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# Triclopyr applied in the winter dormant season can give effective control of bramble (*Rubus fruticosus* L. agg.) without damaging young tree seedlings or other non-target vegetation

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The effect of dormant season applications of triclopyr on the growth and survival of young trees was investigated in two experiments using transplants grown for one season beneath a canopy of Corsican pine prior to treatment with varying concentrations of herbicide. In one experiment, transplants of ash, beech and oak were initially grown with or without competition from bramble. In the second experiment, birch, hazel, oak, Scots pine, Douglas fir and Japanese larch were grown without competition from bramble or other ground flora. Bramble reduced survival and growth of oak and appeared to reduce the tolerance of ash, oak and beech to herbicide applications. Although the precise effect of the herbicide differed between experiments, where adverse effects on survival and growth were found these only occurred at dose rates of 1.92 and 2.88 kg a.i. $ha^{-1}$ and even at these rates some of the species used were unaffected. With the exception of oak and beech in one experiment, survival exceeded 90 per cent at the end of the first growing season after application of herbicide, regardless of dose rate. The same pattern of results was found for height and diameter increments. In a third experiment, dormant season applications of triclopyr reduced bramble cover but appeared to have little effect on other ground flora species. The work reported here indicates that where bramble is threatening to outcompete and kill young tree seedlings application of 0.96 kg a.i. $ha^{-1}$ triclopyr (equivalent to 2 l $ha^{-1}$ Timbrel, 480 g $l^{-1}$ triclopyr; Dow AgroSciences) in water in the winter season can effectively control bramble, while leaving deeply dormant seedlings of oak, beech, ash, birch, hazel, Scots pine, Douglas fir and Japanese larch unharmed.

## Introduction

Bramble (*Rubus fruticosus* L. agg.) is a perennial, semi-evergreen, climbing shrub that is native throughout much of Europe and has been introduced to many other countries where it is often a problem invasive species.[1,2] It consists of a complex mix of related species that spreads by seeds and vegetative stolons. Its vigorous growth habit can sometimes make it a troublesome forest weed: it can prevent newly germinated tree seedlings from establishing; rapidly invade new areas; kill existing regeneration or planted nursery grown stock; and harbour rabbits and voles which can severely damage any remaining seedlings.[3] The harmful effects of bramble result from its ability to out compete tree seedlings for resources such as light, moisture and nutrients, but also from its propensity to physically smother young plants.[4] Bramble can pose a particular problem when woodlands are being managed to encourage natural regeneration where species such as bramble, whose growth is encouraged by the increased light levels following thinning, develop at the expense of slower growing tree seedlings.[4] In addition, scarification, which is often recommended to encourage natural regeneration, can also stimulate the establishment of bramble cover by promoting germination of any seeds present within the seed bank.

Although bramble has been shown in some circumstances to provide some protection from browsing animals,[5–7] under woodland conditions it is possible that only tree seedlings from fast growing species such as ash (*Fraxinus excelsior* L.), willow (*Salix* spp.) and birch (*Betula* spp.) are likely to benefit, and even then only when they are established before the bramble starts to dominate. Slower growing seedlings from species such as oak (*Quercus* sp.) and beech (*Fagus sylvatica* L.), or seedlings of any species which germinate once the thicket is already well established, are unlikely to thrive.[8] Once light levels on the forest floor increase after thinning or felling, an initially sparse cover of bramble can rapidly expand and colonize a site, effectively preventing new tree regeneration,[9] and therefore in British woodlands, some form of local or targeted control is often required to help favour planted or naturally regenerated tree seedlings at the expense of bramble.

Where necessary, bramble can be temporarily controlled through grazing, cutting or deep cultivation, but such operations are usually either very costly, or difficult to carry out without also damaging or disturbing existing tree seedlings or other ground flora. In addition, regrowth of bramble is often rapid once control operations cease. A tractor mounted spring tine cultivator has been used to manage dense bramble thickets by combing bramble canes from among beech seedlings,[10] but effects are likely to be short term.[11] The use of bioherbicides to control bramble has been explored, particularly in Canada, but currently the prospects for identifying an effective mycoherbicide for use in Britain appear slim.[12] Residual soil acting herbicides such as pendimethalin and isoxaben can help to prevent the germination of new seedlings,[13] but do nothing to prevent vegetative spread or control established plants.

Foliar acting herbicides can give successful, longer term control of bramble within woodlands, and are likely to be the simplest and cheapest method of control in many situations.[14,15] Broad-spectrum herbicides such as glyphosate, amitrole, triclopyr, and 2,4-D + dicamba + triclopyr can give good control[14] and can be safely used before tree planting, or prior to the emergence of natural regeneration, but they can severely damage non-target vegetation and existing tree seedlings. However, even after good pre-planting control, bramble will often invade sites where young trees are establishing. If trees are protected from browsing using treeshelters then it is relatively easy to spray a targeted spot of broad-spectrum herbicide without damaging trees. It is also possible to target sprays around the base of unprotected trees, but the risk of causing herbicide damage is much greater even if trees are planted in clearly defined rows. Control of bramble using herbicides is much more difficult in areas of irregularly spaced naturally regenerating trees. Under such conditions, the most useful herbicides would selectively control bramble while leaving tree seedlings and more desirable components of the woodland ground flora unharmed.

Currently, there appear to be no options for using foliar acting herbicides to control bramble selectively while leaving actively growing trees unaffected.[14] However, it may be possible to control semi-evergreen species such as bramble during the winter, when tree species are dormant and less likely to suffer damage from broad-spectrum herbicides,[16,17] Paraquat has been regarded as safe as an overall spray of dormant deciduous fruit trees and bushes providing no green buds are present.[18] Similarly, Willoughby *et al.*[19] showed that paraquat application during the dormant season was generally safe for a wide range of deciduous species, and that weed competition or size of open grown ash seedlings had no effect on tree tolerance. However, Harmer *et al.*[11] found this treatment applied in December caused tip dieback of beech, possibly due to the greater susceptibility of seedlings grown under a canopy of trees and among weed vegetation. Several authors have reported a degree of tolerance of dormant trees to glyphosate,[11,19–21] but effects can vary with time of application and dose rate. Triclopyr applied in the dormant season was found to offer the best combination of effective control and tree tolerance for seedlings of beech and oak (*Quercus robur* L.) growing within bramble.[4,11] Impacts on non-target woodland plants were also found to be low, but in both cases this may have been due, in part, to the herbicides not penetrating the thick cover of bramble present at the experimental sites.

The aim of the work reported here was to determine firstly, whether dormant season application of triclopyr was an effective means of controlling bramble without damaging tree seedlings of a range of species growing beneath a tree canopy and secondly, whether it had adverse effects on other species of the woodland ground flora. Three experiments were undertaken, two observed effects of triclopyr on seedlings grown beneath an overstorey of pine and one studied the effects on ground flora of an ash woodland. The experiments with tree seedlings used transplants grown for one season at the experimental site either with or without bramble. This was done to investigate whether the tolerance of plants grown within the shaded competitive conditions of a bramble thicket differed from that of plants grown without ground flora competition.

## Methods

*Experiment 1: The effect of triclopyr on transplants grown for one season with or without competition from bramble*

This was carried out in a 39-year-old stand of Corsican pine (*Pinus nigra* ssp. *laricio*) at Tugley Wood, Chiddingfold, in the south of England (51.0932° N, 0.5963° W). The site, which is ~60 m above sea level with a mean annual rainfall of *c*. 660 mm, has a brown forest soil of the Wickham 5 Association[22] which is of poorly drained clay-loam texture with a pH of 4.5–5.2. The stand was thinned in 1996 and at the start of the experiment in 2006 there were ~420 stems $ha^{-1}$ with a basal area of *c*. 31 $m^2$ $ha^{-1}$. There were occasional broadleaves in the overstorey including ash and oak, and a sparse understorey including hazel (*Corylus avellana* L.) and sweet chestnut (*Castanea sativa* Mill.). The ground flora was dominated by bramble. The experimental area was fenced to exclude deer such as roe and muntjac (*Capreolus capreolus* L., *Muntiacus reevesi* Ogilby) and also rabbits (*Oryctolagus cuniculus* L.).

The experiment used a randomized split plot design (Figure 1). Prior to planting half of the area was mechanically cleared of ground flora, including any small shrubs present, to create a vegetation-free *without bramble* treatment. The *with bramble* treatment remained uncleared. There were five replicate blocks including each vegetation treatment/herbicide sub-treatment combination. Container grown plants, 20–30 cm tall, of ash, beech and oak (*Q. robur*) were planted in April 2005, protected using vole guards and allowed to grow for one season before application of the herbicide treatments to both *with bramble* and *without bramble* plots during the following winter. Each sub-treatment plot contained one row of each species; there were 15 plants 0.5 m apart in each row and 0.5 m between rows (Figure 1). The five herbicide sub-treatment plots were located at random within each of these two vegetation treatments. There was a 1-m buffer between the sub-treatment plots. The herbicide sub-treatments comprised applications of triclopyr (as Timbrel, 480 g $l^{-1}$ triclopyr; Dow AgroSciences), diluted in water at a volume rate of 400 l $ha^{-1}$, using a knapsack sprayer. Applications were made on 1 or 2 February 2006 at the following rates:

**H0**: no herbicide control, water only sprayed;
**H1**: 0.48 kg a.i. $ha^{-1}$ (equivalent to a product rate of 1 l $ha^{-1}$ Timbrel);
**H2**: 0.96 kg a.i. $ha^{-1}$ (equivalent to 2 l $ha^{-1}$ Timbrel);
**H3**: 1.92 kg a.i. $ha^{-1}$ (equivalent to 4 l $ha^{-1}$ Timbrel);
**H4**: 2.88 kg a.i. $ha^{-1}$ (equivalent to 6 l $ha^{-1}$ Timbrel).

No rain occurred for at least 24 h after treatment. Vole guards were temporarily removed when these treatments were applied. Moveable, hand-held, wooden-framed, plastic-covered screens were temporarily held in place on either side of the herbicide sub-treatment plot while spraying took place, to prevent drift to adjacent plots. After spraying, they were immediately moved to the next herbicide sub-treatment plot. During the lifetime of the experiment, a combination of mechanical weeding and

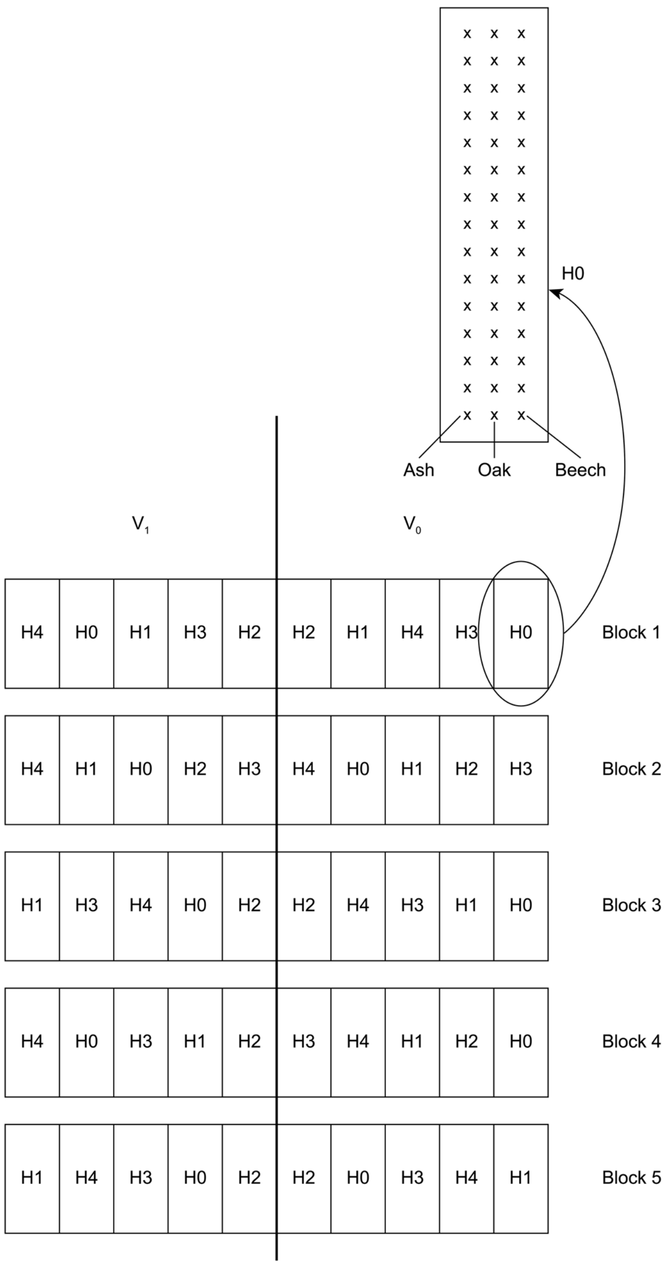


**Figure 1** Schematic layout for Experiment 1.

glyphosate herbicide was used to maintain weed-free conditions in the *without bramble* treatment: planted trees were temporarily protected during glyphosate applications using sprayer hoods on the knapsack sprayers.

Height (cm) and diameter (mm) at ground level were measured in April 2005 at planting, in October 2005 before experimental herbicide treatments were applied, and in October 2006, one growing season after the treatments were applied. Survival was assessed in October 2005 and October 2006. Flushing was assessed in May and June 2006; seedling health during June and August using a 5-point scale (where 1 = completely healthy, 5 = dead). The percentage cover of bramble within each sub-treatment plot was assessed before herbicide treatment in September 2005 and in the growing season after treatment during May and August 2006 using the following classes: $< 5$, $5 < 10$, $10 < 25$, $25 < 50$ and 50–100 per cent. Height (cm) of the bramble thicket beside each seedling (ignoring occasional tall stems emerging from the adjacent thicket) was only measured in September 2005 before herbicide treatments were applied.

### *Experiment 2: Effect of triclopyr on tree seedlings grown in weed-free conditions beneath a tree canopy*

This was carried out at the same site as Experiment 1. During February 2007, container grown plants 20–40 cm tall of birch (*Betula pendula* Roth), hazel, oak (*Q. robur*), Scots pine (*Pinus sylvestris* L.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Japanese larch (*Larix kaempferi (Lindl.) Carrière*) were planted. Trees were established in single species sub-plots of 15 trees comprising 3 rows of 5 trees at 0.5 m spacing between and within rows. Fifteen trees were planted per sub-plot to allow for any non-treatment-related losses, with the intention that there would be at least 10 trees per sub-plot surviving at the end of the growing season which could be given the herbicide treatments. The plants were grown for one season in weed-free conditions created and maintained, as described for Experiment 1. On 3 January 2008, the five triclopyr treatments were applied as in Experiment 1. There was one sub-plot of each species in each herbicide treatment plot which were surrounded by 1 m buffer zones. There were five replicates of each herbicide treatment arranged in a randomized block design.

During October 2007, at the end of the first growing season before the application of the herbicide treatments, the height (cm) and diameter (mm) at ground level of 10 randomly selected plants were measured within each sub-plot. In May 2008, plant health was recorded, and in October 2008, one full growing season following treatment, height, diameter and survival was assessed using the methods described for Experiment 1.

### *Experiment 3: The effect of triclopyr applications during the dormant season on common woodland herbs*

This study was carried out in Silk Wood, at Westonbirt Arboretum (51.6007° N, 2.2367° W) in a stand of neglected mixed coppice with oak standards which had woody and herbaceous species characteristic of NVC W8 ash – field maple – dog's mercury (*Mercurialis perennis* L.) woodland.[23] The overstorey was dominated by ash with some oak and field maple (*Acer campestre* L.) with a well-developed understorey including hazel, dogwood (*Cornus sanguinea* L.) and spindle (*Euonymus europaeus* L.). The stand had a basal area of 25 $m^2$ $ha^{-1}$ and was growing on a typical brown earth of the Waltham series, the soil was *c.* 60 cm deep overlaying limestone and was clay loam in texture.[24,25] During August 2007, 15 plots, 5 × 5 m in size, were established within an area of woodland *c.* 50 $m^2$ in which there was a well-developed ground flora. The percentage cover of each species present was then assessed within a 2 × 2 m quadrat located at the centre of each plot using the following classes: ≤5, 5–10, 11–20, 21–30, …91–100 per cent. These data were then analysed using a combination of cluster and principal component analyses to create five approximately homogenous blocks each comprising three plots with similar covers of similar species. The following treatments were randomly allocated to plots within each block:

**HT0** No herbicide control, water only sprayed.
**HT1** 0.96 kg a.i. $ha^{-1}$ triclopyr (equivalent to 2 l $ha^{-1}$ Timbrel) during the first half of the dormant season on 12th December 2007.

**HT2** 0.96 kg a.i. $ha^{-1}$ triclopyr (equivalent to 2 l $ha^{-1}$ Timbrel) during the second half of the dormant season on 24th January 2008.

The herbicide was applied to the whole 5 × 5 m area of each plot using a knapsack sprayer at a volume rate of 261 l $ha^{-1}$, using water as the diluent. No rain occurred for at least 24 h after treatment. The percentage cover of each species present in the central 2 × 2 m quadrats was assessed immediately prior to spraying and again in April and July 2008, when an assessment of relative health was also made (using a 1–5 scale, where 1 = as the healthiest control plot; 5 = dead).

### Statistical methods

Data were analysed using the Genstat statistical package.[26] For Experiment 1, survival, flushing and bramble cover were investigated using a binomial generalized linear model with a logit link. The survival data for plants in Experiment 2 were analysed using Fisher's exact test. All height and diameter increments were investigated using analyses of variance with the values for height and diameter before herbicide treatment as covariates. Health scores and bramble heights were investigated by analysis of variance with no covariates. Although the herbicide treatments are discrete treatments, they increase in a logical sequence and for ease of interpretation figures have been drawn as line graphs. In Experiment 3, for each plot, the change between 2007 and 2008 in the percentage ground cover of each species, adjusted to account for the initial differences in cover between plots. This change was calculated as

$$\text{Change} = (\%\text{cover2008} - \%\text{cover2007}) \div ((\%\text{cover2008} + \%\text{cover2007}) \div 2)$$

The Kruskal–Wallis one-way analysis of variance with groups was then used to investigate the effects of herbicide treatments on the change in percentage ground cover.

## Results

### Experiment 1

Use of glyphosate and mechanical cutting to create bramble-free conditions was effective and throughout the experiment with a single exception at one assessment date the *without bramble* plots had <5 per cent bramble. In contrast, only one of the *with bramble* plots had <50 per cent cover prior to application of triclopyr which killed bramble and reduced cover. Although regrowth occurred, cover remained lower than 50 per cent throughout summer in all plots treated with herbicide and on some receiving the highest dose it remained <5 per cent in August.

The presence of bramble in the 2005 growing season prior to treatment had no effect on the survival of ash or beech plants with ∼99 and 95 per cent surviving, respectively. In contrast, for oak, *c*. 98 per cent survived in the *without bramble* treatment, whereas significantly fewer, ∼86% ($P < 0.001$), survived in the *with bramble* treatment. At the end of the 2005 growing season, before herbicide treatments were applied, beech plants were *c*. 42 cm tall and both oak and ash were *c*. 37 cm tall. The height of all species was unaffected by the presence of bramble which was ∼40 cm tall in the *with bramble* treatment.

The presence of bramble had a significant effect on the number of ash and oak plants that had flushed by May with a significantly smaller proportion flushing in the *with bramble* treatment (Table 1); in contrast, bramble had no significant effect on flushing of beech. However, the proportion of plants which flushed of all three species was affected to some extent by application of triclopyr with the severity of the effect increasing with dose of herbicide. For all species, H1 did not significantly reduce the proportion which had flushed by May relative to the control, whereas H4 caused the largest reduction which was always significant (Table 1): the other treatments were intermediate and the effect varied with species. Overall

**Table 1** Proportion of plants of each species that had flushed by May in each bramble and herbicide treatment, Experiment 1

| Species | Bramble | Herbicide treatment | | | | | Statistics | |
|---|---|---|---|---|---|---|---|---|
| | | H0 | H1 | H2 | H3 | H4 | BBL | Herb |
| Ash | *Without* | 1.00a | 1.00a | 1.00a | 0.91b | 0.75c | <0.001 | <0.001 |
| | *With* | 1.00a | 1.00a | 0.97b | 0.82c | 0.57d | | |
| | Mtrt | **1.00** | **1.00** | **0.99** | **0.86** | **0.66** | | |
| Beech | *Without* | 0.99a | 0.98a | 1.00a | 0.94a | 0.77b | n.s. | <0.001 |
| | *With* | 1.00a | 0.99a | 0.97ab | 0.89bc | 0.82c | | |
| | Mtrt | **0.99** | **0.98** | **0.99** | **0.92** | **0.79** | | |
| Oak | *Without* | 0.99a | 0.99a | 0.93a | 0.58b | 0.44b | <0.001 | <0.001 |
| | *With* | 0.93a | 0.80b | 0.63b | 0.29c | 0.19c | | |
| | Mtrt | **0.96** | **0.89** | **0.78** | **0.43** | **0.32** | | |

See Methods section for details of bramble and herbicide treatments. BBL = significance of bramble treatment for each species; Herb = significance of herbicide treatment for each species; Mtrt = mean value for each species within each herbicide treatment. Values for each herbicide treatment are the mean proportion of plants that flushed in each of the five replicate plots. Within each row any values with the same letter do not differ significantly ($P > 0.05$). Over all species, the standard errors of the means of the individual bramble/herbicide combinations were <1%–25% of the mean values.

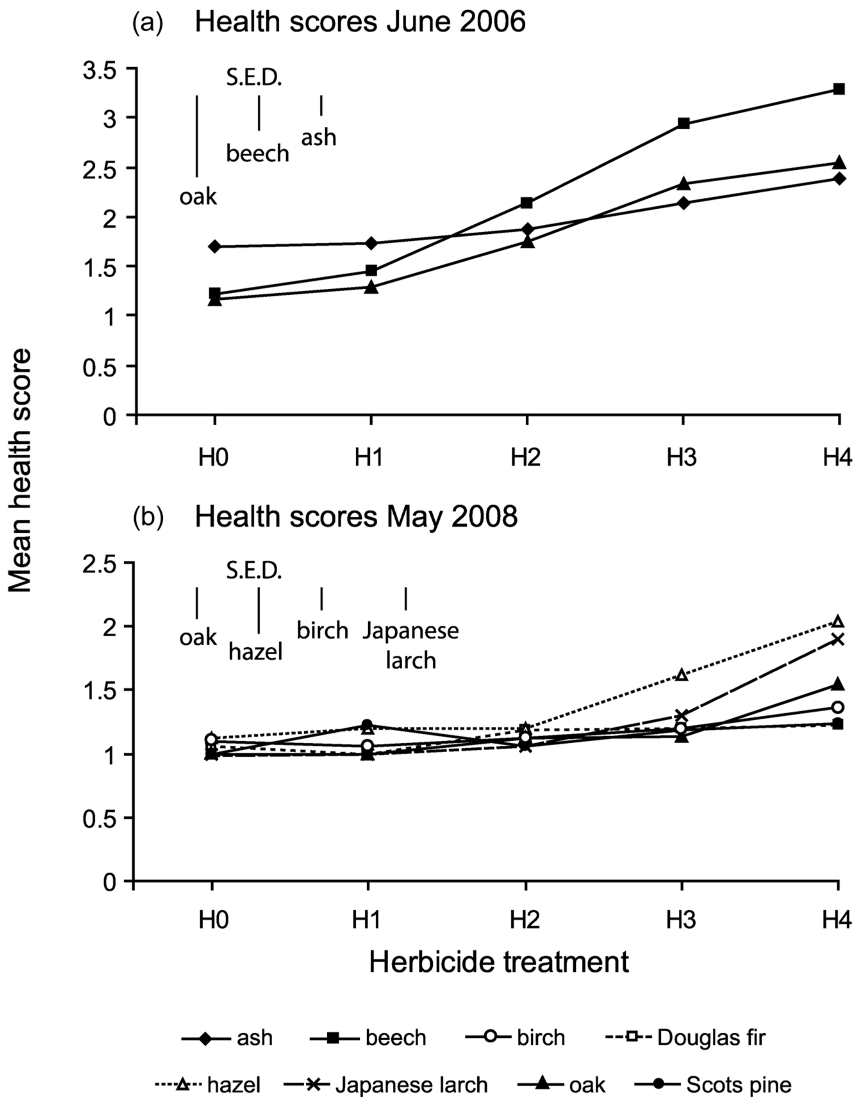


**Figure 2** Mean health score of plants that flushed: (a) Experiment 1 – June 2006 and (b) Experiment 2 – May 2008. Standard errors of differences of means are shown for species where there were significant differences between herbicide treatments.

oak was worst affected and only ~20–40 per cent of plants had flushed by May in the H4 treatment, whereas ~0–80 per cent of ash and beech flushed. There were no significant interactions between the bramble and herbicide treatments. Although for all species the number of plants that flushed had increased by June, the pattern of the results was similar and data are not shown.

The health score of plants was not affected by the bramble treatments (Figure 2a). However, the herbicide treatment had some significant effects. For both ash and oak, although treatments H1 and H2 did not differ significantly from the H0 control, plants receiving higher doses (H3 and H4) had significantly worse health scores ($P < 0.001$). Beech responded differently with health declining progressively as dose of herbicide increased and all treatments had significantly worse scores than the H0 control treatment.

Survival of plants to the end of the growing season after herbicide application varied between species and differed significantly between treatments within species (Table 2a). For all species, survival in the *with bramble* treatment was lower than in the *without bramble* treatment, but this was only significant for oak ($P < 0.001$). At the highest doses of herbicide, only about half as many oak plants survived in the *with bramble* treatment compared with the *without bramble* treatment. Application of triclopyr reduced survival of all species, ash was least affected and oak the most, but for all species the reduction was only significant for the higher H3 and H4 treatments (Table 2).

The effect of treatments on growth of plants was assessed by comparing increments in height and stem diameter at the end of the growing season following application of herbicide (Table 3). The effect of bramble alone was never significant for

**Table 2** Proportion of plants surviving one growing season after dormant season application of triclopyr

(a) Experiment 1: Three species grown for one season either with or without bramble before treatment[a]

| Species | Bramble | Herbicide treatment | | | | | Statistics | |
|---|---|---|---|---|---|---|---|---|
| | | H0 | H1 | H2 | H3 | H4 | BBL | Herb |
| Ash | *Without* | 1.00a | 1.00a | 1.00a | 0.99ab | 0.96b | n.s. | <0.001 |
| | *With* | 0.99a | 1.00a | 1.00a | 0.97ab | 0.93b | | |
| | Mtrt | | | | | | | |
| Beech | *Without* | 1.00a | 0.97a | 0.97a | 0.79b | 0.62c | n.s. | <0.001 |
| | *With* | 0.98a | 0.99a | 0.94a | 0.84b | 0.51c | | |
| | Mtrt | | | | | | | |
| Oak | *Without* | 1.00a | 0.99a | 0.93a | 0.78b | 0.72b | <0.001 | <0.001 |
| | *With* | 0.89a | 0.84a | 0.71a | 0.41b | 0.36b | | |
| | Mtrt | | | | | | | |

(b) Experiment 2: Six species grown in weed-free conditions for one season before treatment

| Species | Herbicide treatment | | | | | Fext[b] |
|---|---|---|---|---|---|---|
| | H0 | H1 | H2 | H3 | H4 | |
| Birch | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | n.s. |
| Douglas fir | 1.00 | 0.98 | 1.00 | 1.00 | 0.98 | n.s. |
| Hazel | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | n.s. |
| Japanese larch | 1.00 | 0.96 | 0.98 | 1.00 | 0.96 | n.s. |
| Oak | 1.00 | 1.00 | 1.00 | 0.98 | 0.98 | n.s. |
| Scots pine | 1.00 | 0.96 | 1.00 | 1.00 | 1.00 | n.s. |

See Methods section for details of bramble and herbicide treatments; n.s. = not significantly different; over all species, the standard errors of the means of the individual bramble/herbicide combinations were <1%–20% of the mean values.

a For details, see footnote to Table 1.

b Significance of Fisher's exact test.

height increment and root collar diameter was only significant for oak ($P < 0.05$). In contrast, application of herbicide had some significant adverse effects on height increment of all species and root collar diameter in beech and oak (Table 3). The mean height increments of all species in the control (H0) plants were ∼6–11 cm and increments tended to decline as the dose of herbicide increased, but with the exception of the H1 treatment for beech, the mean heights were only significantly different from H0 in the H3 and H4 treatments. Mean height increments were negative for beech and oak in the H4 treatment indicating that some live plants had suffered dieback. The pattern of diameter increment was similar to that for height. While treatment had no significant effect on the diameter increment of ash, the H3 and H4 treatments significantly reduced increments of beech and oak relative to the control (H0) treatment. There were some significant interactions between bramble and herbicide treatments for beech and oak which may have been partly due to the relatively poor performance of plants in the H0 – *without bramble* treatment combination.

*Experiment 2*

In May 2008, the health of plants in most herbicide treatments was generally good and similar to the control (H0) treatment (Figure 2b). The health of four of the species studied was adversely affected by herbicides with significant differences from the control only being found at the higher dose rates; in treatment H4 for oak and birch, and treatments H3 and H4 for hazel and Japanese larch (all $P < 0.001$ except birch, $P < 0.05$). The survival of plants until the end of the first growing season was similarly good. There were no significant differences between treatments, the proportion of all species surviving being ∼0.96 with no birch dying in any of the herbicide treatments. Although there was some variation in both height and diameter increments (Figure 3), there was no significant difference between treatments for most species. However, at the highest dose of herbicide (H4), the height increment of Japanese larch and the diameter increment of Scots pine were significantly lower than for other treatments in these species (Figure 3a,3b).

**Table 3** Height and diameter increments for plants in Experiment 1 during the growing season following dormant season treatment with triclopyr

| Species | Bramble | Herbicide | | | | | Statistics | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | H0 | H1 | H2 | H3 | H4 | BBL | Herb | B × H | SEDW |
| *Height increment (cm)* | | | | | | | | | | |
| Ash | *Without* | 6.13a | 4.7a | 5.11a | 2.84a | 4.07a | n.s. | <0.05 | n.s. | 2.14 |
| | *With* | 6.18a | 5.66ab | 3.71ab | 2.27ab | 0.86b | | | | 2.17 |
| | Mtrt | 6.15 | 5.18 | 4.41 | 2.55 | 2.46 | | | | |
| Beech | *Without* | 7.19a | 14.4b | 11.37ab | 5.16a | −0.733c | n.s. | <0.001 | <0.05 | 2.14 |
| | *With* | 10.33a | 10.6a | 5.26b | 2.89bc | −0.37c | | | | 2.13 |
| | Mtrt | 8.76 | 12.5 | 8.32 | 4.03 | −0.55 | | | | |
| Oak | *Without* | 10.7a | 9.48a | 7.24ab | 2.07bc | 0.42c | n.s. | <0.001 | n.s. | 2.92 |
| | *With* | 5.38a | 6.81a | 6.75a | 4.71a | −5.53b | | | | 2.93 |
| | Mtrt | 8.04 | 8.15 | 7.00 | 3.39 | −2.56 | | | | |
| *Diameter increment (mm)* | | | | | | | | | | |
| Ash | *Without* | 1.93a | 1.43a | 1.47a | 1.48a | 1.27a | n.s. | n.s. | n.s. | 0.51 |
| | *With* | 0.03a | −0.11a | 0.03a | −0.36a | −0.43a | | | | 0.51 |
| | Mtrt | 0.98 | 0.66 | 0.75 | 0.56 | 0.42 | | | | |
| Beech | *Without* | 2.13a | 2.45a | 2.14a | 0.93b | 0.55b | n.s. | <0.001 | <0.05 | 0.34 |
| | *With* | 0.96a | 1.8b | 1.19ab | 0.74ac | 0.26c | | | | 0.34 |
| | Mtrt | 1.54 | 2.12 | 1.67 | 0.83 | 0.40 | | | | |
| Oak | *Without* | 2.51a | 2.47a | 1.89ab | 1.08b | 1.14b | <0.05 | <0.001 | <0.01 | 0.64 |
| | *With* | −0.29a | −0.23a | −0.23a | −0.069a | −0.052a | | | | 0.64 |
| | Mtrt | 1.11 | 1.12 | 0.83 | 0.19 | 0.31 | | | | |

Values are means adjusted using height before treatment as a covariate. See Methods section for details of bramble and herbicide treatments. Mtrt = mean value for each species within each herbicide treatment. BBL = significance of bramble treatment for each species; Herb = significance of herbicide treatment for each species; B × H is interaction between bramble and herbicide treatments; within each row any values with the same letter do not differ significantly ($P < 0.05$); SEDW = standard error of difference of means that was used to determine the means within each row that were different, degrees of freedom = 31.

*Experiment 3*

In summer 2007, before application of herbicide, a total of 15 species were recorded on the plots, only 8 occurred on >50 per cent of plots and of these cleavers and bluebell were only present as dried stems, inflorescences and fruits (Table 4). The most abundant species were bramble, ground ivy and dog's mercury with mean cover scores exceeding 20 per cent, for most other species cover was generally less than 5 per cent. Although no species were lost from the area, some did appear to decline in frequency between 2007 and 2008 (Table 4). However, the total number of species recorded increased to 20: three of the new species were naturally regenerating trees and the remaining two were small herbaceous species with low cover scores that may not have been seen previously. The change in percentage cover was investigated for those species which occurred on more than half of the plots before treatment in summer 2007, excluding cleavers and bluebell for which cover could not be assessed. For all species except bramble, which declined in cover, there were no significant effects of herbicide treatments (Table 5).

Assessments of plant health found little obvious herbicide damage. Apart from bramble which was killed or suffered severe dieback, the only obvious damage was in some plots treated during late January. At the April assessment, dog's mercury plants in two plots appeared to be slightly stunted relative to untreated plants, and in two different plots 10–30 per cent of bluebell leaves were slightly pale coloured and twisted or stunted. In July, the only herbicide damage evident was twisted and poorly developed fronds on broad buckler fern.

## Discussion

*Effects of bramble on tree seedlings (Experiment 1)*

In many cases, the presence of bramble delayed flushing and reduced both the survival and growth of young tree seedlings, confirming earlier reports of the negative impact of this species.[3] Competition, particularly for light, can cause morphological changes to young trees, such as the reduction of diameter growth and root growth to allow continued height extension,[27] which is reflected by the fact that diameter growth was more negatively affected than height in our work. Impacts of bramble competition appeared to be somewhat lower in the second year after planting. This corresponds to other work which indicates that that in terms of a critical period of weed competition, for many weed tree species combinations, the first year is most often most important.[28] Although beech diameter increment showed a positive response (H1 *vs* H0 with bramble treatment), releasing trees from bramble cover in the second year after planting did not

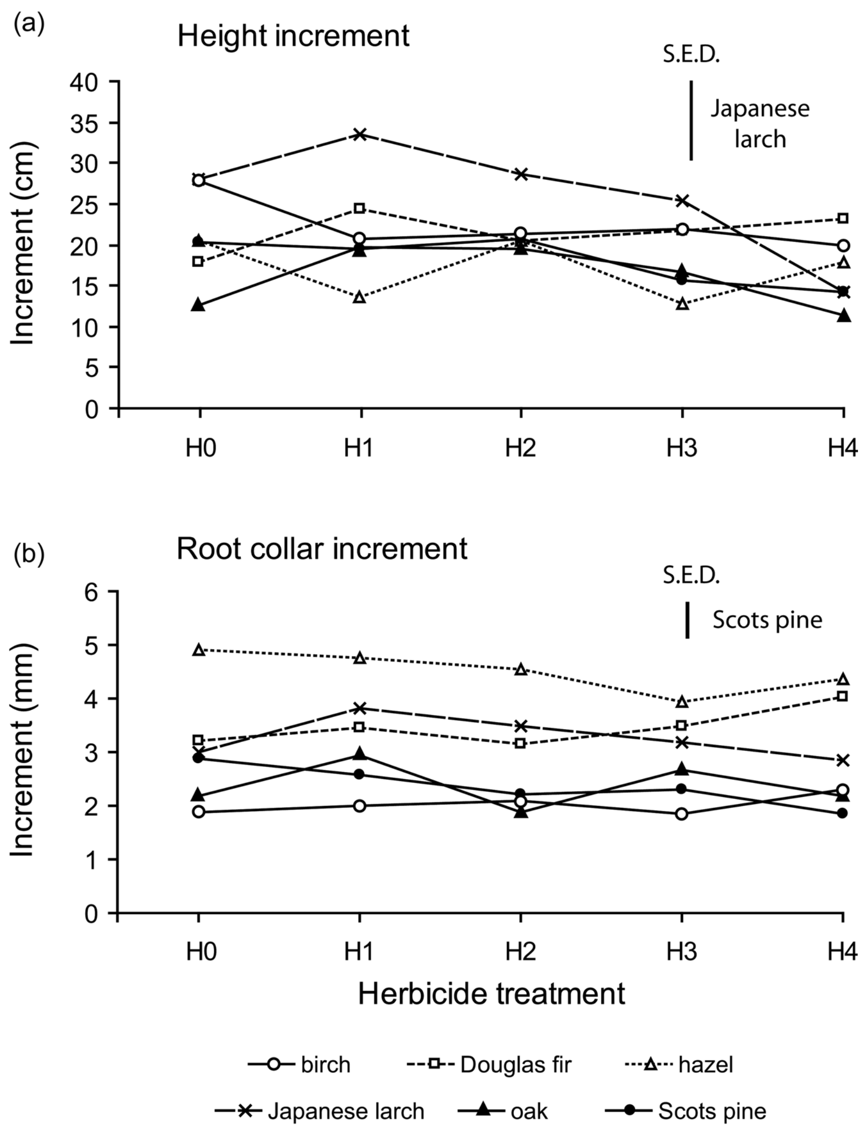


**Figure 3** Growth of six species during the growing season following the application of triclopyr in Experiment 2: (a) mean height increment (cm) and (b) mean root collar diameter increment (mm). Standard errors of differences of means are shown for species where there were significant differences between herbicide treatments.

appear to give any consistent significant benefit to tree growth and survival, again hinting at the first year after planting being most critical. However, it is possible that had the experiment run for longer survival and growth of those three still subject to bramble competition could have worsened significantly.

### *Effects of triclopyr on bramble and tree seedlings (Experiments 1 and 2)*

Bramble can be effectively controlled by triclopyr at rates of 0.96 kg a.i. $ha^{-1}$ applied in summer, or 1.44 kg a.i. $ha^{-1}$ applied in the winter if mixed with diesel.[14,29] Our work indicated good (>70 per cent) control is possible from applications of 0.96 kg a.i. $ha^{-1}$ triclopyr in water in during the winter dormant season. Crucially, our work also showed that rates of up to 0.96 kg a.i. $ha^{-1}$ triclopyr, applied in water the winter dormant season, are generally safe to apply over young oak, ash, beech, birch, hazel, Scots pine, Douglas fir or Japanese larch trees, even if they are growing under a degree of stress given the lower light, moisture and nutrient conditions present beneath a canopy of mature trees.

Higher rates (>1.92 kg a.i. $ha^{-1}$ triclopyr) gave even better control of bramble, but delayed spring flushing, reduced survival of beech, ash and oak, and suppressed tree growth. The growth and survival of other species such as birch, hazel and Douglas fir were unaffected by even the highest doses used in these experiments.

Generally, tolerance to the herbicide seemed to be somewhat reduced when young trees had been subject to competition from

**Table 4** Frequency of species found during summer 2007 and 2008 before and after herbicide treatment during the intervening winter

| Species | Common name | 2007 | 2008 | Change |
|---|---|---|---|---|
| *Anemone nemorosa* | Wood anemone | 0 | 0 | 0 |
| *Arum maculatum* | Lords and ladies | 1 | 2 | 1 |
| *Cardamine flexuosa* | Wavy bitter cress | 0 | 1 | 1 |
| *Circaea lutetiana* | Enchanter's nightshade | 5 | 2 | −3 |
| *Crataegus monogyna* (s) | Hawthorn | 0 | 3 | 3 |
| *Dryopteris dilatata* | Broad buckler fern | 3 | 3 | 0 |
| *Dryopteris filix-mas* | Male fern | 9 | 7 | −2 |
| *Fraxinus excelsior* (s) | Ash | 0 | 8 | 8 |
| *Galium aparine*[a] | Cleavers | 14 | 12 | −2 |
| *Geum urbanum* | Wood avens | 6 | 5 | −1 |
| *Glechoma hederacea* | Ground ivy | 15 | 15 | 0 |
| *Hyacinthoides non-scripta*[a] | Bluebell | 12 | 14 | 2 |
| *Lamiastrum galeobdolon* | Yellow archangel | 8 | 6 | −2 |
| *Lonicera periclymenum* | Honeysuckle | 1 | 1 | 0 |
| *Lysimachia nemorum*. | Yellow pimpernel | 0 | 0 | 0 |
| *Mercurialis perennis* | Dog's mercury | 12 | 13 | 1 |
| *Milium effusum* | Wood millet | 8 | 8 | 0 |
| *Poa trivialis* | Rough meadow grass | 0 | 4 | 4 |
| *Primula vulgaris* | Primrose | 1 | 1 | 0 |
| *Quercus robur* (s) | Pedunculate oak | 0 | 1 | 1 |
| *Ranunculus ficaria* | Lesser celandine | 0 | 0 | 0 |
| *Rubus fruticosus* | Bramble | 14 | 15 | 1 |
| *Urtica dioica* | Common nettle | 6 | 5 | −1 |

Maximum frequency possible = 15; change is increase or decrease between summer 2007 and 2008; (s) = seedlings. Plant nomenclature in this table follows Stace.[35]

[a] Only present as dried stems, inflorescences and fruits.

**Table 5** Mean percentage cover of most frequent species in the summer of 2007 before application of herbicide and in summer 2008 after treatment during the intervening winter

| Species | 2007 | | | 2008 | | | Sig |
|---|---|---|---|---|---|---|---|
| | HT0 | HT1 | HT2 | HT0 | HT1 | HT2 | |
| Male fern | 5 | 8 | 10 | 5 | 20 | 12 | n.s. |
| Ground ivy | 39 | 38 | 25 | 12 | 5 | 5 | n.s. |
| Yellow archangel | 5 | 18 | 20 | 10 | 8 | 5 | n.s. |
| Dog's mercury | 24 | 18 | 35 | 31 | 14 | 35 | n.s. |
| Wood millet | 7 | 5 | 5 | 5 | 5 | 5 | n.s. |
| Bramble | 61 | 52 | 46 | 41 | 5 | 11 | <0.01 |

See Methods section for details of herbicide treatments HT0–HT2 and statistical analyses. Sig = for each species the significance of differences between herbicide treatments in change in cover between 2007 and 2008; n.s. = not significantly different.

bramble in the previous growing season Willoughby *et al.*[19] found that in open grown conditions, the presence of grass weeds did not increase the susceptibility of young trees to dormant season herbicide applications, but Harmer *et al.*[11] reported damage when trees were growing beneath a canopy of trees. It is possible that the stress induced by competition from both the understorey bramble and overstorey trees, combined with changes to dormancy status due to both competition and microclimate, induced physiological changes in seedlings such as reduced maturation of cortical tissues and in particular the formation of the outer protective layer of closely packed, dead cork cambium cells, so reducing resilience to herbicide uptake.[19] As trees and bramble were about the same height, the presence of bramble did not protect trees from the herbicide sprays but it made walking at a steady pace more difficult and consequently the precision of the herbicide treatments was reduced with the risk of local overdosing increasing. However, rates of up to 0.96 kg a.i. $ha^{-1}$ were never damaging, even to trees subject to prolonged competition from bramble.

### *Effects of triclopyr on non-target plants (Experiment 3)*

A major concern about the use of herbicides to control competitive weeds within woodlands is their potential to damage desirable species which occur in the ground flora and it is generally accepted that the abundance and mixture of species present will be adversely affected. While the effects of herbicides on tree establishment are well documented, their impacts on non-target vegetation within woodlands have been relatively little studied, but the limited evidence available suggests that the ground flora is resilient and in general species recover; see Ristau *et al.*[30] and references therein. Detailed observations of species common within British woodlands have generally taken place using potted plants and have been related to the drift of herbicide sprays. While these have studied few species, including yellow archangel and dog's mercury, they have shown that although damage can occur at low doses of herbicide, the magnitude of the effect varies with species.[31–33] There are similarly few studies which have observed the effect of direct application of herbicides at recommended rates to non-target plants growing in natural communities[8,9,34] and the results of these experiments suggest that effects vary and are not necessarily adverse. As most studies have applied herbicides to actively growing non-target plants, there are few data to compare with the dormant season applications made in this study. In addition, triclopyr was only included in Harmer *et al.*'s[11] investigations in which the treatments were also applied during winter. The results of these experiments, one in a beech woodland the other in an oak woodland,[9] were similar to those found in this study of an ash woodland: bramble cover was greatly reduced and while there was some increase in the overall number of species present, the cover of most remained low and was generally unaffected by application of triclopyr. The evidence available indicates that while winter application of 0.96 kg a.i. $ha^{-1}$ triclopyr can give effective control of bramble, it may have relatively little impact on non-target woodland ground flora species which are growing in mixed communities where bramble is a dominant component of the community.

### *Conclusions and practical implications*

The work reported here indicates that where bramble is threatening to out-compete young tree seedlings and other desirable elements of the woodland flora, winter application of 0.96 kg a.i. $ha^{-1}$ triclopyr (equivalent to 2 l $ha^{-1}$ Timbrel; Dow AgroSciences) in water can effectively control bramble, while leaving tree seedlings unharmed. Bramble spreads quickly and to prevent it rapidly re-invading treated areas best results are likely to be obtained from overall sprays treating large, discrete areas, rather than many individual small spots or narrow bands. For effective control, the bramble should have green stems and retain green (not red, or brown) leaves. Tree seedlings must be deeply dormant, ideally with at least 1 month before flushing (e.g. treated between December and February inclusive). Grasses are not susceptible to triclopyr, and our results also indicate that a range of non-target herbaceous species may also be unaffected by treatment during the dormant season. However, given that these results are based on only relatively small-scale trials, including relatively few species of both trees and herbaceous plants, test areas should be sprayed to confirm safety before making any large-scale operational applications. Unfortunately, despite the obvious potential of this treatment, Dow AgroSciences have recently announced their future intention to withdraw Timbrel from the UK market for commercial reasons, although triclopyr-based products may remain available elsewhere.

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## Conflict of interest statement

None declared.

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