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Early growth of environmental plantings in relation to site and management factors

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Summary

In temperate Australia, large-scale revegetation, including with mixed-species environmental plantings, is a recommended option to address land and water degradation in rural landscapes. Although survival and growth are central to the success of revegetation, there is very limited information on this issue. We investigated how site and management practices influence early growth by surveying 33 sites, covering ages from 2-6 years, in north central Victoria, Australia. We measured heights and crown widths of trees and shrubs at each planting, and estimated average growth over time at the scale of: i) individual trees or shrubs (mean height increment) and ii) stand (vegetation cover increment and a 'height integral' increment variable, which integrates differences in both height and stand density). Relationships between growth increment variables and site factors, including climate, site preparation and land use history, were investigated to identify the main factors influencing early growth rates. Increments in mean height were significantly higher for trees established from tubestock than those from direct seeding. Multiple linear regression models for cover increment and height integral increment explained 52% and 67% of the variation, respectively, but with high uncertainty. There were three variables that had significant and common effects shown by both models: planting method (tubestock or direct seeding), cultivation by mouldboard ploughing and pre-planting weed control. Both ploughing and pre-planting weed control improved growth rates. Planting method had a strong effect on early growth, which varied depending on the scale at which growth was considered. At the scale of individuals, growth rates were higher for planted tubestock than for direct seeding, while at the stand scale, growth rates were higher for direct seeding than for planted tubestock.

Keywords: revegetation, mixed species, tubestock, direct seeding, site preparation, cultivation, weed control

Introduction

In the temperate areas of Australia, woody vegetation cover has declined significantly since European settlement, as a result of clearing for agriculture and gradual senescence of older trees (Yates and Hobbs 1997; 2000). Maintaining and increasing tree cover in these landscapes is important for persistence of biodiversity (e.g. Barrett 1997; Bennett and Ford 1997), sequestration of carbon (e.g. England *et al*. 2006; Kanowski and Catterall 2010), reduction of dryland salinity and improvement of water quality (e.g. Stirzaker *et al*. 2002) and increasing agricultural production through enhancement of forage quality and provision of shelter for livestock (e.g. Bird *et al*. 1992; Williams *et al*. 1999). Consequently, governments and regional land management agencies have set targets to increase native vegetation cover in these areas (e.g. Anon 2003a; 2003b).

Since the mid 1990s, the Australian Government has invested in revegetation programs (e.g. Commonwealth of Australia 2005) largely for vegetation establishment. Establishment of mixed-species environmental plantings have been strongly encouraged by supporting policy mechanisms to enhance regional biodiversity. Environmental plantings are defined here as mixed-species plantings of trees and shrubs established for environmental benefits. In contrast, a broader definition of revegetation (Atyeo and Thackway 2009) includes commercial farm forestry for wood production. Environmental plantings have been established, mostly on private land, for various purposes including salinity mitigation, erosion control, stock shelter and biodiversity enhancement. Although some organisations have monitored early survival rates of these plantings, few have assessed their success in achieving environmental objectives (e.g. see Atyeo and Thackway 2009; Zerger *et al*. 2009).

The longer-term success of environmental plantings will depend on their survival and growth. Survival of revegetation is highly variable (e.g. Andrews 2000; Close and Davidson 2003). Regional guidelines for revegetation (e.g. Carr *et al*. 2005; Corr 2003) recommend good site preparation, including weed control before planting or direct seeding, for successful establishment. A review of the methods of establishment of eucalypt seedlings on farmland showed that soil cultivation and weed control improved early survival and growth (Graham *et al*. 2009). Additional factors affecting survival and growth include climate (Stephen 1994; Close and Davidson 2003), soil type (Pinkard 1990; Stephen 1994) and previous land use (Stephen 1994; Andrews 2000). One major gap is the lack of quantitative information on factors influencing early growth of mixed-species environmental plantings.

This study aimed to investigate growth of young environmental plantings in low-medium (400-700 mm y^{-1}) rainfall areas and its relationship with climate and management. For this we measured plant growth parameters in plantings which were 2-6 years old and developed regression models of growth against multiple climate and management variables.

Methods

Study sites and surveys

The study region was in the North Central Catchment, Victoria, Australia (35.19°–37.51° S, 142.64°–144.87° E, which has a temperate climate, with cool, wet winters and hot, dry summers. The region includes four major river catchments (Campaspe, Loddon, Avoca and Avon-Richardson). This study was in the Loddon and Campaspe catchments.

Thirty-three sites, where plantings were at least 10 m wide, were randomly selected from a database compiled by the North Central Catchment Management Authority for dryland revegetation projects. These were planted between 1999 and 2003, and at the time of this study were 2 to 6 years old. About 90% of these were linear plantings, mostly along the edges of paddocks or on drainage lines and their size ranged from 0.12 to 99 ha. Plots (10 m × 10 m) were located randomly within each site. Because there was large variation in the area planted at each site, sites were stratified so that the number of inventory plots increased as planting size increased to a maximum of eight plots per site.

Plots were surveyed during June and July 2005. Within each plot, the numbers, heights and crown widths of all trees and shrubs were recorded. Ground layer flora was not assessed. It was not possible to assess survival rate because there were no records on initial planting density or germination rates (in the case of direct seeding). Mean height (m) was calculated separately for trees and shrubs, and for trees and shrubs combined, as the sum of all heights divided by the number of stems per plot. Crown cover (*CC*, %) of trees and shrubs in the 100 m^2 plots were calculated from crown widths (*CW*) as:

$$CC = \frac{\left[\sum \pi \left(\frac{CW}{2}\right)^2\right]}{no.\ plots} \qquad \text{Equation 1}$$

Plantings were established in different years, so annual growth increments were calculated to compare growth rates. Mean height increment (*HI*, m y^{-1}) was calculated as mean height divided by planting age in years. Height increment describes average growth over time at the scale of individual tree or shrub. It is therefore not a reliable indicator of actual growth if, for example, there are only few trees per hectare. To improve this, we used a ‘height integral’, calculated as mean height multiplied by stand density (number of trees/shrubs per hectare). This integrates both differences in height and stand density at each planting, as an index for stand growth. Height integral increment (*HII*, m ha^{-1} y^{-1}) was calculated as height integral divided by planting age in years. Vegetation cover increment (*CI*, % y^{-1}) was calculated as crown cover at a site divided by planting age in years. Vegetation cover is widely used in ecology as it gives a better indication of plant biomass than other measures such as plant density (Mueller-Dombois and Ellenberg 1974; Elzinga *et al*. 2001). Therefore *CI* is a measure of increments in growth per unit area.

Landholders provided the following information: previous land use (sheep, cattle, sheep + cattle), previous fertiliser application (+/-), previous weed control (+/-), weed control prior to planting (+/-), cultivation using mouldboard ploughing (+/-), ripping (+/-), planting method (planted with tubestock or direct seeded), watering at planting (+/-), fertiliser application at planting (+/-) and grazing after planting (+/-). Weed control was generally glyphosate either spot or broad-acre sprayed. Grazing after planting was typically periodic grazing for 1-2 of weeks every 3-12 months.

Climate data for each of the sites were obtained from the SILO Data Drill (Jeffrey *et al*. 2001; http://www.nrm.qld.gov.au/silo/datadrill/). Rainfall variables were annual rainfall in the planting year and mean annual rainfall since planting. Temperature variables were mean maximum/minimum temperatures of the warmest/coldest months in the planting year and mean maximum/minimum temperatures of the warmest/coldest months since planting. The exact planting dates were uncertain, so we assumed that sites were planted in late winter (August), which is common practice, when estimating rainfall and temperature since planting.

Statistical analyses

Univariate analyses

Trees were present at 32 sites, shrubs at 22 sites, and both trees and shrubs at 21 sites. The effect of life-form (tree vs. shrub) on height growth variables were analysed for these sites by paired t-test. The effects of planting method (planted tubestock or direct seeding) on density (stems ha^{-1}) and height increments were analysed by unpaired t-tests. Height increments were analysed separately for trees and shrubs because: i) mean height was significantly higher for trees, and ii) both life-forms were not present at all sites. The relationship between stand density and percentage cover of trees and shrubs was examined by linear regression. All variables were checked for the assumption of homogeneity of variance and data were natural-log transformed where necessary.

Multivariate analyses

We excluded three management variables (previous land use, watering, ripping) from the multivariate analyses on the basis of either: i) insufficient (<3) observations for some categories (previous land use), or ii) the management was only practiced for tubestock plantings (watering, ripping). Additionally, linear coefficients of correlation (r) were determined using the Pearson's correlation coefficient (n = 33 sites) to indicate whether variables were highly (r >0.9) correlated and should be excluded from subsequent modelling. This was tested among seven management (planting method, weed control, cultivation, fertiliser application, grazing, previous fertiliser application and previous weed control), two stand (density, proportion of trees) and six climate factors (annual rainfall in the planting year, mean annual rainfall since planting, mean maximum/minimum temperatures of the warmest/coldest months in the planting year and mean maximum/minimum temperatures of the warmest/coldest months since planting). Based on this analysis, no further independent variables were excluded from subsequent modelling (data not shown).

General Linear Modelling was used to test the responses of early growth (height increment, tree height increment, cover increment, height integral increment) to planting methods, previous management and climate. Because planting method was a categorical variable (tubestock or direct seeded), it was converted to a binary 'tubestock' variable (1, 0) for the analyses. Stand density was included as a variable, with the exception of the height integral increment model. The complete model was run with no additions or deletions of variables. The distribution of residual errors was used to check the fitted models.

Results

Fifty tree and shrub species were found in the surveys across the 33 sites, *Eucalyptus* (18 species) and *Acacia* (17 species) genera being the most common. Across sites, there was wide scatter in both mean height and % cover for a given planting age and planting method (Figure 1a,b). These figures are not intended to be growth curves, but rather presented to provide an understanding of the variation in data for young plantings of a similar age.

Height growth was significantly higher for trees (0.49 m y^{-1}) than for shrubs (0.32 m y^{-1}; $t = 3.04$, $P < 0.01$, $df = 21$) where both were present. Increments in height were significantly (about 2.4-fold) higher for trees planted as tubestock than for those from direct seeding ($t = 3.24$, $df = 30$, $P = 0.008$; Table 1). Stand density varied from 100 to 4000 stems ha^{-1} and was significantly higher at direct seeded compared with tubestock plantings ($t = 2.57$, $df = 31$, $P = 0.02$; Table 1). Stand density was also significantly but weakly related to cover of trees and shrubs (r^2 = 0.12, P = 0.04). Tubestock plantings had a significantly higher proportion of trees than shrubs compared to direct seeded plantings (t = 2.04, df = 31, P = 0.004; Table 1).

The plantings covered a range of previous land use and management practices (Table 2). Typical practices are expressed here as a percentage of plantings. The most common previous land management was pasture grazed by sheep (81%) with previous fertiliser application (69%). The most typical management practices were planting tubestock (82%) and weed control prior to planting (81%). Half of the sites were watered at planting. Grazing was practiced at 31% of plantings, ripping at 28%, ploughing at 19%, and fertiliser addition at only 9% of plantings.

Mean annual rainfall since planting ranged from 400-738 mm across sites, but was in the 400-550 mm range for about 85% of sites, and was >650 mm at only 6% of sites. Mean maximum/minimum temperatures of the warmest/coldest months since planting ranged from 24.9-30.0 and 2.4-3.5°C, respectively. Linear correlations between growth variables and rainfall and temperature variables were weak (r < 0.32; data not shown).

Multiple linear regression models for both cover increment (F = 3.19, P = 0.014; adjusted r^2 = 0.52) and height integral increment (F = 5.54, P = 0.001; adjusted r^2 = 0.67) were significant, but not for height increment (F = 1.44, P = 0.24; adjusted r^2 = 0.18) or tree height increment (F = 1.40, P = 0.26; adjusted r^2 = 0.17). The standard error of observations was 2.18 % y^{-1} for cover increment and 229 m ha^{-1} y^{-1} for height integral increment.

Planting method, weed control and ploughing had significant effects on cover increment (Table 3). There were no significant effects of any climate variables on cover increment. By comparison, four management variables (planting method, ploughing, weed control, previous weed control) and two climatic variables (mean annual rainfall in the planting year and mean annual rainfall since planting) had significant effects on height integral increment (Table 3).

Stand-scale measures of growth (cover increment and height integral increment) were higher for direct seeded than tubestock plantings (Table 4). Cultivation and weed control both increased growth (Table 4). Height integral increment was 2.3-fold higher where ploughing was practiced and cover increments 1.9-fold higher (Table 4). By comparison, height integral increment was 1.3-fold higher where there was weed control prior to planting and cover increments 1.8-fold higher (Table 4).

Because many of the variables included in the models used different units of measurement, we used standardised coefficients to determine which independent variables had the greatest effect on the dependent variable. The coefficients show that for both cover increment and height integral increment, planting method had the greatest effect (Table 3). That is, a change in planting method would produce more of a change in a given growth variable than would a change in any of the other independent variables tested.

Discussion

Influences on growth

Planting method was found to have a strong effect on early growth of environmental plantings. This effect was dependent on the scale at which growth was considered. At the scale of individual trees or shrubs, growth rates were higher for planted tubestock than for direct seeding (Table 1). At the stand scale, growth rates were higher for direct seeding than for planted tubestock (Table 4). Based on the standardised coefficients in the multivariate analyses (Table 3), planting method had the largest effect of all independent variables on stand-scale growth.

At the stand scale, the higher increments in both vegetation cover and height integral for direct seeded plantings (Table 4) compared to tube stock are likely related to correspondingly higher stand density at direct seeded plantings (Table 1). This finding contrasts with a study of environmental plantings in 10 regions of South Australia (Hassall and Associates 1999) that found no consistent trends between growth and planting method. In contrast, height growth at the scale of average individual tree was significantly higher for tubestock than for direct seeded plantings (Table 1). One likely reason for this difference is that tubestock seedlings were generally 6 to 18 months old at planting and therefore direct seeded trees would have been at least six months younger if both were planted in the same season.

Environmental plantings are highly variable with respect to planting density, geometry and species mix. Here, we found significant differences in vegetation structure and composition between tubestock and direct seeded plantings. Tubestock plantings had a higher proportion of trees and lower density than direct seeded plantings (Table 1). These differences, as well as variation in other factors not considered here, such as species mix, are likely to explain some of the differences in growth.

Ploughing and weed control before planting improved cover increments and height integral increments (Table 3). A review on the effects of management practices on survival and growth of eucalypt seedlings on farmland (Graham *et al*. 2009) suggested that soil cultivation and weed control before and after planting provide benefits for early growth. Inversion of the soil through ploughing would have initially reduced weed cover and may have assisted seed germination by creating a variety of microclimates for germination in direct-seeded plantings. Similarly, weed control prior to planting, generally glyphosate either spot or broad-acre sprayed, would have reduced weeds at establishment. In both cases, a reduction in weeds probably reduced competition for resources including soil moisture, allowing better root development and thus increased growth.

Rainfall over the planting lifetime had a positive effect on height integral increment (Table 3). By comparison, there was a negative effect of rainfall in the planting year on growth (Table 3). It may be that higher rainfall at establishment caused waterlogging or loss of seed from sowing lines. For example, Stephen (1994) found that waterlogging was a major reason for poor seedling establishment across 57 direct-seeded sites, reducing seedling numbers by a factor of twelve. The lack of relationship between cover increment and rainfall is unexpected given that in water limited environments, water availability is a primary determinant of growth. Other factors, such as soil texture and depth, can influence plant available water, and would therefore be expected to affect survival and growth. Increased success of revegetation has been shown on lower slopes where soils tend to have a higher water holding capacity (Andrews 2000). Alternatively, it may be that interactions between rainfall and some other site variables override the direct impact of rainfall.

Assessing the success of environmental plantings

Assessment of the success of environmental plantings will depend on their purpose. For example, if the primary objective is carbon sequestration, the growth and persistence of woody vegetation, particularly longer-lived species, will be an important measure. If the objective is to provide connectivity and habitat for a particular species, success might be measured by the presence/development of specific habitat (e.g. tree hollows) and movement requirements for that species. By comparison, a broader biodiversity objective of increasing habitat for fauna is likely to require a more complex combination of structure and composition to restore ecosystem function, and success will be more difficult to define.

Here, we did not attempt to assess plantings for their habitat value. Reviews suggest that revegetation may not be suitable as habitat for many wildlife species (Kimber et al. 1999; Munro et al. 2007). Both structure and floristic composition are important for a wide range of fauna (e.g. McElhinny et al 2006; Barrett 2000). Local species important for biodiversity may be slow growing. Thus, although a planting might have a higher rate of growth of trees and shrubs, it may not result in better biodiversity outcomes.

Conclusions

For a given region, there is often a set of common establishment and management techniques for environmental plantings (Graham *et al*. 2008). This limits the availability of sufficient sites for a thorough test of site management on growth. This study was a survey of existing sites rather than a designed experiment. We used multi-factor analyses to explore the drivers of early growth. Although there were limitations to the survey, we found distinct drivers of early growth. Ploughing and pre-planting weed control improved growth, probably through an initial reduction in weeds. Planting method had an important effect on all stand structural and growth increment variables. These results are informative for practitioners and land managers in planning future designed trials of environmental plantings. It is clear that growth rates of environmental plantings are highly variable even within a region with similar rainfall. We recommend additional field studies where there is a more even spread of opposing management factors, ideally established as designed trials and where long-term monitoring can be undertaken.

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Table 1 Summary of effects of planting method on planting characteristics. Values are means (SE) of *n* sites. Different letters in the same rows indicate treatments that were significantly different ($P \leq 0.05$).

	Planting method			
	Direct seeded	*n*	Tubestock	*n*
Stand density (stems ha^{-1})	1797 (560) a	6	738 (103) b	27
Proportion of trees	0.50 (0.14) b	6	0.83 (0.04) a	27
Tree height increment (m y^{-1})	0.37 (0.06) b	5	0.62 (0.05) a	27
Shrub height increment (m y^{-1})	0.42 (0.06)	6	0.31 (0.03)	16

Table 2 Summary of previous land use and management practices as a percentage of all sites.

Grouping factor	Percentage of sites	*n*
Direct seeded	18	6
Planted tubestock	82	27
Cultivated	19	6
Not cultivated	81	26
Ripped	28	9
Not ripped	72	23
Weed control prior to planting	81	26
No weed control prior to planting	19	6
Watered	50	16
Not watered	50	16
Fertilised at planting	9	3
Not fertilised at planting	91	29
Grazed after planting	31	10
Not grazed after planting	69	22
Previous fertiliser treatment	69	22
No previous fertiliser treatment	31	10
Previous weed control	22	7
No previous weed control	78	25
Previous land use sheep	81	26
Previous land use cattle	9	3
Previous land use cattle and sheep	9	3

Table 3 Results of general linear modelling for cover increment and height integral increment. RFAv = mean annual rainfall since planting, RFPY = annual rainfall in the planting year, TmaxAv = mean maximum temperature of the warmest month since planting, TmaxPY = mean maximum temperature of the warmest month in the planting year, TminAv = mean minimum temperature of the coldest month since planting, TminPY = mean minimum temperature of the coldest month in the planting year, Prop. trees = proportion of trees, Pweed = previous weed control; Pfert = previous fertiliser application.

	Effect	Coefficient	SE	Standardised Coefficient	*t*	***P***
Cover increment						
	Constant	-4.121	16.949	0.000	-0.243	0.811
	Planting method[1]	-5.891	2.242	-0.744	-2.628	**0.018**
	Cultivation	4.064	1.272	0.513	3.196	**0.006**
	Weed control	3.810	1.198	0.481	3.180	**0.006**
	Grazing	-1.727	1.136	-0.259	-1.520	0.148
	Fertiliser	2.526	1.916	0.238	1.318	0.206
	TmaxPY	-0.649	0.681	-0.490	-0.953	0.355
	TminAv	1.778	2.225	0.162	0.799	0.436
	TmaxAv	0.703	0.941	0.314	0.747	0.466
	Stand density	-0.001	0.001	-0.154	-0.732	0.474
	TminPY	1.372	1.905	0.218	0.720	0.482
	RFPY	-0.004	0.006	-0.137	-0.641	0.531
	Prop. trees	-1.303	2.370	-0.106	-0.550	0.590
	Pfert	0.428	1.095	0.064	0.391	0.701
	RFAv	0.003	0.008	0.076	0.379	0.710
	Pweed	0.334	1.606	0.045	0.208	0.838
Height integral increment						
	Constant	686	1699	0.000	0.404	0.691
	Planting method[1]	-835	162	-0.827	-5.146	**0.000**
	Cultivation	505	125	0.501	4.045	**0.001**
	Weed control	376	121	0.372	3.094	**0.007**
	Pweed	-406	164	-0.427	-2.473	**0.024**
	RFAv	1.882	0.821	0.367	2.292	**0.035**
	RFPY	-1.246	0.560	-0.371	-2.224	**0.040**
	Fertiliser	338	198	0.251	1.709	0.106
	TmaxPY	-96	71	-0.568	-1.346	0.196
	Grazing	-145	119	-0.170	-1.222	0.239
	TminPY	230	200	0.287	1.151	0.266
	Pfert	127	113	0.150	1.125	0.276
	TminAv	254	230	0.182	1.105	0.284
	Prop. trees	259	240	0.165	1.079	0.296
	TmaxAv	32	96	0.110	0.327	0.748

[1] Tubestock binary variable.

Table 4 Summary of growth variables (% cover increment (*CI*) and height integral increment (*HII*)) by different site managements included in the multivariate analyses. Values are means (SE) of *n* sites.

	Trees + shrubs		
Grouping factor	HII (m ha^{-1} y^{-1})	CI (% y^{-1})	*n*
Direct seeded	703 (220)	6.5 (1.8)	6
Planted tubestock	398 (66)	3.0 (0.5)	27
Cultivated	840 (169)	5.9 (1.1)	6
Not cultivated	372 (68)	3.1 (0.6)	26
Weed control prior to planting	480 (83)	4.0 (0.7)	26
No weed control prior to planting	373 (114)	2.2 (0.4)	6
Grazed after planting	274 (83)	1.8 (0.5)	10
Not grazed after planting	544 (91)	4.5 (0.7)	22
Fertilised at planting	521 (26)	3.7 (0.5)	3
Not fertilised at planting	453 (78)	3.7 (0.6)	29
Previous fertiliser treatment	524 (96)	4.2 (0.7)	22
No previous fertiliser treatment	319 (71)	2.4 (0.6)	10
Previous weed control	467 (95)	5.1 (0.9)	7
No previous weed control	458 (87)	3.2 (0.7)	25

List of Figures

Figure 1