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Dense wilding conifer control with aerially applied herbicides in New Zealand

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Abstract

Background: Wilding conifers are a major threat to biological conservation within New Zealand and currently cover at least 500,000 ha throughout the South Island. A range of herbicide treatments was applied to field trials established within wilding *Pinus contorta* (height range 1 – 15 m) and *P. mugo* (height range 0.5 – 5 m) infestations. Measurements of mortality taken two years post herbicide application were used to determine the efficacy of (i) the traditionally used contact herbicide diquat, applied in an application volume of 300 L ha^{-1}, and (ii) a range of systemic herbicides applied in an application volume of 150 L ha^{-1}.

Methods: All herbicides were applied by helicopter using a coarse droplet spectra (VMD = 720 μm) to minimise spray drift. Damage assessments were made two years following application and trees were considered to have died if they had 100% dead foliage. The influence of height class and treatment on tree mortality was assessed using analysis of variance.

Results: For a treatment to be considered effective, a mortality rate of over 85% should be achieved on all trees up to 8 m in height. Under this criterion, none of the treatments used in this study provided satisfactory control of the two wilding species. Application of 7200 g ha^{-1} glyphosate and 120 g ha^{-1} metsulfuron was significantly better than any other treatment, for both species, causing 64% mortality for *P. contorta* and 36% for *P. mugo*. The traditionally used herbicide diquat was the poorest performing herbicide for *P. contorta* and the second poorest performing for *P. mugo*, inducing respective mortality rates of 2.7% and 2.4%. For all herbicides used there was a significant decline in efficacy with increases in tree height.

Conclusion: These results suggest that control of dense wilding pine stands using low spray volumes and coarse droplet size is unlikely to be successful as foliage coverage is poor.

Keywords: Aerial boom spraying; Herbicides; Wilding conifers

Background

In New Zealand, various conifer species were planted for erosion control during the late 1880s (Ledgard 2001). Natural regeneration from these plantings was first noted in the late 1800s. Since then, these conifers, known as wildings, have spread extensively and the total area covered by wilding conifers in the South Island of New Zealand is estimated to be in excess of 500,000 ha (Gous and Raal 2010). Wilding conifers cover more than 200,000 hectares of land administered by the Department of Conservation (DOC), of which approximately two thirds is invaded by *Pinus contorta* (Dougl.) (Gous et al. 2010a, 2010b; Ledgard 2001).

Within New Zealand dense infestations of wildings have been successfully controlled in the past using a combination of a contact desiccant herbicide (15 L ha^{-1} diquat (6,7-dihydrodipyrido [1,2-a:2′,1′-c] pyrazinediium dibromide)) followed by burning (Ray and Davenhill 1991). This treatment was effective as the diquat dessicated the plant tissue and the resulting dry fuel produced a hot burn that killed most of the remaining conifers and viable seed. However, because of risk concerns, fire is no longer an acceptable management option on DOC administered land (P. Willemse, DOC, 2008, pers. comm.). The current practice of spraying with diquat alone is ineffective at

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controlling most mature wilding conifers (Donald 1982; Gous and Raal 2010).

Previous research using pot trials identified potential alternative herbicides for controlling wildings (Gous et al. 2010a, 2010b). The selective and systemic herbicides triclopyr (3,5,6-trichloro-2-pyridyloxyacetic acid), triclopyr/picloram (4-amino-3,5,6-trichloropicolinic acid) and the non-selective systemic combination of glyphosate (*N*-(phosphonomethyl)glycine) and metsulfuron (2-[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]-oxomethyl]sulfamoyl]benzoic acid methyl ester) provided best control of small (height of ~0.3 m) *Pinus contorta*, *Pinus mugo* (Turra) and *Pseudotsuga mensiesii* (Mirb.). Although these herbicide groupings have been identified, little research has been conducted using these herbicides on mature plants, growing in dense infestations that can reach heights of up to 15 m.

Herbicides were applied to two separate field trials that included dense infestations of either *Pinus contorta* or *P. mugo*. Using measurements obtained after two years, the objectives of this project were to determine the efficacy of (i) the traditionally used treatment (diquat) and (ii) a range of alternative systemic herbicides on these two wilding species. For a treatment to be considered effective, a mortality rate of over 85% should be achieved on all trees up to 8 m in height.

Methods

Sites, treatments and application

The site selected for the *Pinus contorta* trial spanned two adjacent properties (Ferintosh Station and Pukaki Downs) that were separated by a small stream (latitude 44° 6′ 00″ S; longitude 170° 07′ 29″), near Twizel. The site of the *Pinus mugo* trial was at Muddy Creek, Central Otago (latitude 44° 59′ 55″ S; longitude 168° 57′ 30″ E). With the exception of diquat, which was applied at the standard 300 L ha^{-1}, all treatments were applied in a total application volume of 150 L ha^{-1}. Application was undertaken with a Robinson R44 helicopter, flying at a ground speed of 30 knots with a release height of 10 m above the tree canopy. The helicopter was fitted with 30 TF5 nozzles (Spraying Systems Co 2006), orientated straight back, evenly spaced along an 8 m wide boom. Flight line separation was 8 m. Measured droplet volume mean diameter (VMD) was approximately 720 μm (Gous and Richardson, 2008).

Treatments (Table 1) were selected based on results from two previous herbicide screening trials (Gous et al. 2010a, 2010b). These treatments were based around combinations of glyphosate/metsulfuron and triclopyr/picloram (Agri Media Ltd 2010). Each treatment was applied to four replicate 0.5 ha treatment plots using a randomised complete block design. A total of 25 trees were randomly selected from each treatment plot and marked for damage assessments. Treatments were applied on 9 January 2009, during the period of active growth to promote translocation of herbicide throughout the trees (Radosevich and Bayer 1979).

Table 1 Details of herbicides (and corresponding active ingredients) applied to *Pinus contorta* and *P. mugo* by broadcast aerial application

Treatment code	Herbicide product [1] (quantity ha^{-1})	Active ingredient (quantity ha^{-1})
R15M15	15 L Agpro Glyphosate 360,	5400 g glyphosate
	150 g Agpro Meturon,	90 g metsulfuron
	1.5 L Pulse penetrant	
R20M20	20 L Agpro Glyphosate 360,	7200 g glyphosate
	200 g Agpro Meturon,	120 g metsulfuron
	1.5 L Pulse penetrant	
G20O	20 L Grazon,	12000 g triclopyr
	130 L Syntol mineral oil,	
G20W	20 L Grazon,	12000 g triclopyr
	15 L Syntol mineral oil,	862 g ammonium sulphate
	1.5 kg Kondemn	
T20W	20 L Tordon Brushkiller XT,	6000 g triclopyr
	20 L Kwickin oil,	2000 g picloram
	1.5 L Pulse penetrant	160 g aminopyralid
DQ15	15 L Reglone,	3000 g diquat
	1.5 L Pulse penetrant	

[1]All herbicides were applied at 150 L ha^{-1} with the exception of DQ15, which was applied at 300 L ha^{-1}.

Damage assessments

Tree health was recorded 24 months following the treatment as the percentage dead foliage in increments of 10%. The crown of each tree was visually divided into three equal sections from top to bottom, with each section scored individually, before averaging to obtain a whole-tree score. A tree with 100% dead foliage was scored as dead.

Analysis

All analyses were undertaken using SAS software (SAS Institute Inc. 2000). Percentage mortality was the dependent variable used in analyses and this variable was transformed for analysis using an arcsine square root transformation to meet the underlying assumptions of the models used. Within each plot, mean mortality in 2 m height classes (0 – 2.0 m; 2.1 – 4.0 m etc.) was used within analyses so that the effects of treatment and tree height on mortality could be examined.

Using this data a general linear model was used to test the effects of replicate, treatment, height class and the interaction between height class and treatment on transformed mortality. All of these terms were included within the model as class level or categorical data. Where the treatment effect was significant, multiple comparisons were undertaken between treatments using the Student-Newman-Keuls (SNK) method.

Results

Data range

For *Pinus contorta,* mean tree heights at the time of treatment ranged from 4.4 – 7.7 m (Table 2). The range of tree height was relatively similar for all treatments and included trees as small as 1.0 – 2.0 m and as tall as 13.0 – 15.0 m. Tree height was markedly lower for *Pinus mugo*, with the treatment mean heights ranging from 1.9 – 3.3 m. All treatments were applied to trees with a minimum height of 0.5 m and maximum height ranging from 4.5 – 5.0 m.

Influence of treatment and height class on mortality

For both species, analyses showed the main effects of treatment and height class to have strong significant effects on mortality (Table 3). The interaction between height class and treatment was not significant for either species indicating that changes in mortality across height classes were relatively similar between treatments (Table 3, Figure 1).

Although mortality rates for *Pinus mugo* were substantially lower than that of *Pinus contorta,* the relative rankings in mortality between herbicides was similar for the two species (Table 4). The two treatments containing glyphosate and metsulfuron (R20M20, R15M15) performed better than the treatments containing triclopyr (G20O, G20W), picloram and triclopyr (T20W) or diquat (DQ15).

There was a clear rate effect between the glyphosate/metsulfuron treatments. The R20M20 treatment (7200 g glyphosate + 120 g metsulfuron) was significantly better than R15M15 (5400 g glyphosate + 90 g metsulfuron) or any other treatment, for both species, causing 64% mortality for *P. contorta* and 36% for *P. mugo* (Table 4). Diquat was the poorest performing herbicide for *P. contorta* and the second poorest performing for *P. mugo*, inducing respective mortality rates of 2.7% and 2.4% (Table 4).

Table 2 Mean tree height and range (in brackets) at the time of spray application for both pine species

Treatment	Tree height (m)	
	Pinus contorta	*Pinus mugo*
R15M15	4.6 (1.0 – 14.0)	3.3 (0.5 – 5.0)
R20M20	4.4 (1.0 – 13.0)	2.5 (0.5 – 5.0)
G20O	6.9 (2.0 – 15.0)	2.2 (0.5 – 4.5)
G20W	7.7 (2.0 – 14.0)	2.4 (0.5 – 5.0)
T20W	4.8 (1.0 – 13.0)	1.9 (0.5 – 5.0)
DQ15	6.8 (1.0 – 14.0)	2.1 (0.5 – 4.5)

Table 3 Analysis of variance showing the significance of replicate and the main and interactive effects of height class and treatment on percentage mortality

Species	Effect	Num DF	Den. DF	*F*-value	*P* value
Pinus	Replicate	7	89	0.17	0.9194
contorta	Ht class (*H*)	7	89	9.89	<0.0001
	Treatment (*T*)	5	89	6.20	<0.0001
	H x *T*	30	89	1.07	0.3892
Pinus mugo	Replicate	3	40	0.70	0.5589
	Ht class (*H*)	2	40	8.65	0.0008
	Treatment (*T*)	5	40	21.10	<0.0001
	H x *T*	10	40	0.86	0.5784

Also shown is the numerator (Num. DF) and denominator (Den. DF) degrees of freedom.

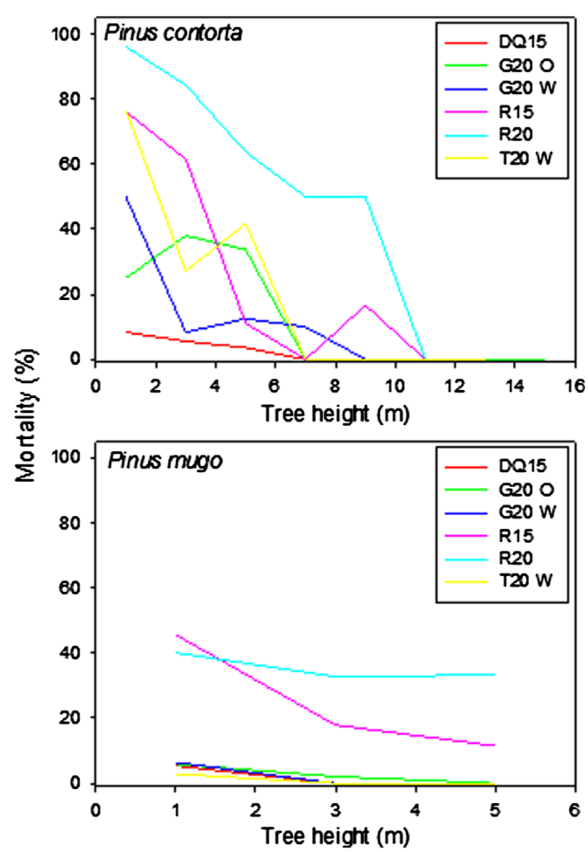

Figure 1 **The relationship between percentage mortality after 24 months and mid-point of each tree height class by treatment for *Pinus contorta* (top) and *P. mugo* (bottom).**

Table 4 Mean mortality and standard error (in brackets) for *Pinus contorta* and *P. mugo* by treatment and height class 24 months after treatment application

	Tree mortality	
	Pinus contorta	*Pinus mugo*
Treatment		
R20M20	63.9 (9.60) A	36.1 (4.15) A
R15M15	31.0 (8.88) B	25.0 (6.32) B
T20W	23.3 (6.72) BC	1.05 (0.71) C
G20O	15.0 (4.95) BC	3.14 (1.72) C
G20W	8.59 (4.52) C	2.54 (1.71) C
DQ15	2.67 (1.51) C	2.38 (1.19) C
Height class		
0 m – 2.0 m	61.7 (9.30) A	17.70 (4.34) A
2.1 m – 4.0 m	37.5 (8.04) AB	8.78 (2.86) B
4.1 m – 6.0 m	28.5 (6.95) AB	6.09 (3.49) B
6.1 m – 8.0 m	12.7 (4.24) B	
8.1 m – 10.0 m	7.78 (7.08) B	
10.1 m – 12.0 m	0.0 (0.0) B	
12.1 m – 14.0 m	0.0 (0.0) B	
14.1 m – 16.0 m	0.0 (0.0) B	

As the terms treatment and height class were significant for both species results from multiple comparison tests are shown. Least square means followed by the same letter are not significantly different at $p < 0.05$.

There was a decline in herbicide efficacy with increases in tree height for both species and all treatments (Figure 1). Overall, the reductions were most marked between the first two height classes from 0 – 2.0 m to 2.1 – 4.0 m (Table 4). The most effective treatment (R20M20) only achieved the 85% threshold for *P. contorta* trees that were less than 2 m in height (Figure 1).

Discussion

This study was initiated for two reasons. Anecdotal evidence suggested that diquat was ineffective in the absence of fire so a key objective was to find more effective alternatives. Secondly, an aerial spray drift incident at mid-Dome in Southland (January 2004) indicated that future aerial herbicide applications would require a spectrum of coarse droplets with very few droplets in the fraction prone to drift (< 150 μm VMD).

Although 15 L ha^{-1} diquat was applied in a total application volume of 300 L ha^{-1}, results show that this treatment was among the least effective. In contrast to the alternative treatments studied, which are all systemic, diquat is a contact herbicide. Systemic herbicides are likely to be more effective at killing dense wilding infestations as these herbicides can be translocated within the plant system to tissues that may be remote from the point of absorption. However, none of the treatments examined in this study provided satisfactory control of the two wilding species. It is likely that this poor efficacy resulted from low foliage coverage as low spray volumes (150 L ha^{-1}) in combination with large droplets (VMD = 720 μm) were applied onto dense tree canopies. Therefore, further work is required to assess the effect of increasing spray volume and reducing droplet size. One such trial is already underway to determine the effect of increasing the spray volume to 400 L ha^{-1} and reducing the droplet spectrum to a VMD of 400 μm for a spray treatment of triclopyr (18,000 g ha^{-1}), dicamba (3,6-dichloro-2-methoxybenzoic acid; 5000 g ha $^{-1}$), picloram (2,000 g ha^{-1}) and ammonium sulphate (2,300 g ha^{-1}) in an oil emulsion (unpublished data). Greater foliage coverage was achieved and the drop size was still sufficiently large to prevent excessive drift. Preliminary results 12 months post application indicate high mortality for *P. contorta* (87%) across the height range tested (2 – 12 m).

Conclusion

This study clearly demonstrates the poor efficacy of the traditionally used diquat treatment. Although efficacy was higher for herbicides with a systemic mode of action, none of these herbicides adequately controlled the two studied species. It is very likely that the poor efficacy of systemic herbicides in this trial was due to poor coverage resulting from low application volumes and large droplet spectrum.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SG was the primary author and co-designed the study. PR undertook all field measurements and co-designed the trial. MSW was the secondary author and undertook all analyses. All authors read and approved the final manuscript.

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