercus petraea* (Matt.) Liebl) grown in mid Wales over 20 years (1994-2014). We hypothesise enhanced tree survival and height but thinner stem diameters and lower tree stability in the longer-term.

*Figure 1. Illustration of conditions in blocks 1 and 2 during surveys in 2014, with sessile oaks (Quercus petraea) heavily shaded by the 9-10m tall Norway spruce (Picea abies) trees (both planted at 2m square spacing).*

*Figure 2. Illustration of conditions in the open block 3 during surveys in 2014, with sessile oaks (Quercus petraea) planted at 2m square spacing.*

## Materials & Methods

*Site description*

The experiment 'Llan12 P94', originally set up by Forest Research to investigate tree growth in shelters, is located in Crychan Forest, approximately 9 miles east of Llandovery, South Wales; north of the Brecon Beacons National Park. The area has an approximate average annual rainfall of 1500 to 2000mm, a mean daily maximum temperature in summer of approximately 18°C and mean daily minimum temperature in winter of approximately -1°C (averaging period 1981-2010) (Met Office, 2015). Soil is likely to belong to the Manod series (611c) with a well-drained, dark brown, slightly stony clay loam topsoil of low natural fertility (NSRI, 2014). The site, at National Grid Reference SN848377, is between 265 and 280m above sea level, on a west facing, 16° gradient slope, with rows planted in an approximately east-west direction.

The site was scarified in 1994 by disc trencher prior to planting; it initially received weed treatment via one application of Propyzamide (Kerb) per year and hand weeding of a small pocket of bracken in mid-summer to prevent the suppression of trees.

There was a high degree of heterogeneity across the site, revealed by observable block differences. Treatments were organised across three blocks (1, 2 and 3) with blocks 1 and 2 amongst rows of Norway spruce (*Picea abies*) trees at 2m square spacing and 9-10m tall at time of surveying, casting heavy shade (Fig. 1), whilst block 3 was open (Fig. 2). Brambles (*Rubus fruticosus*), climbing roses (*Rosa sp.*), ferns (*Pteridophyta sp.*), bracken (*Pteridium sp.*), hawthorn (*Cretaegus sp.*), and some hazel (*Corylus avellana*) and birch (*Betula sp.*) were also present across the site.

*Treatments and experimental design*

The design involved three blocks (1, 2 and 3) with 20 sheltered treatments, one unsheltered open control, and one control in 0.4m spiral guards (see Fig. 3 and Table 1 on next page). The 22 treatments were replicated three times in differing orders, equalling 66 rows. Each row consisted originally of 20 sessile oak (*Quercus petraea* (Matt.) Liebl.) 2+1 transplant trees at 2m square spacing, planted in May 1994. Remnants of the tree shelters were visible on site even after the 20 years duration but most of these had fragmented and were not impairing tree growth in any way. The only exception was TL8 where the folded top edge and rigid square plastic band around the shelter were strangling some trees and may have restricted their diameter growth.

*Data collection and analyses*

In July 2014 the survival of the 60 initial trees in each treatment (20 trees per row, replicated three times) was recorded. The height of each remaining tree was measured using an 8m telescopic height pole, and the diameter at breast height (DBH) taken using a diameter tape measure at 1.3m from the ground. Height to diameter (HD) ratio was used as a proxy for tree stability, as described by Cremer et al. (1982).

As an additional estimate of stability, a Fakopp TreeSonic Microsecond Timer (Model TS-02/2009, Fakopp, Hungary) was used to measure trunk stress wave propagation speed on a randomly selected individual tree of >107mm DBH for each treatment in block 3. More trees could not be assessed, and blocks 1 and 2 were excluded from this acoustic technique, as the majority of oaks in the study were too thin

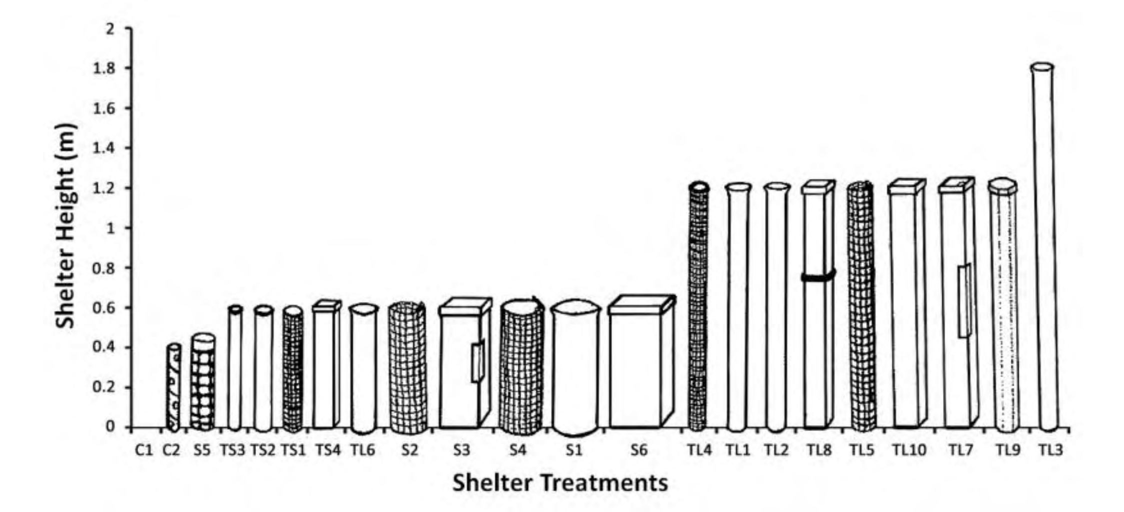


*Figure 3. Diagram illustrating each shelter design, drawn to scale and arranged by size, from small to large (see Table 1, for supplementary information). Rectangular slots on the corners of treatments S3 and TL7 held shelters onto their stakes. The band around treatment TL8 was a preformed rigid plastic clip which secured the shelter to its support.*

to be tested in this way. The instrument measured the time taken for a stress wave to pass through the trunk between two probes, located 1m apart, after the upper probe was struck with a hammer. This process was repeated a minimum of three times, until readings were consistent to within ~1 point, an average time calculated (μs) and converted to speed (km/s). This non-destructive measure was previously found to correlate well with the internal timber properties of other species (Wessels, Malan and Rypstra, 2011), with higher speeds indicating greater tensile or bending strength. This is the first known study to apply the technique to standing sessile oak trees.

*Statistical analyses*

The number of trees surviving by treatment in each of the three blocks was compared to the open control (C1) using the equal variances two sample t-Test, and is summarised here as overall percentage per treatment (Table 2). For each of the measured categories, a univariate Analysis of Variance (ANOVA) test was used to compare the means of the open control (C1) to the sheltered treatments, with both the blocks and treatments as factors. A post-hoc 2-way Dunnett's test was then used to identify which treatments were significantly different from the control in each case. The acoustic

**Table 1. Shelter descriptions summary. Treatments ordered by shelter height then shelter diameter (smallest to largest).**

| Treatment | Type | Shelter Height measured (m) | Shelter Diameter measured (cm) | Shelter Style/Colour & Shape |
|---|---|---|---|---|
| C1 | Control 1 | No shelter | No shelter | - |
| C2 | Control 2 (spiral guard) | 0.4 | Min. 4 (flexible | Various colour spiral guards ● |
| S5 | Shrub shelter | 0.45 | 16.0 | Mesh within two PVC sheets ● |
| TS3 | Tree shelter | 0.6 | 5.5 | Transparent/translucent PVC ● |
| TS2 | Tree shelter | 0.6 | 8.0 | Transparent/translucent PVC ● |
| TS1 | Tree shelter | 0.6 | 9.3 | Mesh within two PVC sheets ● |
| TS4 | Tree shelter | 0.6 | 10.0 | Beige twin-wall polypropylene ■ |
| TL6 | Tree shelter | 0.6 | 11.5 | Green twin-wall polypropylene ● |
| S2 | Shrub shelter | 0.6 | 17.0 | Mesh (formerly bonded to a single thin PVC sheet) ● |
| S3 | Shrub shelter | 0.6 | 19.3 | Brown twin-wall polypropylene ■ |
| S4 | Shrub shelter | 0.6 | 20.0 | Mesh within two PVC sheets ● |
| S1 | Shrub shelter | 0.6 | 22.0 | Brown twin-wall polypropylene ● |
| S6 | Shrub shelter | 0.6 | 25.9 | Brown twin-wall polypropylene ■ |
| TL4 | Tree shelter | 1.2 | 8.3 | Mesh within two PVC sheets ● |
| TL1 | Tree shelter | 1.2 | 9.8 | Brown twin-wall polypropylene ● |
| TL2 | Tree shelter | 1.2 | 9.8 | Green twin-wall polypropylene ● |
| TL8 | Tree shelter | 1.2 | 10.0 | Brown twin-wall polypropylene ■ |
| TL5 | Tree shelter | 1.2 | 10.1 | Mesh (formerly bonded to a single thin PVC sheet) ● |
| TL10 | Tree shelter | 1.2 | 10.5 | Brown twin-wall polypropylene ■ |
| TL7 | Tree shelter | 1.2 | 11.2 | Brown twin-wall polypropylene ■ |
| TL9 | Tree shelter | 1.2 | 11.5 | Brown twin-wall polypropylene ● |
| TL3 | Tree shelter | 1.8 | 9.7 | Brown twin-wall polypropylene ● |

measurements could not be analysed statistically, as there was only one value for each of the 20 shelter types.

## Results

After 20 years only 33% of trees had survived in both the open control (C1) and the spiral guard control (C2) across the experimental site (Table 2). This compares with between 53% to 88% survival in plants grown in 19 of the 20 shelter types, values for 17 of which were significantly ($p<0.05$) greater than the control (C1). The most notable exception was the longer TL3 (1.8m shelter), which had similar survival to the controls. No shelter treatments showed significantly different mean tree heights from the control (C1) (Table 2). For diameter at breast height, trees in three of the shelter treatments were significantly ($p<0.05$) larger than the control (C1). These included two 0.6m shrub shelters (S2 and S6) and one 1.2m tree shelter (TL9). See Table 2.

After 20 years the height:DBH (HD) ratio was significantly ($p<0.05$) lower in 12 of the shelter types when compared to the control (Fig. 4). This included five 0.6m shelters S1, S2, S4, S6 and TL6; six 1.2m shelters TL1, TL2, TL4, TL7, TL9 and TL10 plus the single TL3 1.8m shelter. This would suggest that more than half the shelter types produced trees that were more stable than the open control (C1).

**Table 2. Percentage of surviving trees from an original 60 per treatment, mean tree height and mean diameter at breast height (DBH) with standard errors, 20 years after the experiment began. Asterisks (*) indicate a significant difference ($p<0.05$, $n=60$ in each case) when compared to the unsheltered control (C1).**

| Treatment | Survival (%) | Height (cm) ±SE | DBH (cm) ±SE |
|---|---|---|---|
| C1 | 33 | 667 ±34 | 5.81 ±0.61 |
| C2 | 33 | 587 ±33 | 5.96 ±0.60 |
| S5 | **67*** | 671 ±23 | 6.74 ±0.42 |
| TS3 | **63*** | 637 ±24 | 6.14 ±0.44 |
| TS2 | **68*** | 701 ±23 | 6.96 ±0.43 |
| TS1 | **78*** | 664 ±22 | 7.07 ±0.40 |
| TS4 | **77*** | 628 ±22 | 5.67 ±0.40 |
| TL6 | **78*** | 657 ±22 | 7.61 ±0.39 |
| S2 | **70*** | 666 ±23 | **8.23 ±0.42*** |
| S3 | **68*** | 711 ±23 | 7.08 ±0.43 |
| S4 | **88*** | 652 ±20 | 7.60 ±0.37 |
| S1 | **73*** | 627 ±23 | 7.59 ±0.41 |
| S6 | **72*** | 730 ±23 | **8.29 ±0.41*** |
| TL4 | **75*** | 680 ±22 | 7.38 ±0.40 |
| TL1 | **63*** | 634 ±24 | 7.11 ±0.44 |
| TL2 | **68*** | 602 ±23 | 7.60 ±0.42 |
| TL8 | **68*** | 604 ±23 | 6.07 ±0.42 |
| TL5 | 65 | 640 ±23 | 6.38 ±0.44 |
| TL10 | **70*** | 567 ±23 | 6.97 ±0.42 |
| TL7 | **58*** | 671 ±25 | 7.21 ±0.46 |
| TL9 | 53 | 677 ±26 | **8.19 ±0.47*** |
| TL3 | 35 | 645 ±35 | 7.06 ±0.64 |

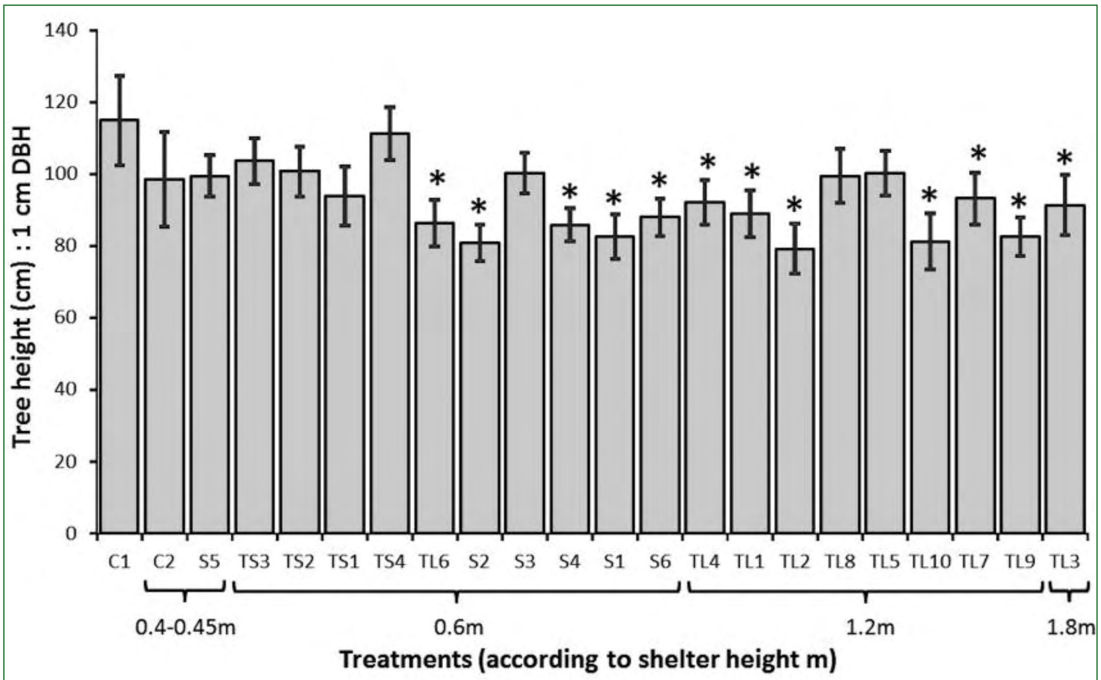


*Figure 4. Mean sessile oak (Quercus petraea) height to diameter at breast height (DBH) ratio according to treatment, 20 years after the experiment's initiation. Data shown represent a mean with standard errors, with significant difference ($p<0.05$, $n=60$ in each case) relative to the control (C1) indicated by an asterisk (*). Treatments were ordered by shelter height (square brackets) then shelter diameter (smallest to largest). See Fig. 1 for visual key and supplementary Table S1 for more detailed shelter characteristics. Height to DBH ratio is used here as a proxy for tree stability.*

## Discussion

This study examined the long-term effects of tree and shrub shelters on sessile oak growth and form over two decades. The research, carried out in 2014, utilised an upland experimental site in Crychan Forest near Llandovery, South Wales, planted in 1994. The hypotheses tested were that mature trees originally grown in shelters would have a higher survival rate and be taller, but have thinner stem diameters and be less stable, than unprotected control trees of the same age grown at the same site.

The first hypothesis tested here was correct, with survival significantly ($p<0.05$) promoted in the majority of trees grown in shelters compared to the open control (Table 2). Shelters are known to be effective for controlling damage by herbivores (Gill, 1992). More vigorous growth may also contribute to better survival, particularly in areas of shade (Kobe et al., 1995). It was further hypothesised that tree height would be promoted by shelter use. There were no significant effects of shelters on height following the 20 year period in this study (Table 2). Shorter-term studies suggest that height can be stimulated by shelters (Potter, 1991; Mayhead and Boothman, 1997; Mayhead and Price, 1998). However, Ponder (2003) suggested that the height growth of sheltered oaks slowed after ten years and were similar to an open control.

It was hypothesised that tree shelters would reduce stem diameter at breast height (DBH). However, this was significantly higher in three of the shelter treatments (S2, S6 and TL9) when compared to the control (Table 2). Height to diameter (HD) ratio was next calculated as a proxy for tree stability. This was significantly lower ($p<0.05$) in 12 from 20 (60%) of the shelter treatments (Fig. 4). This proxy measurement suggests that tree shelters potentially enhance the stability of trees in the longer term.

To complement this we piloted the use of a Fakopp TreeSonic Microsecond Timer (Model TS-02/2009, Fakopp, Hungary) to look at trunk stress wave propagation speed >107mm DBH. This was done on randomly selected individual trees from each treatment and revealed a mean of 3.24km/s (S.E. 0.05, $n=20$) with a range from 2.79 to 3.85km/s for shelter treatments compared to an unsheltered control (C1) of 3.11km/s ($n=1$) and a spiral guard control (C2) of 3.12km/s ($n=1$). The treatments with significantly ($p<0.05$) lower mean HD ratios also gave a mean speed of 3.24km/s ($n=12$). These observations broadly support our findings that tree stability may be enhanced by some shelter treatments.

A possible explanation for the higher mean DBH and height to diameter (HD) ratio could be due to increased wind exposure of trees after they had outgrown their shelters. This would promote greater physical movement in the wind and investment into stem diameter and stability. This is likely a thigmomorphogenic response (Jaffe, 1973), with resistance against movement in the wind increased (Coutand et al., 2008). Whilst tree shelters may initially protect young trees, crown exposure to wind intensifies as they grow tall and emerge from the shelters.

## Conclusions

This study, for the first time, provides evidence of positive effects of tree shelters on the survival and stability of trees in the long-term (>two decades). However, research here is limited to one species at one site. Future research is needed in this area and could exploit the various experimental tree shelter testing sites established in the 1980s and 1990s. Such research could also look at rooting characteristics and physically test stability using mechanical pulleys. Clearly tree shelter use will have impacted on tree growth and success over the past decades but we are yet to fully understand the impacts of this legacy without this further research.

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