A review of stumping back and case study of its use in the rehabilitation of poorly performing pole-stage sycamore

Ian Short[a*], Jerry Hawe[b], Jerry Campion[a] and Ricky Byrne[c]

Abstract
First rotation broadleaf plantations present a range of inherent challenges to the achievement of good form and vigour. Where biotic and/or abiotic factors compromise early growth and stem quality, appropriate management interventions to improve these are required. An historical review of "stumping back" literature is presented together with a case-study. The B-SilvRD broadleaf silviculture research project includes a "rehabilitation" strand, whereby innovative measures to improve poorly performing stands of commercial broadleaves are being trialled. One such pilot trial involves a 17year-old sycamore (*Acer pseudoplatanus* L.) plantation, which had not performed well and required significant intervention to improve its silvicultural and economic viability. This paper reviews the literature on stumping back and presents a case-study with results of three different line thinning/stumping back treatments, including analysis of different light regimes and the impact of light levels on coppice regrowth.

Keywords: *Broadleaf, silviculture,* Acer pseudoplatanus*, coppice*.

Introduction

Ireland's current forest resource has largely been created through state-funded afforestation in the last century, which has seen over 720,000 ha of new plantation forest established since the 1920's. Due to the relatively poor quality land available for afforestation, together with the need to develop an economically-viable timber resource, the national planting programme up until the 1980s was based almost entirely on fast growing exotic conifer species. During the eighties there was a realisation of the need to widen the species base (COFORD 2012). Since state support for forestry development in the private sector began in the early eighties, over 60,000 ha of new broadleaved plantations have been established (Hendrick and Nevins 2003, Forest Service 2012). More than 9,000 ha of sycamore (*Acer pseudoplatanus* L.) are present in Ireland, approximately 5% of the broadleaf forest estate (Forest Service 2013). Unlike the established conifer forest, broadleaves have proven to be much less suited to the challenging first rotation conditions inherent in green field sites. Exposure, soil conditions, low intra-specific species competition due to relatively low stocking densities, high light levels and weed competition are all

[a] Teagasc Forestry Development Dept., Ashtown Food Research Centre, Dublin 15.
[b] Sylviron Ltd., Appleyard, Turlough, Castlebar, Co. Mayo.
[c] Russellstown, Bridgetown, Co. Wexford.
[*] Corresponding author: Ian.Short@teagasc.ie

aspects of the open, green field environment which present particular impediments to broadleaf crop quality (Hawe and Short 2012). Add to this the potential pitfalls of species selection, provenance selection and availability, ground preparation and a range of post-planting biotic and abiotic challenges and it is hardly surprising that first rotation broadleaf woodlands in Ireland are sometimes compromised in terms of vigour and, more often, stem quality.

The Broadleaf Silviculture Research and Development (BSilvRD) project, a five-year project funded by the Dept. of Agriculture, Food and the Marine, comprises three main strands which seek to improve the quality of broadleaf plantations:

1. Establishment of broadleaves;

2. Thinning of pole-stage broadleaves – maintaining and enhancing existing good quality;

3. Rehabilitation of poorly performing pole-stage broadleaves.

The rehabilitation strand aims to address the quality issues relating to existing broadleaf plantations through the application of novel treatments and the development of innovative silvicultural solutions (for example, see Short and Hawe 2012 and Short 2013).

Where species/site requirements are not so incompatible, there may be some means to reinvigorate the original species, potentially within environmental conditions which are now more favourable than those existing at the time of original planting. This article introduces stumping and coppicing as a means to rehabilitate poorly performing broadleaves and includes a case-study of a pilot trial that was intended to investigate the rehabilitatory silviculture of a poorly-performing stand of pole-stage sycamore in Ireland. Systematic thinning treatments were conducted and the impressive resultant regrowth from the sycamore stools is now being investigated and managed. Related practices of stumping back and conversion of stored coppice are outlined below.

Stumping back

Stumping back is the practice of cutting back top growth at, or a few years after, planting to stimulate a vigorous initial shoot (Evans 1984). It has previously been known as “heading down” (Nicol 1820, Billington 1825, James 1991), “cutting over” (Bolton 1956) and “cutting back” (Hough 1882). Stumping back is not a new practice and has predominantly been used for broadleaves but is seldom done nowadays. However, its benefits have been known for at least the last two centuries. In his *Memorial on the Culture of Woods* to the French Government in 1742, de Buffon of the Royal Academy of Paris said this about young trees that had been stumped back:

> … they shoot out with vigour the superabundance of their nutriment and produce, the very first year, a shoot more vigorous and higher than the old trunk was after three years. I have repeated this experiment so often, that I can give it as a certain fact and the most useful practice that I know in the culture of woods.

In 1820 Nicol wrote in his Kalendar for the month of March, under the title of "Heading down trees":

> It is now a proper time to examine all plantations which have been three or four years planted, to see if the [hard-wood] trees are in a thriving state; and such as have not begun to grow freely should be headed down to within three or four inches of the ground. The cut must be made with the pruning knife in a sloping direction, with one effort. Great care should be taken not to bend over the tree in the act of cutting. By so bending, the root may be split; a thing which too often happens.
>
> The operation of cutting over young trees should not be performed at an earlier period of the season, because the wounded part might receive much injury from the severe weather in January and February and the expected shoot be thereby prevented from rising so strong and vigorous.

Stumping back is usually done to improve the growth rate or form of young trees, damaged by frost, browsing or other impact, as recorded by the Society for Promoting Christian Knowledge (1851):

> More attention is required by deciduous trees, especially the oak and chestnut, than by the fir tribe, for they seldom grow straight and freely at first. When, therefore, they have stood two years, they should be cut down to the ground, or at least to the last bud or two; this operation should be performed in the autumn and in the following spring one or more strong clean healthy shoots will be sent up. In the ensuing autumn, the best of these should be selected for the future tree and the others removed. The chosen stem will afterwards make rapid progress, as all the strength of the root will be directed to a stem capable of profiting by its supplies, instead of the former hard wooded and stunted plant. Plants so managed will soon surpass in every respect those which are suffered to struggle through their infancy unaided by the pruning knife; not only will a better and straighter young tree be produced, but much time will be gained instead of lost, as might first be apprehended.

More recently Çiçek and Tilki (2007) found that the growth of poorly developing or heavily browsed *Fraxinus angustifolia* (Vahl.) seedlings was increased following stumping two years prior. Mayhead and Boothman (1997) investigated the effect of treeshelter height on the growth of young sessile oak (*Quercus petraea* (Matt.) Liebl.). Sixty percent of the trees in 1.8 m tree shelters bent over and touched the ground after the shelter was removed. It was concluded that the trees would not recover and that the only treatment likely to ensure an upright tree would be stumping back. Billington (1825, p. 70) recommended such a practice with oak suffering similarly:

> When oaks have been drawn up weak and tall, without any side branches, among other trees, which is frequently the case, the best method I believe to be adopted with them, after the others have been taken out, would be to head them down at different heights, when they might be formed with a little art and care into the most beautiful and useful trees; whereas, when they are left in that state, they hardly ever come to anything and are a continual eye-sore.

Köstler (1956, p. 309) recommends stumping back of planted sweet chestnut (*Castanea sativa* Mill.) after severe injury by frost or in the case of ugly growth form. Madden (1945) reports his delight at the result of a stumping back operation carried out in a partially cleared stand of ash (*Fraxinus excelsior* L.) in Ireland in which there were:

> … extensive patches of crooked, deformed and diseased natural ash-neither a straight nor a healthy plant in the lot. There they stood, ten or twelve feet high and, for all their deformity, their cutting back on the morrow afforded me no satisfaction. … After one short year, however, this cutting back of natural ash has proved a definite success. What sturdy, straight shoots! No doubt of where they are going-the sky is the limit. Each stump has sent out from two to six shoots, I take out my rule and measure several, finding that they measure from one foot to eight feet in height. I place the average height at 2 feet 10 inches.

He goes on to suggest that the coppice shoots will be singled the following year, a practice whereby the best shoot is selected and retained whilst the other shoots are removed:

> The secateurs in my hand are itching for the work. Selection from such a pick will be easy and agreeable work.

A nearby planted stand of 7-year-old Norway spruce (*Picea abies* (L.) H. Karst.)/ ash mixture in which the ash had similarly been stumped back was not so successful:

> I examine six of the stumps which had been cut back. Three have not

> put out any shoots and the other three have sent out crooked, deformed, diseased and practically horizontal shoots. Where is the sturdiness, the vigour and the health of the natural ash shoots?
>
> He speculated that perhaps the planted ash had smaller root systems and less vigour than the natural regeneration. But an alternative reason could perhaps be the influence of shading from the Norway spruce.

As highlighted by Madden (1945) above, subsequent singling of the coppice shoots should be carried out to favour the best shoot. Bolton (1956) wrote:

> Some hardwoods tend to remain in check for an unduly long time: that is to say, although they remain alive and healthy, they make no height growth. Where this condition is still obtaining by the fourth year it is worth while cutting them over at ground level, when strong, fast-growing coppice shoots will be thrown up. The strongest one of these should be retained, the remainder being removed.

Singling is also highlighted in the British Sylva and Planters' and Foresters' Manual (Society for Promoting Christian Knowledge 1851) cited above.

Stumping back is particularly suited to ash, oak (*Quercus* spp.) and sycamore (van Miegroet 1956, Bolton 1956) but should not be carried out in beech (*Fagus sylvatica* L.) (Bolton 1956, Kerr and Evans 1993) which is not as successful at coppicing. However, young beech are frequently coppiced in mountainous regions of continental Europe (Joyce et al. 1998) when they have been badly damaged during extraction operations and are cut back to produce shoots with better form. Kerr (1995) and Kerr and Boswell (2001) describe the use of stumping back in ash planted in a frosty valley dip, which, despite having been planted densely and with a nurse species, had been frosted back a number of years. The five-year-old ash were stumped back to about 10 cm above ground, stimulating resprouting. The resultant selection and production of one strong shoot with good growth rate led to the shoot tips being above the zone of very cold air after the first season. The effect of stumping back on the growth rate of sycamore is similar. If little sign of growth was seen in sycamore during the second year after planting, Stevenson (1985) had no hesitation in stumping back to ground level and, later, singling to one dominant shoot. Usually the subsequent growth is rapid and the stumped plants soon catch up with the untouched ones (Stevenson 1985). However, this was not the case in common walnut (*Juglans regia* L.) that was stumped back at the time of planting (Hemery and Savill 2001) but it may be that there was insufficient root systems to produce the results other authors have reported from later stumping back operations. Clark and Brocklehurst (2011) stumped back common and black walnuts (*J. regia* and *J. nigra* L., respectively) that exhibited very poor stem form, caused by repeated frosting, 5 or 6 years after planting and had great success. The shoots were subsequently singled resulting in most trees having one single strong shoot with good apical dominance.

Stumping back can also be carried out as a pre-emptive treatment in cases where advance natural regeneration could be damaged by the felling of overstory trees. Joyce et al. (1998) note this for beech and Hiley (1931, p. 74-75) describes its use in oak woodland with advance natural regeneration of ash:

> Ash often regenerates itself freely in old mixed woods, especially under oak which is dying back in the crown and letting in more than the usual amount of light. Where this is happening the oaks may be cut and the advance growth used for stocking the ground, intervening areas being planted up with other trees, including some shade-bearing species. In this way dense groups of ash, which can in time be thinned out to one or two trees may be cheaply secured. The advance growth of ash is likely to be damaged by the removal of the old trees and it is safer to cut it back to an inch or two above the ground before the wood is felled, as it will then sprout very vigorously. This method of cutting back advance growth before felling the big trees over it is regularly applied with success to hardwoods in the Harvard forest in Massachusetts and the same treatment is used with planted out ash on some English estates. It is found that the trees which are cut back sprout so vigorously that they overtake trees which have been left untouched.

As has been demonstrated, stumping back normally occurs when the trees are young. A related practice to stumping back and singling, but carried out in more mature stands, can be employed in the conversion of stored coppice to high forest.

Stored coppice conversion

Neglected stands of coppice develop a high forest structure following growth after the cessation of regular cutting. The resultant trees, known as "stored coppice", may, in comparison to single-stemmed trees, exhibit inferior growth and have worse stem form and butt sweep (Harmer 2004). Often the trees produced are less windfirm. However, the quality of stored coppice can be improved by thinning and singling the stools to leave only the best stem. The French *balivage intensif* system of converting coppice to high forest uses this principle (Troup 1928). Storing coppice is likely to be most successful where stools are vigorous, young and have been cut close to the ground (Harmer 2004). In sycamore an acceptable high forest crop can be formed if shoots are thinned after it has been decided to store coppice (Stern 1989), although Hiley (1931) recommended that, to grow large timber from stored coppice, only rootstocks of six inches or less (approximately 15 cm) should be used because their roots are still vigorous and exposed wounds will soon heal. However, sycamore up to 80-100 years old coppices well (Savill 2013) but the species does not endure many successive cuttings (Troup 1928). It may therefore be more appropriate to convert to sycamore high forest rather than maintain a coppice system. Sycamore coppice regrowth has often been used to restock stands on clearfelled sites (Henriksen and Bryndum 1989, Tillisch 2001).

Billington (1825) has a chapter specific to "reclaiming and bringing woods and plantations that have been neglected, or got into a ruinous stunted state for want of thinning, etc. into a healthy and profitable condition", in which he says:

> …I would begin to head some of them down (the weakest and those with the fewest branches on) to different heights from the ground and perhaps cut some close to the soil, according to circumstances; … Trees of 20, 30, or even more years' growth, might probably be renovated and set in a growing vigorous state again, which would be of immense importance. (p. 303-304)

The B-SilvRD project initiated an unreplicated pilot study in a poorly performing sycamore plantation to investigate the effect of stumping back 17-year-old stems with the objective of producing a productive high forest system. As part of the trial, we are investigating the impact of three systematic thinning intensities and resultant altered light regimes on the consequent sycamore coppice regrowth.

Case study

<u>Site description, trial design and treatments</u>

The 1.2 ha site is situated near the village of Kilkelly, Co. Mayo in the west of Ireland (latitude 53.90°, longitude -8.78°). The site is privately owned and was planted under the Afforestation Programme in 1996 with pure sycamore at 2 m × 2 m spacing (2,500 stems ha^{-1}). Elevation is 125 m and at the time of planting the site was exposed. Soil type is poorly drained acid mineral (EPA 2013).

A consultancy report in March 2009 described the crop as "extremely poor" with relatively extensive areas not having closed canopy and possibly requiring reconstitution via underplanting (Hawe 2009). Top height at this time was 6 m with a projected maximum mean annual volume increment of 4 m^3 ha^{-1} (Yield Class 4) (HMSO 1981). Speculation as to the possible causes for poor performance included: exposure, inappropriate species/provenance choice, mineral soil rooting depth limited to around 30 cm and lack of early maintenance.

Considering the poor performance of the original sycamore crop, discussions between the owner, managers and research staff concluded that systematic line thinning treatments should be carried out with a view to underplant with an alternative species. It was decided to carry out line thinning in three treatments (Figure 1):

1. remove 50% canopy cover by cutting alternate lines (Treatment 1:1);
2. remove 50% canopy cover by cutting 2:2 lines (Treatment 2:2);
3. remove 75% canopy cover by cutting 3:1 lines (Treatment 3:1).

The trial was designed as a pilot demonstration trial rather than a fully replicated research trial. However, the trial has provided indications of areas for further research. Each trial measurement plot consists of one 4-line bay and has at least one similarly treated bay either side of it to act as a buffer between neighbouring treatments.

The thinning was carried out in February 2011, motor manually with low impact quad and timber arch extraction of any viable firewood cords. Underplanting was not carried out directly following thinning as originally planned.

The growing season after the thinning showed strong coppice regrowth from the cut stools; much stronger than had been anticipated and clearly benefitting from improved sheltered conditions than had been the case at the time of initial establishment. The site was now being surrounded by well-established conifer stands on three sides and an overgrown hedgerow on the west side, together with more intimate shelter from the remaining sycamore crop. Observing the strong coppice regrowth, particularly in the 3:1 treatment (see Figure 2), there was an opportunity to examine the potential to reconstitute the sycamore crop, potentially as a two-tier, single species woodland, via singling of the resultant coppice.

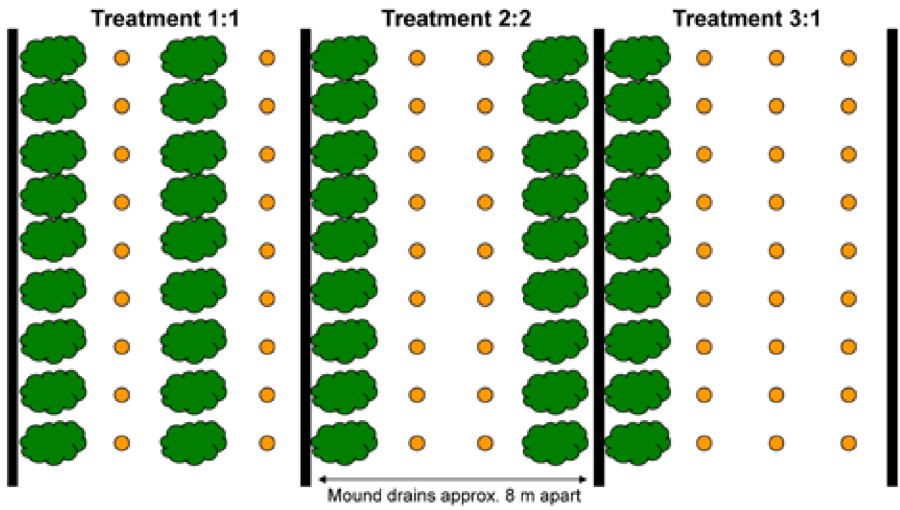

Figure 1: *Diagrammatic representation of the thinning treatments. Circles represent harvested trees. Buffer areas adjacent to each measurement area are not shown.*

Figure 2: *Coppice regrowth in the 3:1 plot at the beginning of growing season 2 following cutting.*

Data collection

After three growing seasons it was visually apparent that there were differences in the coppice regrowth between the three treatments. To quantify this all the coppice stools within each treatment plot were measured in September 2013, at the end of the third growing season since felling. Parameters measured were: height of the tallest two shoots per stool; shoot diameter at 5 cm from the stool of the two tallest shoots; number of shoots per stool; number of shoots >1 m tall per stool. To investigate the light available to the coppice five hemispherical photos were taken per treatment at 1.2 m above ground. Each photo was taken from randomly assigned locations in the mid-line of the treatment. In the 2:2 and 3:1 treatments data from the four coppice stools adjacent to the location were analysed. In the 1:1 treatment data from the two coppice stools adjacent to the location were used. Definitions of the parameters are in the glossary below.

Results

Data are presented in Tables 1 and 2 below and illustrated by Figure 3. The 1:1 treatment plot had less coppice shoots per stool than the 3:1 treatment and a reduced proportion of the shoots were >1 m tall than the 2:2 and 3:1 treatments. Three years after cutting, the height of the tallest two shoots per stool ranged from 40 - 403 cm, the shortest appeared to be in the 1:1 treatment and the tallest appeared to be in the 3:1 treatment. The mean height of the tallest two shoots appeared to be greatest in the 3:1 treatment and the smallest appeared to be in the 1:1 treatment. The mean diameter of the tallest two shoots exhibited a similar trend.

Five hemispherical photos (e.g. see Figure 4) were taken per plot and data from the stools adjacent to them were used to produce means. The two stools adjacent to one photo location in the 1:1 plot were both dead.

Figure 3: *Sycamore coppice understory three growing seasons after maidens were cut to three intensities: a) 1:1; b) 2:2; c) 3:1.*

Table 1: *Data from three plots three years after cutting maidens to three intensities: 1:1; 2:2; 3:1. Numbers in parentheses are standard deviations.*

Parameter	Treatment					
	1:1		2:2		3:1	
No. stools in plot	33		29		59	
No. dead stools in plot	4		5		5	
No. live stools in plot	29		24		54	
% of stools that are alive in plot	88		83		92	
Mean no. shoots per live stool	7.4	(5.34)	8.6	(4.92)	11.5	(6.15)
Mean no. shoots >1m tall per live stool	2.8	(2.57)	6.3	(3.96)	8.6	(5.08)
Mean % shoots >1m tall per live stool	37.0	(32.30)	74.0	(27.10)	75.0	(18.70)
Mean height of tallest 2 shoots per stool (cm)	139.1	(52.63)	194.8	(41.57)	239.1	(60.38)
Mean diameter of tallest 2 shoots per stool (mm)	13.1	(5.62)	20.1	(5.53)	22.4	(5.52)

Figure 4: *Hemispherical photos taken in September 2013, three years after cutting maidens to three intensities: 1:1; 2:2; 3:1.*

There was a positive trend for gap fraction and openness to increase with increased tree lines removed, the greatest being in the 3:1 treatment and the least in the 1:1 treatment (Table 2). The trend for leaf area index (LAI) was negative, with the least LAI in the 3:1 treatment and greatest in the 1:1 treatment. The total PPFD over the canopy was 42.71 mol m^{-2} day^{-1} during the growing season for each of the treatments. The mean total PPFD under the canopy tended to increase with the intensity of tree line removal. The sub-sample of coppice stool data is provided in Table 2.

Table 2: *Data derived from analyses of hemispherical photographs and sub-sampling of coppice stool data three years after intervention. Numbers in parentheses are standard deviations.*

Parameter	Treatment					
	1:1		2:2		3:1	
Gap Fraction (%)	7.00	(0.480)	23.10	(1.960)	38.10	(4.890)
Openness (%)	7.30	(0.490)	24.40	(2.120)	40.30	(5.100)
Leaf Area Index	3.00	(0.200)	1.90	(0.170)	1.30	(0.300)
Diffuse PPFD under canopy (mol m^{-2} d^{-1})	0.63	(0.112)	2.15	(0.251)	3.59	(0.350)
Direct PPFD under canopy (mol m^{-2} d^{-1})	4.07	(0.828)	16.14	(1.851)	24.70	(2.977)
Total PPFD under canopy (mol m^{-2} d^{-1})	4.71	(0.803)	18.29	(1.962)	28.29	(3.296)
Total site factor	0.11	(0.019)	0.43	(0.046)	0.66	(0.077)
Mean % shoots >1 m tall per live stool	37.20	(13.920)	67.00	(21.640)	71.20	(11.940)
Mean height of tallest 2 shoots per stool (cm)	160.10	(37.000)	175.80	(22.530)	224.10	(24.320)
Mean diameter of tallest 2 shoots per stool (mm)	14.80	(2.720)	18.10	(2.540)	21.00	(2.550)

Discussion

The silviculture being applied in this trial is novel in Ireland but a similar systematic thinning regime has been used in Romania for the conversion of hornbeam coppice to high forest. Tulbure and Duduman (2012) describe a trial in which "corridors" or bands 4-7 m wide are created in 15-year-old hornbeam coppice and replanted with a mixture of beech (*Fagus sylvatica*), sessile oak and pedunculate oak (*Q. petraea* and *Q. robur* respectively) with the objective of creating a mixed species high forest system. A more dramatic, but similar, system is described by Marion (1961) for the conversion of coppice systems to high forest with an alternative species in which 3 m wide strips, spaced 5-6 m apart, of poor coppice are bulldozed and replanted with the substitute species. Marion (1961) also notes that strips 1-3 m wide can be used in the substitution of species. Whilst strips 3 m wide are narrow in comparison to those used in our study, Marion was discussing underplanting shade-bearing coniferous species. Evans (1984) provides summarized results of a few rehabilitation treatments employed in a coppice-with-standards system with oak standards over 18-year-old ash and hazel coppice. One of the treatments used was to strip fell leaving 3 m wide "hedges" 16 m apart and replant with oak:Norway spruce 3 row:3 row mixture. The system was found to benefit the form of the oak but yield was reduced compared with clearfelling and replanting with the 3 row:3 row mixture. Our results suggest that, if regeneration is to be from sycamore coppice, 50% or more of the original planted lines of stems need to be felled, but not as alternate lines, resulting in strips 4-6 m wide, to provide sufficient light such that the stools can produce shoots and grow satisfactorily for three years. As the upper canopy continues to close during the following years the coppice growth may become impacted to such an extent that the recommendation should be to fell 75% or more of the original planted lines.

Three growing seasons after cutting, the mean number of coppice shoots per live stool ranged from 7.4 to 11.5 depending on the treatment. Other studies have demonstrated that the number of coppice shoots tends to reduce over time. Stumps from six-year-old sycamore maidens that were coppiced at 15 cm height had produced on average 7.8 shoots per stool after one growing season but this reduced to 3.5 per stool after six growing seasons (Harmer and Howe 2003). Nicolescu et al. (2011) reports 4.6 shoots per stool from 5-year-old sycamore coppice in Romania. With few exceptions, most angiosperm trees with stems <10-15 cm produce numerous coppice shoots after felling and typically 75-90% of these die off within five to ten years. Our results support the idea that the amount of light available to stool shoots also limits their number. The frequency of stool shoots produced relative to the amount of incident light is of no surprise. It has long been known that light plays an important part in the success of stool shoot production. For example, Gayer in 1889 (cited in Brown and Nisbet (1894), vol II, p 179) wrote:

> The first essential for the development of stool-shoots or root-suckers is the supply of light; for stools that are deeply overshadowed, or otherwise deprived of light, either throw out no shoots or stoles, or else develop them only sparsely and indifferently.

Indeed, the coppice-with-standards system requires for its success the careful management of the overstory to ensure that sufficient light is available for the understory coppice stools to thrive (Troup 1928) and continuous cover forestry systems similarly require careful management of light for their success.

Ellenberg's indicator values for British plants (Hill et al. 1999) designates sycamore as an intermediate shade to semi-shade plant when a sapling, more shade tolerant than ash and oak but less so than beech. Niinemets and Valladares (2006) list sycamore as 3.73 ± 0.21 for shade tolerance on a scale of 1 – 5 with 1 being light demanding and 5 being shade tolerant. For comparison, beech was 4.56 ± 0.11, ash was 2.66 ± 0.13 and pedunculate oak was 2.45 ± 0.28. Petriţan et al. (2007) determined quantitatively that sycamore is mid-tolerant of shade. Harmer et al. (2010) use Ellenberg's indicator values to classify sycamore as shade tolerant. Our treatments resulted in 12%, 40% and 62% of the incident photosynthetically active radiation (PAR) being available to the understory sycamore coppice in the 1:1, 2:2 and 3:1 treatments, respectively. The resultant trends in shoot growth broadly agree with that reported by Dreyer et al. (2005) and Delagrange et al. (2006). When PAR was reduced to below 25% of full intensity, sycamore seedling diameter and height growth were greatly reduced (Dreyer et al. 2005, Delagrange et al. 2006) and sapling occurance may be reduced or eliminated when light availability is below a certain threshold (Petriţan et al. 2009).

It should be noted that coppice shoots may differ physiologically from intact stems and can appear more juvenile (Wendling et al. 2014). Leaves of intact plants typically photosynthesise below their capacity. For example, leaves of coppiced red oak (*Q. rubra* L.) saplings in Wisconsin forest openings tended to maintain photosynthetic rates and stomatal conductance near to their morning maxima throughout the day but gas exchange rates of leaves of untreated saplings typically declined during the day following a mid-morning maximum (Kruger and Reich 1993). A similar trend has been reported by Tschaplinski and Blake (1989) for *Populus deltoides* and *P. maximowiczii*×*nigra*. Diurnal photosynthetic patterns of retained stump leaves and new coppice leaves showed that decapitation increased the photosynthetic potential of tissue by increasing net photosynthetic rates in the early afternoon, thereby eliminating the post-midday reduction typical of intact plants.

The height of the tallest shoot per stool of sycamore coppice regrowth in southern England, 2-3 years after cutting, ranged from 0.5 - 4 m with a mean of 1.6 m. Sixty-two percent of the longest shoots per stool were >1.2 m tall (Harmer and Howe 2003).

The difference in the success and growth rate of the coppice shoots between our three treatments is evident (see Figure 3). The range for the tallest two shoots per stool from our study was similar (0.4 – 4.0 m). The mean height of the tallest two shoots per stool from our study ranged from 1.39 – 2.39 m, dependent on the treatment. Approximately 75% of the two tallest shoots per stool were >1 m tall in the 2:2 and 3:1 treatments but only 37% of the shoots from the 1:1 treatment were >1 m tall. The mean height and diameter of the two tallest shoots per stool increased with the amount of available light. Röhrig (1967) observed a similar trend with both height and radial growth. Bonosi (2006) also describes steadily increasing height growth of sycamore seedlings with increasing light availability.

A search of the literature has failed to find any published work on correlating sycamore coppice understory growth parameters to understory light availability or measures of overstory canopy structure (i.e., openness, gap fraction, LAI). Our results suggest a positive trend between the mean diameter of the tallest two shoots per stool and canopy openness, gap fraction, LAI and diffuse, direct and total PAR under canopy. Similar trends were found for the mean height of the tallest two shoots per stool and the percentage of shoots per stool. Some useful comparisons can be made from studies that, by proxy, have affected the overstory canopy structure and the amount of available light to an understory coppice. Gardiner and Helmig (1997) found that the intensity of thinning below of a 28-year-old water oak (*Q. nigra* L.) overstory to either 40% or 60% of original basal area had an effect on coppice shoot height and diameter growth during the first five years. Water oak is a shade intolerant species and by year two, coppice shoots in the heavily thinned plots grew 15% taller than those under the lightly thinned overstory and the difference was maintained five years after the thinning. Shoot diameter increment was similarly affected. Coppice shoot growth reduced as canopy closure advanced. The early benefits of the heavy thinning treatment on stem growth had diminished by year 7 when dominant coppice shoots averaged 2.7 cm DBH and 4.5 m tall, irrespective of the thinning treatment. The heavier thinning prolonged coppice survival and the period between the initial thinning and additional treatments will be determined by the amount of overstory originally removed if coppice regeneration is to be sustained. Lockhart and Chambers (2007) report a similar trial with cherrybark oak (*Q. pagoda* Raf.) and found no significant difference in coppice height during the five years following thinning to either 70-75% or 45-50% original stocking intensity.

The long-term effect of oak standards on growth of a 40-50 year-old hornbeam coppice in a coppice-with-standards system in France was investigated by Bergez et al. (1990) who found no influence of a standard on individual stool growth. However, coppice basal area was negatively affected within 5 m of a standard, despite the shade tolerant nature of hornbeam. It is hoped that our trial will continue to be monitored over the next decade or more so that the full silvicultural impact of carrying out the operations we have conducted can be assessed.

Conclusions

Historical literature provides a wealth of knowledge, much of which is still relevant today. Stumping back could still have a place in Irish broadleaf forestry today. Whilst it must be remembered that the trial is not fully replicated, the results suggest that coppicing/stumping back of pole-stage plantation sycamore may have potential for successful stand rehabilitation if there is enough overstory removed to allow sufficient light for the coppice shoots to progress. Three years after systematic thinning, it appears that the removal of 75% of the tree lines will be most successful, both in producing sufficient shoot growth and sufficient number of shoots to facilitate subsequent singling, but a fully replicated trial across different sites should be initiated to confirm whether this is the case. A pilot trial in the 3:1 treatment has since been initiated to investigate the impact of singling coppice shoots because we believe that the 3:1 treatment will provide the best chance to support the rehabilitation of the stand to a quality high forest with minimal further overstory interventions. Fundamental to the future commercial quality of the re-configured stand is the stem form of the regrowth. This is often excellent, particularly in the 3:1 treatment where shoot extension is greatest. While this may be due to improved growth conditions, it remains to be seen whether this remains the case following singling and on into the rotation but historical literature supports our view. Furthermore, there may be some economic impact by effectively returning a proportion of the stand to year zero. However, this may be offset by more vigorous and better quality material continuing to catch up the original growing stock. A future economic study of the stand rotation may shed some light on this.

Acknowledgements

Funding for the B-SilvRD project is provided under the National Development Plan, through the COFORD Forest Research Programme, administered by the Department of Agriculture, Food and the Marine. Especial thanks are due to Mr Vivian Kenny, the owner of the plantation in which the trial is being conducted. The authors also wish to thank the editor and reviewers for helpful comments and suggestions which greatly improved this manuscript.

References

Bergez, J.E., Cabanettes, A., Auclair, D. and Bédéneau, M. 1990. Effet des réserves de taillis sous futaie sur la croissance du taillis. Étude préliminaire. *Annals of Forest Science* 47: 146-160.

Billington, W. 1825. *A Series of Facts, Hints, Observations and Experiments on the Different Modes of Raising Young Plantations of Oaks, "For Future Navies," From* *the Acorn, Seedling and Larger Plants, Shewing the Difficulties and Objections That Have Occurred in the Practical Part*. London.

Bolton, Lord. 1956. *Profitable Forestry*. Faber & Faber Limited, London. pp. 68-69.

Bonosi, L. 2006. The influence of light and size on photosynthetic performance, light interception, biomass partitioning and tree architecture in open grown *Acer pseudoplatanus*, *Fraxinus excelsior* and *Fagus sylvatica* seedlings. *Schriftenreihe Freiburger Forstliche Forschung* 34, Albert-Ludwigs Universität und Forstl. Versuchs- und Forschungsanstalt , Baden-Württemberg, (ed.). Freiburg 118 p. Cited in Petriţan, A.M., Lüpke, B.V. and Petriţan, I.C. 2007. Effects of shade on growth and mortality of maple (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and beech (*Fagus sylvatica*) saplings. *Forestry* 80: 397-412.

Brown, J. and Nisbet, J. 1894. *The Forester. A Practical Treatise on the Planting and Tending of Forest Trees and the General Management of Woodland Estates*. 6th ed. William Blackwood and Sons, London.

Çiçek, E. and Tilki, F. 2007. The effect of stumping back on survival and growth of planted *Fraxinus angustifolia* Vahl. *Asian Journal of Plant Science* 6: 546-549.

Clark, J. and Brocklehurst, M. 2011. Stumping in walnut. *Quarterly Journal of Forestry* 105: 275-279.

COFORD. 2012. *Forest Genetic Resources in Ireland*. COFORD National Consultative Committee on Forest Genetic Resources 2012. COFORD, Dublin.

de Buffon, M. 1742. Quoted in: Nicol, W. 1820. *The Planter's Kalendar; or the Nurseryman's & Forester's Guide in the Operations of the Nursery, the Forest and the Grove*. 2nd ed. Archibald Constable and Co., Edinburgh. p. 296.

Delagrange, S., Montpied, P., Dreyer, E., Messier, C. and Sinoquet, H. 2006. Does shade improve light interception efficiency? A comparison among seedlings from shade-tolerant and -intolerant temperate deciduous tree species. *New Phytologist* 172: 293–304.

Dreyer, E., Collet, C., Montpied, P. and Sinoquet, H. 2005. Caractérisation de la tolérance à l'ombrage des jeunes semis de hêtre et comparaison avec les espèces associées. *Revue Forestière Française* 57: 175-188.

EPA. 2013. EPA Geo Portal website maps. Available at http://gis.epa.ie/Envision [Accessed September 2015].

Evans, J. 1984. *Silviculture of Broadleaved Woodland*. Forestry Commission Bulletin 62. HMSO, London

Forest Service 2012. *2011 Annual Report*. Department of Agriculture, Food and the Marine, Dublin.

Forest Service 2013. *National Forest Inventory Republic of Ireland – Results*. Covering the National Forest Inventory, 2009–2012. Department of Agriculture, Food and the Marine, Dublin.

Gardiner, E.S. and Helmig, L.M. 1997. Development of water oak stump sprouts under a partial overstory. *New Forests* 14: 55-62.

Gayer 1889. *Waldbau*. Cited by: Brown, J. and Nisbet, J. 1894. *The Forester: A Practical Treatise on the Planting and Tending of Forest Trees and the General Management of Woodland Estates*. Vol. II. William Blackwood and Sons, London.

Harmer, R. 2004. Coppice silviculture practiced in temperate regions. In *Encyclopedia of Forest Sciences* vol. III, Eds. Burley, J., Evans, J. and Youngquist, J.A. pp. 1045-1052.

Harmer, R. and Howe, J. 2003. *The Silviculture and Management of Coppice Woodlands*. Forestry Commission, Edinburgh.

Harmer, R., Kerr, G. and Thompson, R. 2010. *Managing Native Broadleaved Woodland*. The Stationery Office, Edinburgh.

Hawe, J. 2009. *Vivian Kenny – Thinning of broadleaf plantations*. Unpublished report. Sylviron Ltd., Castlebar, Co. Mayo.

Hawe, J. and Short, I. 2012. Poor performance of broadleaf plantations and possible remedial silvicultural systems – a review. *Irish Forestry* 69: 126-147.

Hemery, G. and Savill, P. 2001. The use of treeshelters and application of stumping in the establishment of walnut (*Juglans regia*). *Forestry* 74: 479-489.

Hendrick, E. and Nevins, D. 2003. Foreword to: Fennessy, J. and MacLennan, L. (Eds). *Managing Our Broadleaf Resource to Produce Quality Hardwood Timber.* Proceedings of the COFORD seminar 10–11th October 2002, Carrick-on-Shannon. COFORD, Dublin.

Henriksen, H.A. and Bryndum, H. 1989. Zur Durchforstung von Bergahorn und Buche in Dänemark. *Allgemeine Forst- und Jagdzeitschrift* 38–39: 1043–1045 . Cited in: Hein, S., Collet, C., Ammer, C., Le Goff, N., Skovsgaard, J.P. and Savill, P. 2008. A review of growth and stand dynamics of *Acer pseudoplatanus* L. in Europe: implications for silviculture. *Forestry* 82:361–385.

Hiley, W.E. 1931. *Improvement of Woodlands*. Country Life Ltd., London.

Hill, M.O., Mountford, J.O., Roy, D.B. and Bunce, R.G.H. 1999. *Ellenberg's Indicator Values for British Plants*. Institute of Terrestrial Ecology, Huntingdon.

HMSO 1981. *Yield Models for Forest Management*. Forestry Commission Booklet 48. HMSO, London.

Hough, F.B. 1882. *Elements of Forestry*. Robert Clark & Co., Cincinnati. p. 52.

James, N.D.G. 1991. *An Historical Dictionary of Forestry and Woodland Terms*. Basil Blackwell Ltd., Oxford. p. 83.

Joyce, P.M., Huss, J., McCarthy, R., Pfeifer, A. and Hendrick, E. 1998. *Growing Broadleaves. Silvicultural Guidelines for Ash, Sycamore, Wild Cherry, Beech and Oak in Ireland*. COFORD, Dublin.

Kerr, G. 1995. The silviculture of ash in southern England. *Forestry* 68: 6370.

Kerr, G. and Boswell, R.C. 2001. The influence of spring frosts, ash bud moth (*Prays fraxinella*) and site factors on forking of young ash (*Fraxinus excelsior*) in southern Britain. *Forestry* 74: 29-40.

Kerr, G. and Evans, J. 1993. *Growing Broadleaves for Timber.* Handbook 9. Forestry Commission. HMSO, London.

Köstler, J. 1956. *Silviculture*. Translated from *Waldbau* by Anderson, M.L. Oliver and Boyd, London.

Kruger, E.L. and Reich, P.B. 1993. Coppicing alters ecophysiology of *Quercus rubra* saplings in Wisconsin forest openings. *Physiologia Plantarum* 89: 741-750.

Lockhart, B.R. and Chambers, J.L. 2007. Cherrybark oak stump sprout survival and development five years following plantation thinning in the lower Mississippi alluvial valley, USA. *New Forests* 33: 183-192.

Madden, T.S. 1945. Observations on the results of cutting back naturally regenerated and planted ash at Donadea Forest. *Irish Forestry* 2: 74-75.

Marion, J. 1961. Conversion of degraded hardwood forests in France. *Unasylva* 15(1). Available from http://www.fao.org/docrep/x5398e/x5398e06.htm#conversion of degraded hardwood forests in france. [Accessed September 2015].

Mayhead, G.J. and Boothman, I.R. 1997. The effect of treeshelter height on the early growth of sessile oak (*Quercus petraea* (Matt.) Liebl.). *Forestry* 70: 151-155

Nicol, W. 1820. *The Planter's Kalendar; or the Nurseryman's & Forester's Guide in the Operations of the Nursery, the Forest and the Grove. 2nd Ed. p. 296-297.*

Nicolescu, V.N., Sandi, M., Sandi, W., Pricop, A. 2011. Early growth performances of sycamore maple (*Acer pseudoplatanus* L.) treated as high forest or coppice: a case study. *Applied Forestry Research in the 21st Century*. Book of Abstracts, International Conference, Forestry and Game Management Research Institute, Prague-Průhonice (Czech Republic), September 13-15, 2011, pp. 64.

Niinemets, Ü. and Valladares, F. 2006. Tolerance to shade, drought and waterlogging of temperate Northern Hemisphere trees and shrubs. *Ecological Monographs* 76: 521-547.

Petriţan, A.M., von Lüpke, B. and Petriţan, I.C. 2007. Effects of shade on growth and mortality of maple (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and beech (*Fagus sylvatica*) saplings. *Forestry* 80: 397-412.

Petriţan, A.M., von Lüpke, B. and Petriţan, I.C. 2009. Influence of light availability on growth, leaf morphology and plant architecture of beech (*Fagus sylvatica* L.), maple (*Acer pseudoplatanus* L.) and ash (*Fraxinus excelsior* L.) saplings. *European Journal of Forest Research* 128: 61-74.

Röhrig, E. 1967. Wachstum junger Laubholzpflanzen bei unterschiedlichen Lichtverhältnissen. *Allg. Forst. Jagdztg* 138: 224-239. Cited in: Petriţan, A.M., von Lüpke, B. and Petriţan, I.C. 2007. Effects of shade on growth and mortality of maple (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and beech (*Fagus sylvatica*) saplings. *Forestry* 80: 397-412.

Savill, P. 2013. *The Silviculture of Trees Used in British Forestry*. 2nd ed. CABI: Wallingford.

Short, I. 2013. The potential for using a free-growth system in the rehabilitation of poorly performing pole-stage broadleaf stands. *Irish Forestry* 70: 157-171.

Short, I. and Hawe, J. 2012. Possible silvicultural systems for use in the rehabilitation of poorly performing pole-stage broadleaf stands – Coppice-with-standards. *Irish Forestry* 69: 148-166.

Society for Promoting Christian Knowledge. 1851. *The British Sylva and Planters' and Foresters' Manual*. Published under the direction of the Committee of General Literature and Education appointed by the Society for Promoting Christian Knowledge, London. p. 105-106.

Stern, R.C. 1989. Sycamore in Wessex. *Forestry* 62: 365-382.

Stevenson, G.F. 1985. The silviculture of ash and sycamore. *Proceedings of National Hardwoods Programme*. Commonwealth Forestry Institute, Oxford**:** 25-31.

Tillisch , E. 2001. Æren trænger sig frem . *Dan. Skovbrugs Tidssk* 86: 1-96. Cited in Hein, S., Collet, C., Ammer, C., Le Goff, N., Skovsgaard, J.P. and Savill, P. 2008. A review of growth and stand dynamics of *Acer pseudoplatanus* L. in Europe: implications for silviculture. *Forestry* 82: 361-385.

Troup, R.S. 1928. *Silvicultural Systems*. Clarendon Press, Oxford.

Tschaplinski, T.J. and Blake, T.J. 1989. Photosynthetic reinvigoration of leaves following shoot decapitation and accelerated growth of coppice shoots. *Physiologia Plantarum* 75: 157-165.

Tulbure, C. and Duduman, G. 2012. A conversion method of young hornbeam coppices and its possible impact on future stand structural attributes. *Annals of Forest Research* 55: 281-296.

van Miegroet, M. 1956. Untersuchungen über den Einfluß der waldbaulichen Behandlung und der Umweltsfaktoren auf den Aufbau und die morphologischen Eigenschaften von Eschendickungen im schweizerischen Mittelland. *Mitteilungen Schweizerischen Anstalt forstliche Versuchswesen*. 32, 229–370. Cited in Dobrowolska, D., Hein, S., Oosterbaan, A., Wagner, S., Clark, J. and Skovsgaard, J.P. 2001. A review of European ash (*Fraxinus excelsior* L.): implications for silviculture. *Forestry* 84: 133-148.

Wendling, I., Trueman, S.J. and Xavier, A. 2014. Maturation and related aspects in clonal forestry—Part II: reinvigoration, rejuvenation and juvenility maintenance. *New Forests* 45: 473-486.

Definitions

Openness	Percentage of open sky (unobstructed by vegetation) in a hemispherical image.
Gap fraction	Fraction of pixels in a hemispherical image unobstructed by foliage.
LAI	Leaf Area Index calculated with the LiCor LAI2000 generalised linear method and corrected for foliar clumping.
PAR	Photosynthetically active radiation, i.e. the 400-700 nm waveband.
PPFD	Photosynthetic Photon Flux Density, i.e. the Photon Flux Density of PAR (also referred to as Quantum Flux Density) is the number of photons in the 400-700 nm waveband measured per unit time on a unit surface.
Diffuse PPFD under canopy	Average Diffuse Photosynthetically-active Flux Density under canopy for the growing season (mol m^{-2} d^{-1}).
Direct PPFD under canopy	Average Direct Photosynthetically-active Flux Density under canopy for the growing season (mol m^{-2} d^{-1}).
Total PPFD under canopy	Average Total Photosynthetically-active Flux Density under canopy for the growing season (mol m^{-2} d^{-1}).
Total site factor	$\frac{\text{Average daily direct+diffuse radiation under canopy}}{\text{Average daily direct+diffuse radiation over canopy}}$