Ponderosa pine needle length: an early indicator of release treatment effectiveness

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Received June 20, 1991

Accepted December 19, 1991

MCDONALD, P.M., SKINNER, C.N., and FIDDLER, G.O. 1992. Ponderosa pine needle length: an early indicator of release treatment effectiveness. Can. J. For. Res. **22**: 761–764.

Growth responses of ponderosa pine seedlings range from fast to slow after release and often demonstrate the effectiveness of the prescribed treatments. Although several morphological parameters have heen identified as being sensitive to competition, no link to future growth and treatment effectiveness has been made. Shrubs and grasses in four 1- to 3-year-old ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) plantations in northern California were treated by several manual and chemical release techniques that resulted in differing amounts of competition to ponderosa pine seedlings. Differing amounts of competition in turn affected pine growth and led to a wide range of stem heights, diameters, and needle lengths. Correlation coefficients indicated that 1-year-old needles, measured 2–4 years after treatment, were positively associated with pine height and diameter up to 7 years after treatment and potentially beyond. Consequently, length of 1-year-old needles may provide a useful early indication of longer term treatment effectiveness.

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La réaction des semis de pin à bois lourd, après à un dégagement, va de lente à rapide et reflète souvent l'efficacité du traitement qui a été recommandé. Même si plusieurs caractères morphologiques ont été identifiés pour leur sensibilité à la compétition, aucun lien avec la croissance future et l'efficacité du traitement n'a été mis en évidence. Plusieurs techniques de dégagement, manuelles et chimiques, ont été utilisées pour traiter les arbustes et les herbes dans quatre plantations de pin à bois lourd (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*), âgées de 1 à 3 ans et situées dans le nord de la Californie. Ces traitements ont provoqué divers niveaux de compétition pour les semis de pin à bois lourd. Ces divers niveaux de compétition ont en retour affecté la croissance des semis et entraîné une gamme étendue de hauteurs de tige, de diamètres et de longueurs des aiguilles. Les coefficients de corrélation ont révélé que la longueur des aiguilles de 1 an, mesurée 2 à 4 ans après le dégagement, était positivement reliée à la hauteur et au diamètre des pins jusqu'à 7 ans après le dégagement et possiblement au-delà. La longueur des aiguilles de 1 an pourrait donc être utile comme indice précoce de l'effet à plus long terme d'un traitement.

[Traduit par la rédaction]

Introduction

An on-going quest of vegetation management specialists is for an easily seen, quantifiable parameter that indicates seedling growth response to treatment. Capability of early prediction of the response to release treatments, for example, can show that a planned second treatment will not be needed, or can direct timely application of additional treatments that lead to higher seedling survival and growth.

Several morphological parameters of conifer species have been shown to be sensitive to competitive influences. Number of buds on *Pseudotsuga menziesii* (Mirb.) Franco seedling leaders in southwest Oregon related directly to amount of shrub and hardwood competition and was a good indicator of future seedling vigor (Tappeiner *et al.* 1987). In a later paper, Harrington and Tappeiner (1991) found that bud number, bud size, and internode number can be used to judge tree reponse to treatment, as well as to diagnose the onset of severe competitive stress. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) seedlings in northern California, which were fertilized at time of planting, had markedly larger (placed in highest category) terminal bud widths than unfertilized seedlings after one growing season, and visually longer apical shoots after two seasons, suggesting that bud width indicated future apical shoot growth (Gerald A. Walters, Pacific Southwest Experiment Station, U.S. Forest Service, Redding, Calif., personal communication).

Fritts *et al.* (1965) measured average yearly needle length for individual trees of *Pinus edulis* and *Pseudotsuga menziesii* in Colorado and correlated these data with monthly weather records over a 10-year period. They concluded that needle length was correlated with size of annual growth rings, a measure of tree vigor. In northern California, needle length of ponderosa pine seedlings differed significantly ($p < 0.05$) 5 years after several manual and chemical release treatments were applied (McDonald and Fiddler 1990). Longer needles were associated with treatments that were most effective for controlling vigorous shrubs and grasses, and shorter needles, with ineffective treatments.

This paper reports on a study that relates a single morphological parameter, needle length, to height and diameter growth of ponderosa pine seedlings after various release treatments in northern California. The objective of this study was to determine when, for how long, and to which pine growth parameters needle length was related.

Methods

Site and species

The study was part of a larger effort on plantation ecology and vegetation manipulation techniques. Four to 7 years of post-treatment data on conifer seedlings and competing species were collected from four ponderosa pine plantations in northern California. Longitude was 122°W, with latitudes of 39 to 41°N. The four study areas were located on moderately productive sites, at elevations ranging from 1080 to 1650 m, with slopes from 5 to 25%. After harvest, scattered

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Printed in Canada / Imprimé au Canada

TABLE 1. Competing species, treatments, and resulting plant density in December 1984, by study area

Study area, year[a]	Competing species	Treatments	% density[b] Shrubs	Grasses
Elk Springs, 1981	Greenleaf manzanita, Sierra chinkapin, snowbrush, grasses	Grub 0.6-m radius	45	89
		Regrub and expand 0.6-m radius to 1.2-m radius	9	30
		Grub 1.2-m radius	49	97
		Regrub and expand 1.2-m radius to 1.8-m radius	5	45
		Hexazinone	8	23
Logan Lake, 1980	Greenleaf manzanita, snowbrush, Sierra chinkapin	Grub entire plot	29	—
		Grub 1.2-m radius once	47	—
		Grub 1.2-m radius twice	43	—
		2,4-D	45	—
		Hexazinone	17	—
Snag, 1980	Whiteleaf manzanita, deerbrush, grasses	Grub entire plot	58	132
		Grub 1.2-m radius once	76	160
		Grub 1.2-m radius twice	32	8
		2,4-D	62	145
		Hexazinone	0	1
Lees Summit, 1981	Deerbrush greenleaf manzanita, snowberry, grasses	Glyphosate	18	—
		2,4-D	39	—
		Grub entire plot	70	—
		Grub 1.2-m radius once	42	—

[a] Years are study establishment dates.
[b] Percent plant density of competing vegetation on treated areas relative to control.

trees, slash, and competing vegetation were placed in piles or windrows and subsequently burned. All four areas were similar in that the competitive potential was high, with aggressive species regenerating via sprouting, from seed banks in the soil, or from windblown seeds (Table 1). The most competitive species included greenleaf manzanita (*Arctostaphylos patula* Greene), whiteleaf manzanita (*Arctostaphylos viscida* Parry), deerbrush (*Ceanothus integerrimus* H. & A.), snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), Sierra chinkapin (*Castanopsis sempervirens* (Kell.) Dudl.), snowberry (*Symphoricarpos* spp.), and numerous grasses (mostly *Bromus* spp. and *Stipa* spp.). Ponderosa pine seedlings from appropriate seed zones were grown in nurseries for 1 year and outplanted as bare-root seedlings.

Manual and chemical release treatments,[2] applied 1–3 years after planting, represented many of those currently used in northern California and southwest Oregon (Table 1). Manual release involved grubbing or cutting woody and herbaceous species one or more times on plots of a given size, or grubbing plots to an expanded radius. Chemical release involved several herbicides, which were applied once with a hand-held pressurized boom having nozzles and droplet sizes that simulated helicopter application. Hexazinone was applied as soon as access permitted in the spring; 2,4-D and glyphosate were applied in the fall.

Measurements and analysis

Experimental design was totally randomized, with three or four replications per study area. Sampling intensity for competing vegetation was five randomly selected, seedling-centered, 4-m^2 plots in each replication. Sampling intensity for ponderosa pine was 15–25 seedlings per treatment in each replication in each study area. Sample size depended on seedling spacing and amount of suitable area. Sampling was always done in the fall. Pine height and diameter (measured at 30 cm above mean groundline) were quantified on each seedling, with additional checking for damage by insects, browsing, or herbicides. Study areas were measured annually for the first 2 years after treatment, with some areas being measured the 3rd through 5th or 7th years. Needles were measured on 5–15 seedlings per treatment in each replication. These seedlings were randomly selected from among those measured for height and diameter. Needles (one per seedling) were from an upper whorl and were 1 year old. The SAS statistical package was used to perform analysis of variance, regression, and correlation analyses (SAS Institute Inc. 1988).

Results and discussion

Growth response of ponderosa pine seedlings in the four study areas differentiated according to the amount and timing of competing vegetation that developed after treatment. In general, all vegetation present the first year or two after treatment had a strong negative influence. Consequently, treatments that created a larger area with fewer plants, either through manual or chemical release, were the most effective and promoted the best pine growth. All study areas were remarkably free of insect or browsing damage.

To test that no statistical difference was present in initial seedling size, ponderosa pines on all four study areas were checked by analyses of variance (SAS Institute Inc. 1988). No significant difference ($p > 0.05$) in pine seedling diameter or height the first growing season after treatment was found among treatments in any of the four study areas. Another early trial was used to regress stem height and diameter against needle length. As expected, the regression equations were site specific, had no general predictive value, and therefore are not presented here.

[2] This paper neither recommends the pesticide uses reported, nor implies that they have been registered by the appropriate governmental agencies.

TABLE 2. Correlation coefficients (r) and probability values (p) showing relationship between ponderosa pine needle length and mean growth parameters

Study area	Years after treatment[a]	Growth parameter	Years after treatment[b]	n	r	p
Elk Springs	1	Height	4	6	0.25	0.6352
	1	Diameter	4	6	0.29	0.5719
	2	Height	4	6	0.72	0.1055
	2	Diameter	4	6	0.77	0.0705
	3	Height	4	6	0.92	0.0098
	3	Diameter	4	6	0.91	0.0120
	4	Height	4	6	0.90	0.0143
	4	Diameter	4	6	0.91	0.0107
Logan Lake	2	Height	6	7	0.60	0.1586
	2	Diameter	6	7	0.41	0.3631
	3	Height	6	5	0.97	0.0050
	3	Diameter	6	5	0.95	0.0125
	5	Height	6	7	0.12	0.8042
	5	Diameter	6	7	0.49	0.2601
	6	Height	6	7	0.57	0.1786
	6	Diameter	6	7	0.71	0.0759
Snag	1	Height	7	5	0.34	0.5744
	1	Diameter	7	5	0.55	0.3341
	2	Height	7	6	0.94	0.0045
	2	Diameter	7	6	0.91	0.0126
	3	Height	7	6	0.79	0.0632
	3	Diameter	7	6	0.85	0.0312
	7	Height	7	6	0.47	0.3440
	7	Diameter	7	6	0.54	0.2643
Lees Summit	1	Height	5	5	-0.04	0.9473
	1	Diameter	5	5	-0.13	0.8312
	2	Height	5	5	0.85	0.0671
	2	Diameter	5	5	0.88	0.0497
	4	Height	5	5	0.93	0.0202
	4	Diameter	5	5	0.90	0.0347
	5	Height	5	5	0.83	0.0799
	5	Diameter	5	5	0.79	0.1151

[a]Years after the treatment when the needles were measured.
[b]Years after treatment when height and diameter were measured.

To determine which pine seedling growth parameter related best to needle length, we compared annual increments of stem diameter and height to total values of diameter and height. Analysis of annual increments of pine seedling height and diameter yielded some correlation coefficients as high as those for total values, but consistency was lower. Consequently, total values of stem height and diameter are recommended; they are easier to use and are more reliable.

Of particular diagnostic value were the arraying of treatments (Figs. 1 and 2 as examples), the correlation coefficients, and the probability values (Table 2). Treatment arrays showed that longer needles were associated with the more intensive treatments (spray or grub entire plot), and shortest needles with the least intensive treatments (control, treated once) (McDonald and Fiddler 1990). Of note was that small treated areas (1.2-m radius for example) did not create a competition-free area below ground for very long. Shrubs on the edge of treated areas apparently extended their roots into the treated area quickly and denied critical site resources to roots of pine seedlings. Consequently, pine growth in these areas did not differ significantly from that of seedlings in the control and in some instances was actually lower. Also, the herbicide 2,4-D caused extensive damage to pine leaders and a marked reduction in growth that was still manifest 7 years after treatment.

Based on the treatment arrays and r- and p-values, needle length appeared to be significantly related to ponderosa pine seedling growth when measured 2–4 years after treatment. Needle measurements at 1, 5, 6, and 7 years after treatment were tested and lacked significance. Needles measured 1 year after treatment were not old enough to fully reflect the altered environmental conditions. Needles measured 5–7 years after treatment indicated lower values of r and higher values of p than when measured in years 2–4 (Table 2), using seedling height as an example (Fig. 2). Needle length, as measured in years 2–4, was strongly related to treatment response for at least 7 years after treatment, the longest time span studied.

Conclusions

Results indicate that the length of 1-year-old ponderosa pine needles, measured 2–4 growing seasons after various vegetation management treatments, was significantly correlated with total height and diameter. Therefore, results

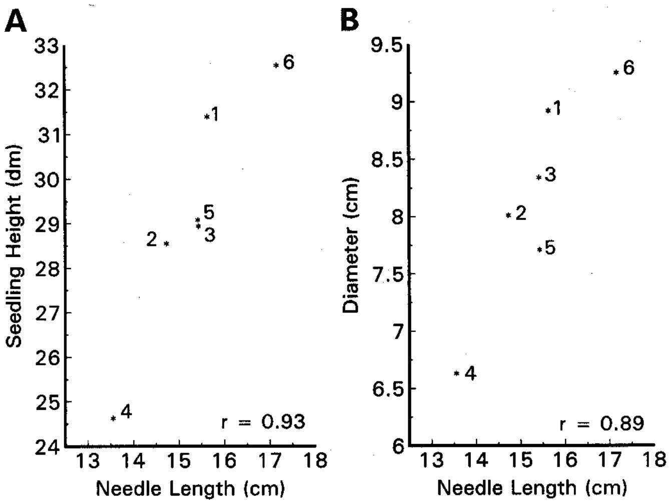

FIG. 1. Relationship at Snag study area between mean needle length 2 years after treatment and mean ponderosa pine seedling height (A) and mean diameter (B) 7 years after treatment. Treatments by number are as follows: 1, grub entire plot; 2, grub 1.2-m radius once; 3, grub 1.2-m radius twice; 4, spray 2,4-D with pressurized boom; 5, control; and 6, spray hexazinone with pressurized boom. Inferred treatment slopes (Fig. 1A) and intercepts (Fig. 1B) differed significantly (F = 2.25, $p < 0.05$ and $F = 2.33$, $p < 0.05$, respectively), indicating that some complicated interactions among treatments are not completely accounted for by needle length.

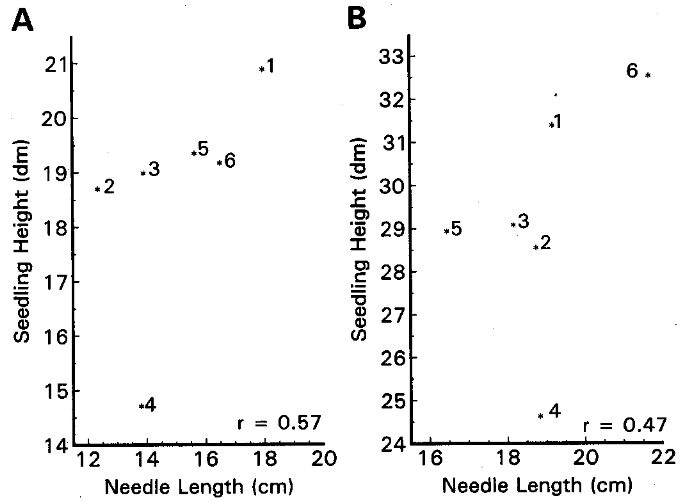

FIG. 2. Relationship (A) at Logan Lake between mean pine stem height and mean needle length 6 years after treatment, and (B) at Snag between mean pine stem height and mean needle length 7 years after treatment. Treatments by number are as follows: 1, grub entire plot; 2, grub 1.2-m radius once; 3, grub 1.2-m radius twice; 4, spray 2,4-D with pressurized boom; 5, control; and 6, spray hexazinone with pressurized boom.

indicate that length of 1-year-old needles could be a useful tool for indicating future seedling growth response. This finding, even though based on results from four separate areas, was site specific and precluded development of a general predictive model. The relationships found, however, are encouraging and suggest that a model with a broader scope of inference may be developed by incorporating additional variables such as aspect, elevation, species of competing vegetation, and site quality. Work on this model is progressing.

Acknowledgements

We are grateful for the constructive comments of reviewers: John Fiske, Pacific Southwest Region, USDA Forest Service, San Francisco, California; Dave Haywood, Southern Forest Experiment Station, USDA Forest Service, Pineville, Louisiana; Wyman Schmidt, Intermountain Forest and Range Experiment Station, USDA Forest Service, Bozeman, Montana; and Steve Tesch, Forestry Intensified Research Program, Oregon State University, Medford, Oregon.

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