Woody plant responses to various clearing strategies imposed on a poplar box (*Eucalyptus populnea*) community at Dingo in central Queensland

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Abstract

The efficacy of individual tree treatment (stem-injection), aerially applied root-absorbed herbicide and mechanical felling (with and without subsequent fire) in controlling woody plants was compared in a poplar box (*Eucalyptus populnea*) woodland community in central Queensland, Australia. All treatments reduced woody plant populations and basal area relative to the untreated control. Chemical control and 'mechanical felling plus fire' treatments were equally effective in reducing woody plant basal area 7 years after the treatments were imposed. However, mechanical felling alone was less effective. There was a clear tendency for the scattered tree (80% thinning) treatment to recover woody plant basal area towards pre-treatment levels faster than other clearing strategies, although this response was not significantly different from 20% clump retention and mechanical felling (without burning) treatments.

Introduction

Poplar box (*Eucalyptus populnea*) woodlands in Queensland have been cleared to increase pasture production (Walker *et al*. 1972; Scanlan and Burrows 1990) for more than 150 years (Weston *et al*. 1980). In the second half of the 19th century, ringbarking (Robertson 1966; Robertson and Beeston 1981) was the most common method of killing the trees and, with inexpensive labour available, trees on large areas were ringbarked between 1890 and the 1940s.

The introduction of 'frill ringing' and poisoning with arsenical tree killers in the 1940s and 1950s helped reduce the amount of labour required and trees on more country were treated. By this time, land managers were increasingly treating regrowth on previously treated country. Following World War II, large-tracked tractors (bulldozers) became available and these have been used to clear extensive areas of poplar box woodland (Robertson and Beeston 1981). The labour needed was again reduced with the advent of the stem-injection method (Robertson 1966) of applying the modern herbicides, 2, 4, 5-T and picloram. These herbicides were very effective at killing a range of woody plants when correctly applied (Robertson and Moore 1972).

The 1980s saw the introduction of the soil-applied liquid herbicide hexazinone (Velpar L®), which can also be applied by stem-injection, and the granular herbicide tebuthiuron (Graslan®), which can be applied aerially. The reduced labour costs of aerial application and its effectiveness in controlling a number of woody species (Burrows *et al.* 1994) allowed large areas to be treated quickly. Concurrent with these later developments was a growing understanding of soil, water and nature conservation principles and how to apply these to achieve responsible and sustainable development. This meant that the land manager had a number of strategies available, such as retaining untreated areas as clumps or strips, when clearing woodlands. Burrows (1990; 1993) devised guidelines for woodland clearing which recommended the retention of timber on at least 20% of the area as intact strips (corridors) or clumps.

The aim of this study was to assess how effective a number of clearing strategies (all available tree-clearing techniques in commercial use and applied to eucalypt woodlands, at the time the trial commenced[1]) were in controlling woody species

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in a poplar box woodland and to assess how much regrowth appeared following each treatment. The effects of retaining some of the trees in different landscape arrangements were also studied.

Materials and methods

Site

The experimental site was situated on 'Wandobah', a beef cattle grazing property in the Dingo area of central Queensland (23°36.4´S, 149° 25.22´E). The woodland site was dominated by poplar box (*Eucalyptus populnea*) in association with Queensland blue gum (*E. tereticornis*), narrow-leaved ironbark (*E. crebra*), ghost gum (*Corymbia dallachiana*), bloodwood (*Corymbia clarksoniana),* scrub leopardwood *(Flindersia dissosperma*), bull oak (*Allocasuarina luehmannii*), vinetree (*Ventilago viminalis*) and ironwood (*Acacia excelsa*). Understorey woody species present included false sandalwood (*Eremophila mitchellii*), currant bush (*Carissa ovata*) and whitewood (*Atalaya hemiglauca*). Other woody species recorded in the treatment plots are given in Table 1.

The owners of 'Wandobah' had a tree management program in place involving timber treatment every 30 years or so. The woody plants present on the trial site were regrowth following previous clearing by ringbarking in the 1920s and 1950s. The trial site had been treated most recently during the 1950s and was therefore due for treatment under this management regime, when the trial treatments were imposed.

Rainfall

Rainfall for the site (Table 2) was below average in the establishment year (1987), average or slightly above average for 1988–1990, and well below average for the years 1991–1997.

Experimental design

Six woodland management strategies and a control treatment were imposed in a randomised block (7 treatments × 3 replications) layout. The treatments were:

[1] Tree clearing is now subject to regulation in Queensland. Broad-scale clearing of remnant woodlands has been phased out, with no clearing permits granted after January 1, 2007. While control of regrowth is still permitted, the appropriate guidelines from the Queensland Department of Natural Resources and Water (NRW) should be consulted before proceeding and permits may be required. Some clearing in remnant woodlands is still permitted for certain purposes (clearing fence lines, access to weed outbreaks etc.), but the appropriate guidelines must be followed and NRW approval may be needed before proceeding.

Table 1. Other woody plants recorded at the 'Wandobah' experimental site.

Acacia bidwillii	Corkwood wattle	*Ehretia membranifolia*	Peach leaf
Acacia harpophylla	Brigalow	*Eremophila longifolia*	Berrigan
Acacia salicina	Sally wattle	*Eremophila deserti*	Ellangowan poison bush
Alectryon diversifolius	Scrub boonaree	*Eucalyptus cambageana*	Dawson gum
Alectryon oleifolius	Boonaree	*Eucalyptus crebra/E. populnea* hybrid	
Alphitonia excelsa	Red ash	*Grevillea striata*	Beefwood
Allocasuarina luehmannii	Bull oak	*Hakea fraseri*	Bootlace oak
Apophyllum anomalum	Broom bush	*Harrisia martinii*	Harrisia cactus
Archidendropsis basaltica	Dead finish	*Jasminum didymum* subsp. *racemosum*	Native jasmine
Breynia oblongifolia	Coffee bush	*Maytenus cunninghamii*	Yellow berry bush
Psydrax odorata		*Maireana microphylla*	Cotton bush
Psydrax oleifolia	Myrtle tree	*Melaleuca nervosa*	Paperbark teatree
Capparis canescens	Wild orange	*Myoporum montanum*	Boobialla
Capparis lasiantha	Nipan, wait-a-while	*Opuntia stricta*	Common pest pear
Capparis loranthifolia	Narrow-leaved bumble	*Opuntia tomentosa*	Velvety tree pear
Capparis mitchellii	Bumble bush	*Owenia acidula*	Emu apple
Carissa ovata	Currant bush	*Owenia venosa*	Crow apple
Cassia brewsteri	Bean bush	*Parsonsia lanceolata*	Rough silkpod
Cassia tomentella	Bean bush	*Petalostigma pubescens*	Quinine berry
Clerodendrum floribundum	Lolly bush	*Sarcostemma viminale* ssp. *brunonianum*	Caustic creeper
Corymbia tessellaris	Moreton Bay ash	*Santalum lanceolatum*	Sandalwood
Denhamia oleaster	Olive-leaved denhamia	*Terminalia oblongata*	Yellowwood
Dodonaea viscosa	Sticky hop bush	*Ventilago viminalis*	Vinetree

(a) All woody plants taller than waist high treated by stem-injection with the herbicide Velpar L® [active ingredient (a.i.) 250g/L hexazinone] (Figure 1). (SI All)
(b) 80% of all trees (>7m tall) and all shrubs taller than waist high treated by stem-injection with Tordon Timber Control Herbicide® (a.i. 50g/L picloram plus 100g/L triclopyr). The 20% of untreated trees were left scattered as evenly as possible throughout the plot. (Scattered)
(c) All woody plants taller than waist high treated by stem-injection with Tordon Timber Control Herbicide® on 80% of the area while woody plants on the remaining 20% of the plot were retained as a clump in each corner of the treated plot[2] (Figure 2). (Clumps)
(d) Pellets containing the root-absorbed herbicide Graslan® (a.i. 200g/kg tebuthiuron in a clay pellet) were applied aerially to the soil surface on 80% of the area with the remaining 20% of the area left untreated as strips (Figure 3). (Strips)
(e) All woody plants pulled over by 2 bulldozers joined by a heavy chain. (Pulling)
(f) As for (Pulling) but fenced to exclude stock and burnt 30 months after pulling (Figure 4). (Pulling+Burn)
(g) Untreated control. (Control)

The two stem-injection herbicides used were considered equally effective for killing eucalypts and the decision to use both was guided by industry practice. All treatments were grazed during the trial at conservative stocking rates.

Plot size for treatments SI All, Scattered, Clumps and the untreated control was 9 ha (300 m × 300 m). The treatment Strips was applied to 18 ha plots (600 m × 300 m) with the assessment area (300 m × 300 m) centrally located (Figure 3). This longer plot was needed to ensure that the aircraft applied the treatment evenly to the assessment area. Treatments Pulling and Pulling+Burn were applied to 4.5 ha plots (300 m × 150 m) (Figure 4). The margins of each 9 ha plot were clearly marked prior to treatment by applying paint to the stems of trees on or near the boundary. Trees to be retained in the scattered trees treatment (Scattered) were marked with a band of different coloured paint as were the untreated clumps in treatment Clumps.

The treatments were applied by commercial contractors and carried out to the relevant commercial industry standard. The stem-injection technique involved cutting horizontally through the bark of the plant into the sapwood at an oblique downward angle with a narrow-bladed axe. A measured amount of herbicide was immediately applied in the bottom of the cut. The next cut was made beside the previous cut but not joining it, the distance between the centres of the cuts depending on the herbicide being used (13 cm for Tordon Timber Control Herbicide® and 15 cm for Velpar L®). A team of 7–10 men carried out the stem-injection treatments and the time taken to treat each plot was recorded (Table 3).

In treatment SI All, 1 ml of undiluted Velpar L® was applied to each cut. For treatments Scattered and Clumps, 2 ml of Tordon Timber Control Herbicide®, diluted at 1 part herbicide to 1.5 parts water, was placed in each cut. Plants with a diameter less than 25 mm at waist height were

[2] The plots were only 9 ha (300 m × 300 m) and the minimum size of a retained clump recommended by Burrows (1990; 1993) was 3 ha which meant a centrally located clump would take up too much of the available assessment area. To overcome this, a notional clump was positioned in each corner of the plot and 20% of the assessment transects were placed within these clumps (Figure 2).

Table 2. Rainfall records (mm) for 'Wandobah' for the period 1987–2006 and the long-term (1897–2005) district mean for Dingo.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1987	75	7	19	51	36	32	18	12	10	97	68	41	466
1988	74	88	90	78	51	30	93	97	0	14	24	126	765
1989	59	83	159	176	121	7	40	10	17	51	53	28	804
1990	41	30	136	85	84	26	4	0	0	29	9	266	710
1991	112	187	0	20	73	15	32	0	0	0	22	144	605
1992	99	141	8	17	72	1	5	35	7	0	39	27	451
1993	50	4	15	0	11	7	20	27	26	28	100	27	315
1994	11	6	241	4	8	9	2	2	6	21	2	96	408
Trial mean	**65**	**68**	**84**	**54**	**57**	**16**	**27**	**23**	**8**	**30**	**40**	**94**	**566**
District mean	**117**	**112**	**72**	**38**	**37**	**35**	**30**	**21**	**24**	**45**	**63**	**100**	**694**

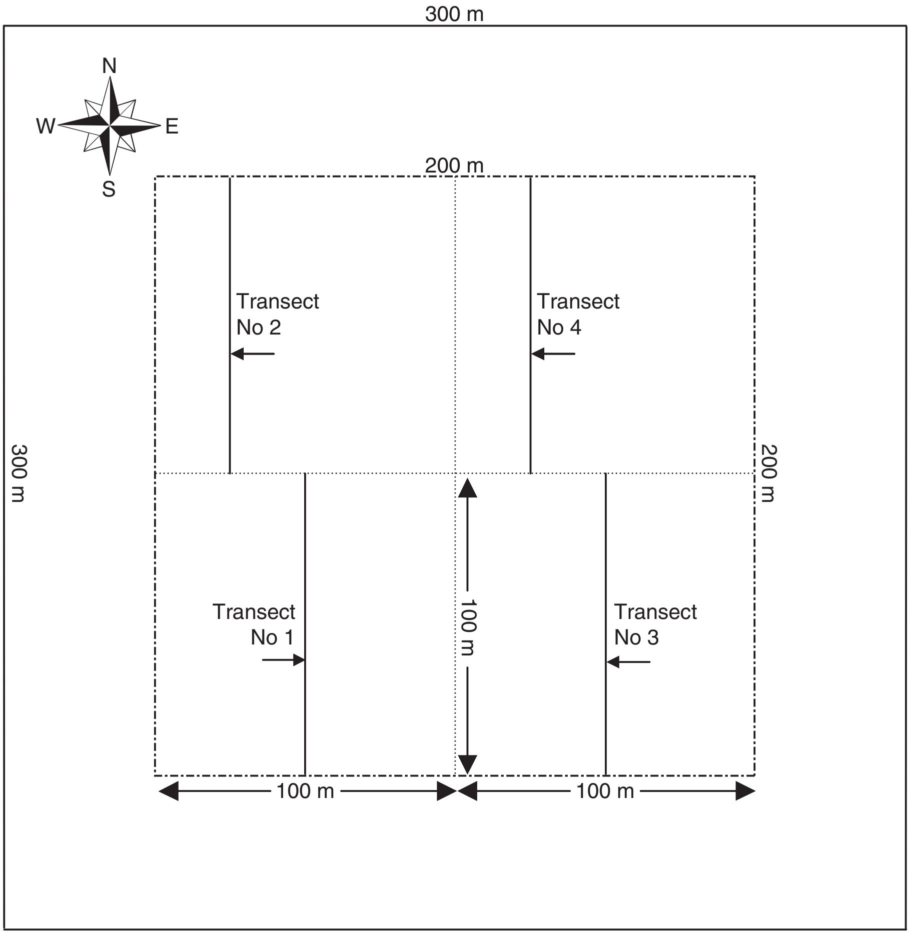


Figure 1. Plot layout for treatments SI All, Scattered and Control.

cut nearly through with the axe at waist height, broken over and the herbicide applied to the cut surface. Plants less than waist high (approximately 1.2 m) were generally left untreated, in line with standard commercial practice.

For treatment Strips, a single-engine agricultural aircraft applied Graslan® pellets at 7.5 kg/ha (1.5 kg/ha a.i.), by flying at approximately 50 m above ground level and distributing the pellets over an 18.3 m swath at each pass. The passes, marked at each end by white helium-filled balloons which could be seen above the woodland canopy, were spaced 12.8 m apart, which gave a swath overlap of approximately 43 % and a very even distribution of the pellets on the soil surface (Table 4).

For treatments Pulling and Pulling+Burn, all trees and shrubs were pulled over using a heavy chain between two 105 kw (140 hp) bulldozers (pulling or chaining). The roots of some trees were torn from the ground, while other trees broke off at ground level and most small plants simply bent over and sprang back up when the chain had passed. Following pulling, half the area was fenced to exclude stock (treatment Pulling+Burn) (Figure 4), while the other half (treatment Pulling) was grazed. A fire-break was placed around the fenced area and the area was burnt 30 months after pulling, by which time there was adequate fuel (dead woody material and dry grass) available for effective burning of the plots.

Woody plant assessment

Assessments of treatments SI All, Scattered and Control were made in a 200 m × 200 m

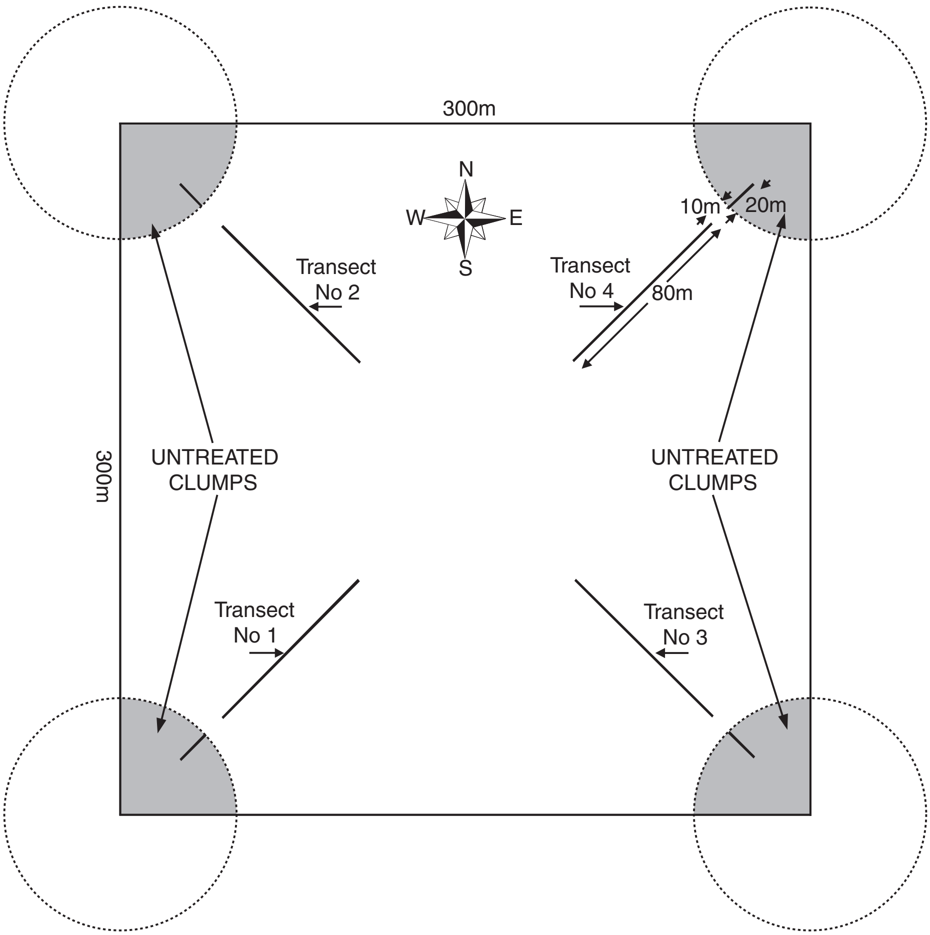


Figure 2. Plot layout for treatment Clumps.

Table 3. The number of operators and the time taken to stem-inject trees and shrubs in 9 ha plots. The variation in density of woody plants is seen by the varying time needed to treat the plots.

Treatment	Rep. No.	Number of operators	Time in minutes	Time/man/ha in minutes
SI All	1	10.0	90.0	100.0
	2	8.0	210.0	186.7
	3	7.0	120.0	93.3
Mean			140.0	126.7
Scattered	1	10.0	60.0	66.7
	2	8.0	210.0	186.7
	3	9.0	90.0	90.0
Mean			120.0	114.4
Clumps	1	10.0	60.0	66.7
	2	8.0	270.0	240.0
	3	7.0	165.0	128.3
Mean			165.0	145.0
Overall mean		8.6	141.7	128.7

sub-plot centrally located in each plot, which left a 50 m treated buffer around the assessment area. Each sub-plot was divided into 4 sectors (100 m × 100 m) and a north-south recording belt transect, 100 m long × 4 m wide, was located in each sector (Figure 1). The southern end of each transect was the origin and the northern end was a fixed photo point. For treatments Pulling and Pulling+Burn, only 2 belt transects were established in each plot (Figure 4). For treatment Clumps, four 110 m transects were positioned on the plot diagonals so that 20 m of the transect was within the untreated clump and the remaining 90 m in the treated area. For observations, a 10 m unrecorded buffer was positioned between the untreated clump and the treated area. The origin for each transect was within the untreated area. The photo point was the northern-most end of each transect (Figure 2).

Similarly, for treatment Strips, the plot was divided into 4 sectors, with a transect in each sector (a random location along each strip boundary). Again each transect was 110 m, positioned with 20 m of the transect within the untreated strip, 80 m in the treated area and a 10 m unrecorded buffer between the untreated strip and the treated area (Figure 3). The origin for each transect was within the untreated area.[3]

The woody plants within each belt transect on each treatment plot were recorded using the TRAPS (Transect Recording and Processing System) methodology (Back *et al*. 1997; 1999). The position, species, height and basal circumference at 30 cm high were recorded for each woody plant within each belt transect.

The plants were identified to species and their position was recorded along the transect to the nearest 10 cm, whether right or left of the transect centre line and the distance out from the line to the nearest 10 cm. This allowed the relocation of each individual plant at later recordings. The basal circumference at 30 cm and the height of each plant were recorded. Basal circumference was not recorded for plants less than 30 cm high or with a basal circumference of less than 30 mm. For spreading shrubs, the width (at right angles to the transect line) and length (along the line) of the canopy of each shrub were recorded. A plant was considered dead if no live material was found at 2 consecutive annual recordings. The date of death was then accepted as the first date. A photograph was taken along each line from the northern end at each recording time.

The results cover the period 1987 (when the trial treatments were imposed) — 1994 (when some of the treatment plots were stick-raked, *i.e.,* all woody debris and small woody plants were pushed into windrows using a bulldozer fitted with a special blade, and others re-treated).

[3] The purpose of 20 m of untreated woodland at the beginning of each transect in treatments Clumps and Strips was to reflect the 20% of the area retained and also to enable the recording of any seedling establishment along the edge of the untreated area (encroachment). The 10 m unrecorded buffer was to avoid partially treated areas confounding the treatment effects.

Statistical analysis

A conventional analysis of variance utilised the proportional changes in woody plant numbers and basal area to determine the significant effects of treatments. The initial analysis assessed the effectiveness of each woody plant (timber) control technique used in the study, but not the overall strategy that was being tested. This was done by comparing the percentage change in number or basal area of live plants remaining 1 year and 7 years following the application of the various treatments, in the treated areas only. The untreated areas in treatments Clumps and Strips were excluded from this analysis, as was the Scattered trees treatment.

Results

E. populnea trees and saplings represented only a small proportion (about 18%) of the total number present on the plots prior to applying treatments, but made the greatest contribution to total stand basal area (about 72%) (Table 5). This table also highlights the variation in woody plant numbers and basal area between treatments for *E. populnea* and other woody species.

Table 4. The number of samples taken and the number of pellets found in 0.5 m^2 litter traps placed along transect lines in the second replicate of treatment Strips, to ascertain the evenness of spread of the Graslan® pellets after aerial application.

Transect	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5	Mean
1	4	1	6	5	NS[1]	4.0
2	5	4	3	4	NS	4.0
3	4	3	4	5	6	4.4
4	5	4	5	5	7	5.2
					Mean	4.4

[1] NS = Not sampled.

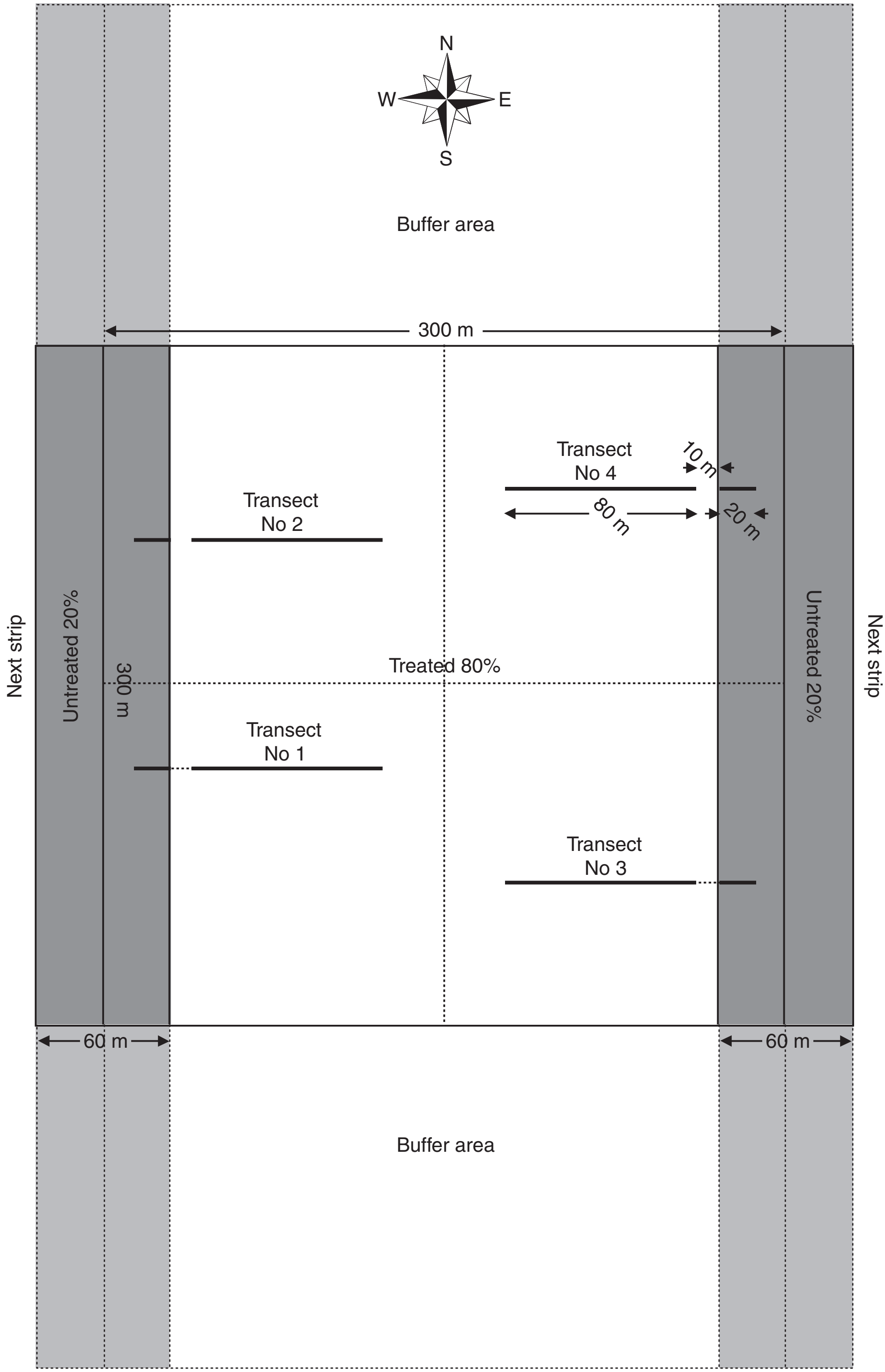


Figure 3. Plot layout for treatment Strips.

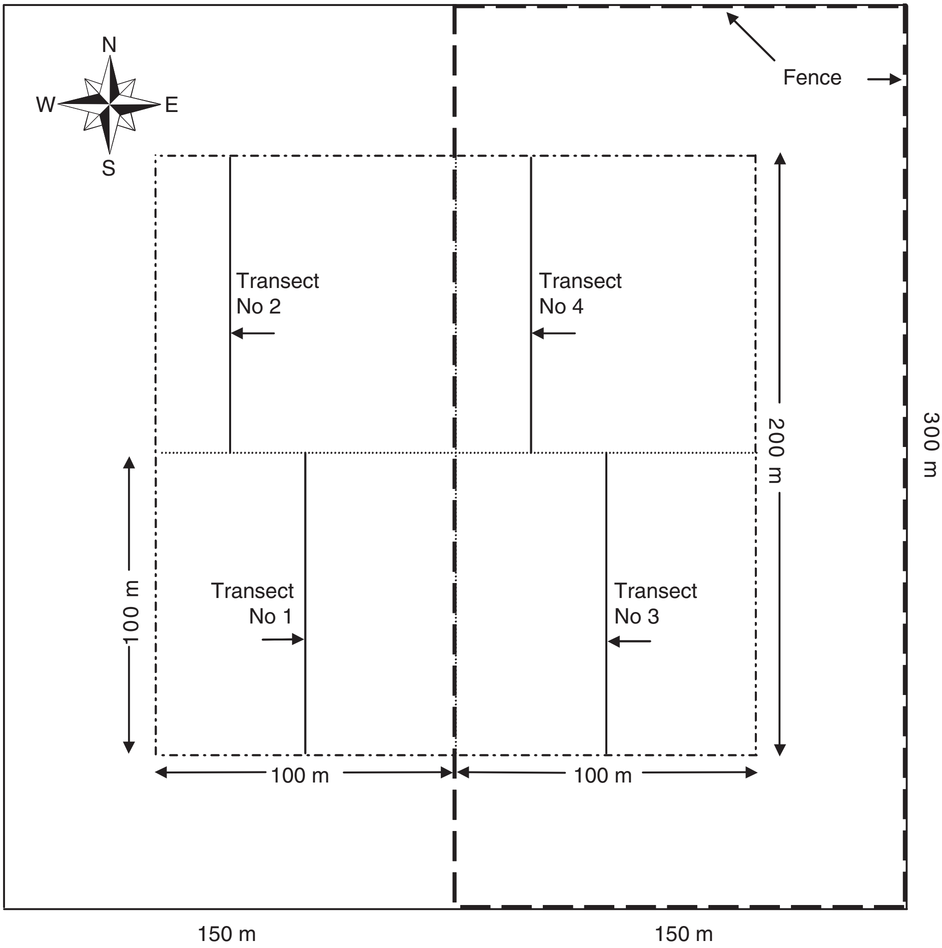


Figure 4. Layout for treatment Pulling (pulled only) and treatment (Pulling+Burn) (pulled, fenced and burned 30 months later).

Woody plant control — treated areas only

Application of the 3 herbicides killed the treated trees and shrubs very effectively (Figure 5). The stem-injection treatments [treatment SI All (Velpar®) and treatment Clumps (Tordon TCH®)] gave similar significant reductions in plant populations at both 1 year and 7 years following treatment.

Aerially applied Graslan® treatment (Strips) reduced *E. populnea* populations significantly more ($P<0.05$) than treatment (Clumps) at 1 year following treatment, and both stem-injection treatments after 7 years. This treatment (Graslan®) gave a significantly greater reduction in the population of all woody plants than all other treatments after both 1 year and 7 years. The pulling treatments killed only those trees and shrubs that were completely removed from the ground, as most plants that were broken off or bent over regrew. After 7 years, Pulling+Burn had significantly reduced the number of woody plants overall more than Pulling, which was similar to the control; however, the change in the *E. populnea* population alone was not significantly different in treatments Pulling, Pulling+Burn and Control.

All timber treatments reduced the basal area of all woody plants including *E. populnea* to near zero (Figure 5) at 1 year following treatment. While this effect persisted, by 7 years following treatment, the reductions in basal area of both all woody species and *E. populnea* on the pulling treatment were less ($P<0.05$) than on all other timber treatments but greater than on control.

Table 5. Number and basal area of *E. populnea* plants and all other woody plants recorded in each treatment over the period reported.

Woody plant population (number/ha)						
Year	1987 (before treatment)		1988		1994	
Treatment	*E. populnea*	Other spp.	*E. populnea*	Other spp.	*E. populnea*	Other spp.
SI All	542	3671	187	2731	217	2496
Scattered	508	1592	256	1358	394	1633
Clumps	383	3183	200	2658	217	2669
Strips	567	2567	135	1760	119	1512
Pulling	608	1267	408	1083	429	1671
Pulling+Burn	471	2704	250	2325	321	2146
Control	542	1887	537	1996	517	2196

Basal area (m^2/ha)						
Year	1987 (before treatment)		1988		1994	
Treatment	*E. populnea*	Other spp.	*E. populnea*	Other spp.	*E. populnea*	Other spp.
SI All	6.233	2.375	0.135	0.350	0.444	0.635
Scattered	5.885	4.093	2.212	2.700	3.215	3.409
Clumps	6.002	3.192	1.569	1.465	2.408	1.492
Strips	5.392	3.113	1.335	1.085	1.619	1.201
Pulling	11.008	0.893	0.004	0.001	2.642	0.845
Pulling+Burn	6.842	2.762	0.000	0.000	0.587	0.301
Control	6.506	2.142	6.473	2.130	7.975	2.486

Treatments:
SI All — all trees stem-injected
Scattered — 80% of trees stem-injected, the remainder left as scattered trees
Clumps — 80% of trees stem-injected, the remainder left in clumps
Strips — 80% of trees treated with soil-absorbed herbicide aerially applied, the remainder left untreated as a strip
Pulling — all trees and shrubs pulled over by 2 bulldozers dragging a chain
Pulling+Burn — as for Pulling but also burned 30 months after pulling
Control — control, untreated

Comparing woodland management strategies

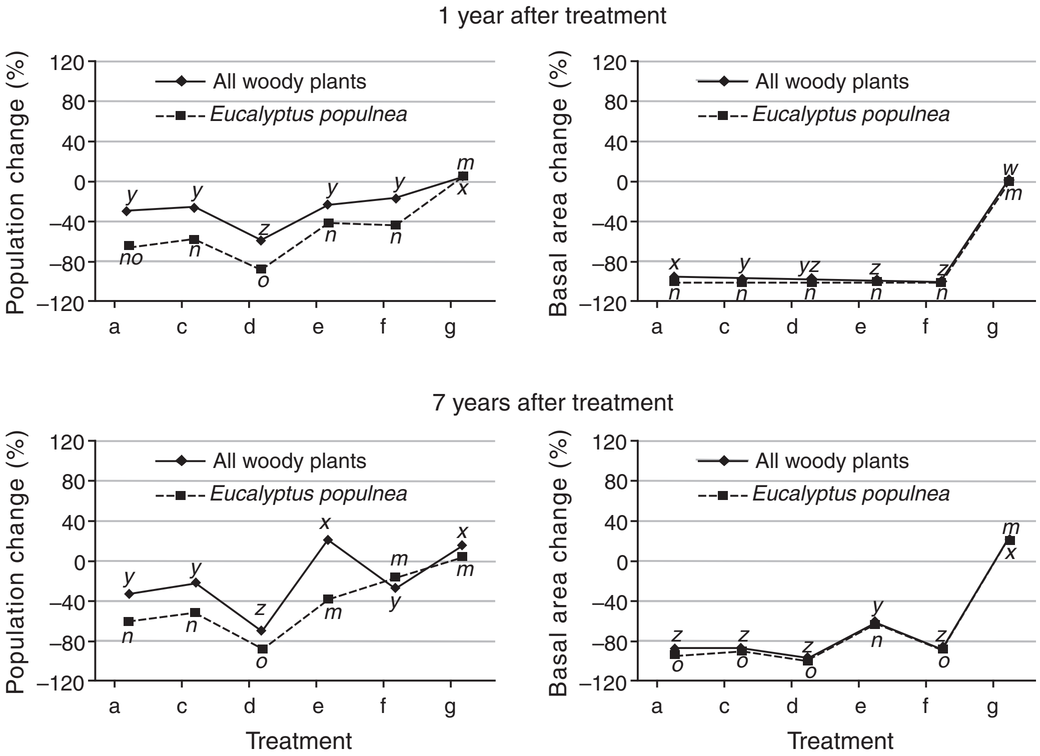
This analysis compares the changes in the population and basal area for *E. populnea* (Figure 6) and for all woody plants present (Figure 7) in each strategy and takes into account the 20% of untreated plants in treatments Scattered, Clumps and Strips. The various plant height classes used in this analysis were selected to represent a number of growth forms of the woody plants. Plants to 1.2 m represented seedlings and young plants, >1.2–3 m represented shrubs and small saplings, >3–10 m were large saplings and small trees and >10 m were mature trees. There were no significant differences between treatments for the <1.2 m size class owing to low numbers of plants and great variability within treatments, so this size class is not shown in Figures 6 and 7. Very few seedlings were recorded in any treatments over the course of the experiment.

Changes in E. populnea *population*. All timber treatment strategies resulted in a significantly greater reduction in the total population of *E. populnea* than the untreated control at both 1 year and 7 years following treatment (Figure 6). Treatment Strips gave a significantly greater reduction in total population than Scattered, Clumps, Pulling and Pulling+Burn after 1 year, and was more effective than Scattered, Clumps and Pulling after 7 years. Most treatments reduced the population of poplar box by only about 50%.

Plants >10 m tall. Reductions in population at both 1 and 7 years following treatment followed the order: SI All, Pulling and Pulling+Burn > Clumps and Strips > Scattered > Control ($P<0.05$).

Plants >3–10 m tall. SI All, Clumps, Pulling and Pulling+Burn gave similar reductions in population after 1 year, but after 7 years, Pulling and Pulling+Burn had higher populations in this size class than their pretreatment levels.

Plants >1.2–3 m tall. Data for this size class were quite variable owing to low numbers of plants and variable plot responses, so no interpretation has



Treatments: [See Experimental Design for herbicide application rates]
SI All — All trees stem-injected with Velpar ® herbicide (a)
Clumps — All trees in treated area stem-injected with Tordon TCH ® herbicide (c)
Strips — Graslan ® herbicide granules applied aerially to all treated area (d)
Pulling — All trees and shrubs pulled over by 2 bulldozers dragging a chain (e)
Pulling+Burn — as for Pulling but also burned 30 months after pulling (f)
Control — untreated (g)

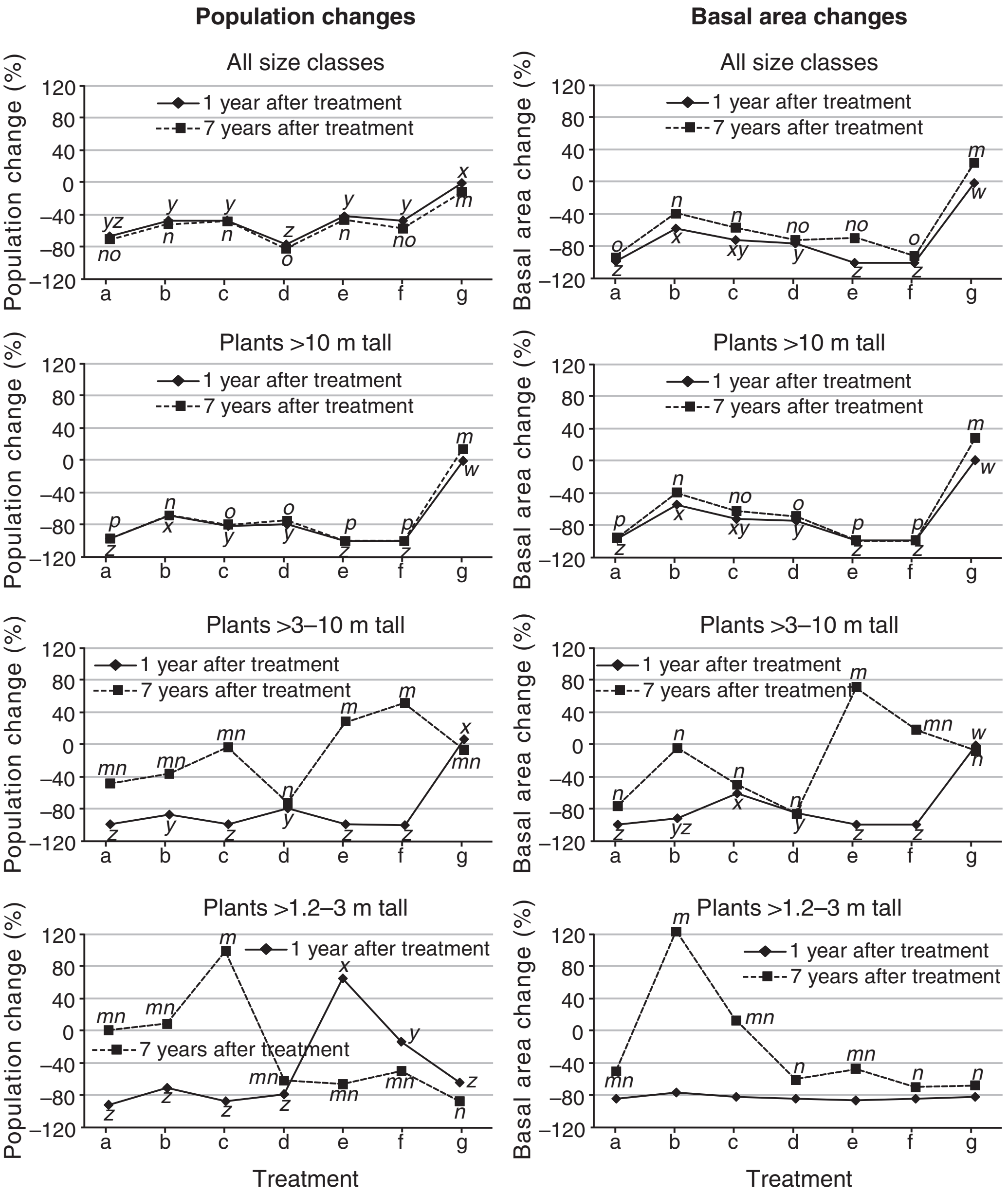
Figure 5. Effects of the various treatments within treated areas only on all woody plants present and *Eucalyptus populnea* plants only at 1 year (1988) and 7 years (1994) following treatment. Letters in italics indicate significant differences ($P<0.05$) between treatments. Treatment Scattered has not been included as the untreated trees are scattered throughout the plot area whereas the retained trees in treatment Clumps are in clumps and treatment Strips in strips and can be excluded from the treated area for this comparison.

been attempted. Part of this variability resulted from plants in the smallest category (<1.2 m tall) having grown into this category by 7 years after treatment.

Changes in E. populnea *basal area.* All timber treatment strategies reduced the total basal area of *E. populnea* significantly more than the untreated Control, at both 1 year and 7 years following treatment. While SI All, Pulling and Pulling+Burn resulted in significantly greater reductions in total basal area than the other treatments at 1 year after treatment, this effect was significant only for SI All and Pulling+Burn over Scattered and Clumps by 7 years after treatment application.

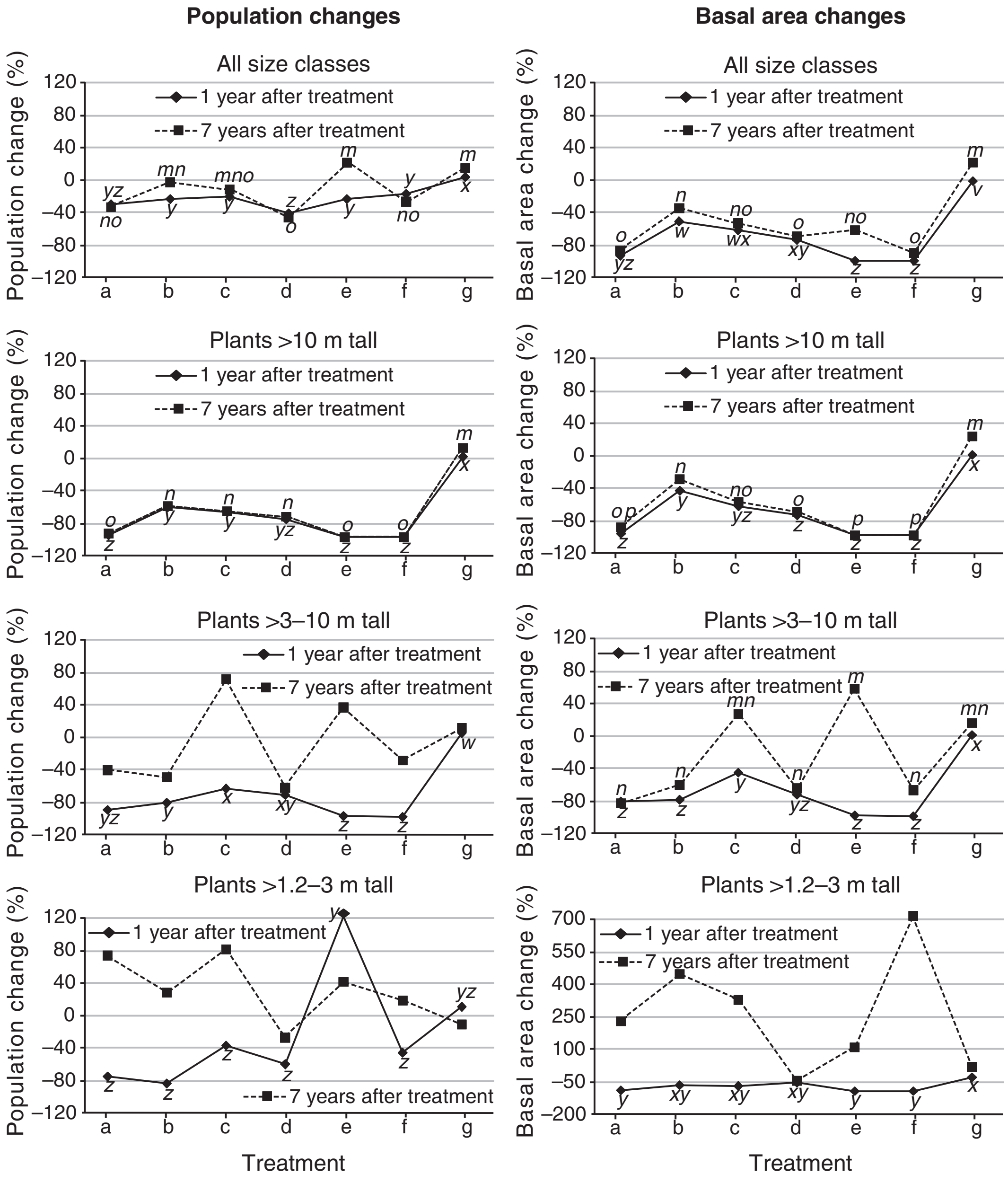
For plants in the size classes >10m tall, the reductions in basal area following treatment were very similar to the total population results. For plants in the >1.2–3 m tall size class, there were no significant differences in basal area change after 1 year following treatment (Figure 6), because of low numbers of plants present and very small basal area recorded in this size class. The differences in basal area change after 7 years were due to low numbers of plants and plants moving from one size class to another which masked any treatment effect.

Changes in population of all woody plants. All timber treatment strategies reduced the total population of all woody plants significantly more than the untreated Control 1 year after treatment, with the largest reduction being only about 40%.



Treatments: [See Experimental Design for herbicide application rates]
SI All — all trees stem-injected (a)
Scattered — 80% of trees stem-injected, the remainder left as scattered trees (b)
Clumps — 80% of trees stem-injected and the remainder left in clumps (c)
Strips — 80% of trees treated with soil-applied herbicide aerially applied with the remainder left untreated as a strip (d)
Pulling — all the trees and shrubs pulled over by 2 bulldozers dragging a chain (e)
Pulling+Burn — as for Pulling but also burned 30 months after pulling (f)
Control — untreated (g)

Figure 6. Changes in the population and stand basal area of various height classes of poplar box (*Eucalyptus populnea*) over time as a proportion of the pre-treatment (1987) values. Letters in italics denote significant differences ($P < 0.05$) between treatments at that particular time (1 year or 7 years following treatment).



Treatments:
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Pulling — all the trees and shrubs pulled over by 2 bulldozers dragging a chain (e)
Pulling+Burn — as for Pulling but also burned 30 months after pulling (f)
Control — untreated (g)

Figure 7. Changes in the population and stand basal area of various height classes of all woody plants over time as a proportion of the pre-treatment (1987) values. Where present, letters in italics denote significant differences ($P<0.05$) between treatments at that particular time (1 year or 7 years following treatment). Note different scale on y axis (Plants >1.2–3 m tall).

Strips reduced total woody populations more ($P<0.05$) than Scattered, Clumps, Pulling and Pulling+Burn after 1 year but only Scattered and Pulling after 7 years. By then, Scattered, Clumps and Pulling were similar ($P>0.05$) to the control (Figure 7). The reductions were most pronounced in the category Plants >10 m tall, with a marked recovery in the category Plants >1.2–3 m tall on most treatments by 7 years.

Changes in basal area of all woody plants. All timber treatment strategies significantly reduced ($P<0.05$) total basal area of all woody plants relative to the untreated Control at 1 year and 7 years after treatment. Pulling and Pulling+Burn gave the greatest reduction 1 year after treatment and Scattered and Clumps gave the least reduction when compared with Control. After 7 years, SI All, Strips and Pulling+Burn showed greater basal area reduction than Control and Scattered.

Discussion

Efficacy of the various control methods

All clearing strategies studied here were representative of standard commercial practice at the time. The results provide insights into the net effect of conservation (tree retention) and pasture production (as inferred from woody plant basal area) outcomes, when the various clearing strategies are compared. They have shown that there was little difference in the efficacy of Velpar L® and Tordon Timber Control Herbicide® when used to control woody plants on this site using the stem-injection technique (Figure 5). The study has also shown that Graslan®, applied aerially, was more effective in reducing the population of these woody plants in the short (1 year) and medium (7 years) term. The short-term effect of pulling on the *E. populnea* population was similar to the stem-injection treatments but, without a follow-up fire, this treatment resulted in a similar population to the untreated control in the medium term.

The data also showed that, initially, the *E. populnea* population was controlled more effectively than the other woody species present but that basal area reduction was similar for both groupings. This was a function of the greater proportion of 'other woody species' in the smaller size classes, which were missed when stem-injection or pulling was carried out. In addition, a number of these 'other woody species' were resistant to Graslan® application at the rate used. Some of these were *Capparis lasiantha*, *Carissa ovata*, *Grevillea striata*, *Owenia acidula* and *Ventillago viminalis.*

While reductions in woody plant basal area following the various clearing treatments were similar in the short term (1 year), woody plant basal area increased much more quickly on the Pulled (but not burnt) treatment than on the other treatments in the medium term (7 years). This was a result of rapid regrowth of smaller plants, either missed or just bent over in the pulling process, along with regrowth from broken off stumps of larger trees. Burning the pulled area after a period, when the amount of fuel was adequate, killed many of the small plants as well as some of the stumps that re-grew. This result indicates that, if pulling is the chosen control strategy for woody species on these areas, it is important to include a burn following the pulling to maximise timber control over time.

Logistics of the various control methods

The time taken to stem-inject the trees in the various plots of treatments SI All, Scattered and Clumps varied, reflecting the population density of trees in these plots. The 'scattered tree' plots took almost as long to treat as SI All as the operators still had to walk over the whole area (Table 3) even though 20% of the trees on those plots were not treated. Time taken per ha was similar to that for commercial operators working on commercial jobs and, using present day labour rates, these times could be utilised to estimate the contemporary cost of the various timber treatment techniques.

Aerially applied Graslan® proved a very quick and efficient timber control technique which, because of the proprietary equipment used, gave excellent coverage with the herbicide (Table 4). However, the disadvantage with this herbicide is that it is non-selective and all plants on the treated area might be killed. The application of this herbicide is strictly controlled because of the environmental damage that could be caused if the herbicide is used incautiously. The supplier is responsible for supplying the herbicide as well as organising the aerial operator who applies it. Pulling of timber on each 9 ha plot took an average of 110 minutes (12 min/ha) using two 105 kw (140 hp) bulldozers (tracked tractors).

This was probably slower than when pulling larger areas but a rate of 10 min/ha (6 ha/h) for commercial pulling of this type of timber is quite acceptable.

Comparing the woody plant control strategies tested

The effectiveness of clearing strategies in optimising pasture production will be influenced by the survival rate and regrowth rate of the woody plants remaining after each clearing treatment is applied. On an area basis, the competitiveness of retained (untreated) trees will also affect overall pasture productivity. There is a strong negative exponential relationship between tree basal area and potential pasture production in poplar box woodlands (Scanlan and Burrows 1990; Burrows 2002). In fact, woody plant basal area is a better indicator than woody plant population of the competitive effects trees have in limiting pasture productivity, since basal area integrates the influence of both size and number of the woody plants (cf. McIvor 2006). Retaining 20% (or more) of the trees and shrubs in a woodland after a clearing event will obviously suppress pasture production on the area relative to total clearing.

The level of suppression will be determined by the distribution of these trees. A clearing strategy where trees compete with pasture over the whole paddock (*e.g.* scattered tree treatment) should decrease pasture production to a greater extent than one which retains the same basal area of trees in intact blocks and strips, while minimising their competitiveness with pasture elsewhere. This is because the slope of the negative exponential relationship between tree basal area and pasture production is greatest at low tree basal areas. In most situations, retaining scattered trees simply ensures this strong competitive influence is distributed over the whole paddock. [One exception to this generalisation occurs when low densities of long-lived, deep-rooted trees are retained on very infertile soils in semi-arid areas (Ebersohn and Lucas 1965; Christie 1975)].

Seven years after the treatments were applied, the percent reduction in the population of poplar box trees (all size classes) in the Strips treatment was not statistically different from that in the plots where all trees were either stem-injected with Velpar®, or pulled and burnt (Figure 6). This was despite the fact that a proportion of the trees were not treated in the Strips, *i.e.*, 20% of the area was retained intact. A similar response in percent basal area reduction was obtained, although in this case Pulling was equally effective.

It could be argued that responses from the Clumps and Strips strategies in this study do not provide a valid comparison, given the differing herbicides used on the targeted areas in each case. In theory, retaining trees as clumps or strips should give similar results. This did not occur with Clumps and Strips in our study as the chemical methods were different. The Graslan® applied in the Strips treatment was more effective in reducing the poplar box population (where all size classes on the treated area were actually treated) than the Tordon TCH® herbicide used in the Clumps treatment (where only plants greater than waist high were treated) (Figure 5). For a broad-scale application it would be possible to retain strips or square/rectangular clumps using Graslan®, but this was not possible at the experimental scale used.

Controlling woody plants to increase pasture production in grazing lands is rarely a simple 'one-off' operation. This is why a large proportion (51%) of the land cleared in Queensland, prior to the introduction of clearing bans, was of regrowth (Department of Natural Resources and Water 2007), *i.e.*, the re-clearing of areas that had been 'cleared' at least once beforehand. One reason for this is that standard control methods (as utilised in the present trial) are rarely effective in killing all species or all plant sizes and new seedlings invariably establish after the initial clearing. Such variable responses are apparent in the changes in the populations and basal areas of 'all woody plants' under the clearing strategies examined here (Figure 7) — especially in the smaller size classes of plants. Nevertheless, some trends become evident when the data are inspected for all size classes and all woody plants combined, 7 years after the trial commenced.

At this time, reduction in woody plant population was greater for the Strips treatment than for the Scattered, Pulling and Control treatments (Figure 7). While the Scattered treatment, the clearing strategy which has been practised by many graziers who wished to retain scattered trees for shade and/or potential harvest later for milling, fencing timber etc., was statistically better than the control in reducing tree basal area, it was statistically less effective than total clearing treatments (SI All and Pulling+Burn) as well as the Strips treatment. This result has important implications for pastoralism given the previously discussed strong negative exponential relationship between tree basal area and potential pasture yield. Thus, from a pasture production perspective, it is more beneficial to retain trees in strips and clumps than to retain the equivalent tree basal area in a 'scattered tree' or park-like format. An earlier economic analysis (see Burrows 2002) supports this conclusion. Thus, there is a conflict between objectives of producing pasture and producing timber products in conjunction with grazing. Clearing decisions might be different, therefore, in those situations where retained trees have timber or fodder tree value as great as or greater than pasture. In woodlands of very low density with large, deep-rooted trees growing on infertile semi-arid or arid soils, the retention of trees for shade and deep cycling of soil nutrients from leaf drop can be appropriate. In this situation any clearing may have a detrimental effect on pasture production.

Regrowth rates and growth data from the present work will be of value to land managers in planning regrowth control programs. It is significant that, on the treated areas, the populations of all woody species for all except the Graslan treatment after 7 years had been reduced by only about 30%. The remaining plants, as mentioned earlier, survived the initial treatment as they were either too small to be treated or were left as part of the clearing strategy design and were able to grow on and quickly restrict pasture productivity. Further, emerging knowledge of the on-going tree population changes ('tree thickening') in Queensland's grazed woodlands (*e.g.* Burrows *et al.* 2002; Fensham *et al.* 2003; Bray *et al.* 2007; Krull *et al.* 2007) could lead to a future re-assessment of present tree-clearing controls on grazing lands. Tables 3 and 4, along with other data included in the text, have been provided to enable future treatment costing to be estimated.

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