Antelope bitterbrush reestablishment

A CASE STUDY OF PLANT SIZE AND BROWSE PROTECTION EFFECTS

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ABSTRACT

After an intense stand-replacement fire in south-central Oregon, 1-y-old (1+0) bareroot seedlings of antelope bitterbrush (*Purshia tridentata* (Pursh) DC. [Rosaceae]) were outplanted over a 4-y period. Paired-plots were established to examine the benefits of protecting the plants from damage due to animal browsing with Vexar® mesh tubing. In the first growing season, height growth in the protected plots was 18.4 cm (7.4 in) compared with 15.6 cm (6.3 in) in the unprotected plots. Survival was also higher in the protected plots (70% as compared with 62%). Larger plants had greater survival than smaller plants. Survival after the first growing season was well correlated with survival up to 3 y later (r = 0.59, *P* = 0.01). Use of browse protection will increase survival and growth, but one must weigh the added costs against the alternative of planting more shrubs initially.

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KEY WORDS
Purshia tridentata, browse, shrub establishment

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Reestablishing antelope bitterbrush protected by Vexar following the Lone Pine Fire. Photo by Joel P Okula

In August 1992, the Lone Pine Fire burned more than 12 000 ha (29 640 ac) in 4 d on the Winema National Forest in south-central Oregon (USDA Forest Service 1992). The fire burned with high intensity for 2 reasons: fire had been excluded from this landscape for decades and considerable forest fuels had accumulated, and 1992 was the seventh consecutive drought year. This stand-replacing fire damaged many hectares of the ponderosa pine ecosystem, most of which was classified as a *Pinus ponderosa*/*Purshia tridentata*/*Stipa occidentalis* plant association (Volland 1985). As mitigation for the fire, much of the area was intensively replanted with ponderosa pine (*Pinus ponderosa* P.& C. Lawson [Pinaceae]). Postburn surveys of the area indicated that antelope bitterbrush (*Purshia tridentata* (Pursh) DC. [Rosaceae]) stocking was poor, averaging only 156 plants/ha (63/ac). In similar unburned areas, stocking was between 1730 and 4550 plants/ha (700 to 1841/ac). Because antelope bitterbrush is a primary food source for big-game animals, namely mule deer, elk, and pronghorn antelope (Nord 1965; Kufeld 1973; Kufeld and others 1973; Stuth and Winward 1977; Guenther and others 1993), an effort was made to restore the shrubs on this important mule deer range. Between 1993 and 1997 approximately 2.7 million bitterbrush shrubs were planted on 1410 ha (3480 ac) of mule deer winter range and 1310 ha (3240 ac) of summer/transitional range at 1680 and 272 seedlings per ha (680 and 110 per ac), respectively.

Results of the monitoring program that examined growth and survival of antelope bitterbrush seedlings planted on the winter range are reported here. The monitoring program recorded the size of seedlings at planting and continued to monitor the growth and survival of the seedlings until fall of 1997. Monitoring plots were divided into two subplots, one protected the seedlings from damage due to animal browsing with mesh tubing (Vexar®, NSW Plastics LLC, Roanoke, Virginia), and one provided no protection. Associations between plant size and browse protection for growth and survival were examined to determine whether these factors are important in the artificial regeneration of antelope bitterbrush.

MATERIALS AND METHODS

Shrub Establishment

For all 4 y of plantings (1993–1996), 1+0 bareroot shrubs (shrubs grown for 1 growing season in a nursery) were used. Seedlings were grown at the USDA Forest Service Bend Pine Nursery in Bend, Oregon (which ceased operation in 1997). Seed source of the seedlings differed over the years. Local seeds were not available the first 2 years, so seeds from bulked Idaho collections were used in 1993 and a mixture of sources from multiple states was used in 1994. The exact locations of the 1993 and 1994 seed collections are unknown. The 1995 and 1996 plantings used local seeds collected from unburned areas of the Chiloquin Ranger District near the burned area.

Shrubs were planted in the spring (April and early May) of each year on sites that had been salvage logged. At each planting spot, a 45 x 45 cm square (18 x 18 in) was scalped to reduce competition. The estimated number of hectares (acres) planted each year was 153 (378) in 1993, 239 (591) in 1994, 422 (1043) in 1995, and 545 (1347) in 1996.

Sampling Design

Each year, monitoring plots were established in newly planted areas by using a stratified random sampling design. Planting locations were first stratified by aspect (N, NE, E, SE, and so on) and elevation (305-m [1000-ft] elevation bands). Within each of these strata, sample points were randomly chosen from where measurement plots were initiated. The number of samples within each stratum was proportional to the area of the stratum. Three different plot types were used over the course of the study. In 1993, 32 sets of paired 0.08 ha (0.20 ac) circular plots were used. In one of each plot-pair, bitterbrush plants were protected from browsing with tubes of Vexar plastic netting that were 7.5 cm in diameter and 45 cm high (3 x 18 in). Shrubs were left unprotected in the other plot. The number of seedlings per circular plot ranged from 8 to 25 and averaged 14. From 1994 through 1996, plots were 2 m (6.6 ft) wide transects. In 1994, the first 50 plants encountered were left unprotected. A second plot of 25 plants, 3 to 5 m (10 to 16 ft) away and parallel to the first transect, was chosen and protected from browse damage by the use of Vexar. In 1995 and 1996, the same procedure was used except that subplots consisted of 25 plants with Vexar and 25 without Vexar. This nested design yields 2 subplots (with and without Vexar) for each whole plot.

Number of whole plots established were 32 in 1993, 11 each in 1994 and 1995, and 14 in 1996. Each year a sample plot represented a different number of hectares. This was a function of available resources for a given year. In total, 2075 plants were sampled from a population of about 2.3 million seedlings. For each remeasurement, crews returned to the same plots and measured the same shrubs. Individual shrub identity was maintained throughout the period of the study. Because the reestablishment program took 4 y and all measurements ended in 1997, plots were measured for different lengths of time. The first year's plots, established in 1993, had data from 5 years (1993–1997); whereas plots established in the 1996 plantings had data for 2 years (1996–1997).

Data Collection

Immediately after planting, all sampled shrubs were measured for initial height, maximum crown width (measured on the widest axis), and diameter of the root collar immediately below the cotyledon scar. Beginning 1 mo after planting, and monthly thereafter during the first growing season, vigor was estimated visually for each seedling in the 1994–1996 plantings. Vigor was an estimate of the percentage of a plant that had living foliage and was scored on a 0 to 4 scale: 0 = dead, 1 = 0 to 25% of crown with leaves, 2 = 26% to 50% of crown with leaves, 3 = 51% to 75% of the crown with leaves, and 4 = >75% of crown with leaves. Plants were examined also for browsing (0 = no browsing, 1 = less than one-half of crown browsed, 2 = more than one-half of crown browsed). The same observers measured vigor to reduce variation from observer interpretations.

At the end of each growing season (mid-September to early October), plants were scored for survival, vigor, height, and width. Each spring, seedlings were scored for survival, vigor, and browsing.

Data Analysis

The analyses took different forms, depending on the variables being examined. When the effects of Vexar (subplot data) on percentage survival and growth were examined the subplot means were used. Likewise, percentage survival of the subplots was used to examine survival trends over time. Individual shrub data were used to examine the effect of shrub characteristics on survival.

The effect of Vexar, a categorical variable, was examined with the SAS GLM procedure (SAS 1990). Because of the large year-to-year variation in survival, the regression model took the form:

$$\text{Survival}_{ijk} = \mu + \text{Year}_i + \text{Whole plot}_{j(i)} + \text{Vexar}_k + (\text{Vexar}_k \times \text{Year}_i) + e_{ijk}$$

where:

Survival_{ijk} is the percentage survival in the *i*th year on the *j*th whole plot for Vexar treatment *k* (yes/no), μ is the overall mean, Year_i is the effect of the *i*th year, $\text{Whole plot}_{j(i)}$ is the effect of the *j*th whole plot in the *i*th year, Vexar_k is the effect of the *k*th Vexar level (yes/no), $(\text{Vexar}_k \times \text{Year}_i)$ is the Vexar x year interaction, and e_{ijk} is the variation between subplots. Because planting stock quality varied by year, the data were also analyzed by year using a reduced equation that omitted the Year and Vexar x Year effects. Statistical significance was $P = 0.05$ for all models.

Subplot means were not always normally distributed, especially when viewed over all 4 planting y where an obvious bimodal distribution was present. Data from each individual year were more normally distributed. Because transformations did not change any of the results, data were left untransformed.

Individual shrub survival and its relation to individual shrub size variables was examined with logistic regression with the SAS Catmod procedure (SAS 1990) as individual survival is a categorical (yes/no) variable. Each year was examined individually because of the large difference in survival from year to year. Independent variables examined in these analyses were initial root-collar diameter, height, and crown width. With logistic regression, the dependent variable became logit (% survival), where logit (% survival) = log (probability of surviving / probability of mortality) = log (% survival / (1 – % survival)). The following model was used:

$$\text{Logit (survival)} = \text{Whole plot}_i + \text{Vexar}_j + b^*\text{variable} + \text{error},$$

where:

Whole plot_i is the effect of the *i*th whole plot, Vexar_j is the effect of Vexar, and b is the coefficient to be multiplied by the independent variable (diameter, height, or crown width).

Because the effect on survival of the independent variables (that is, plant size variables) is not readily apparent with logistic regression, simple regression was used to indicate the effect of increased plant size on survival. To do this, the average survival of all shrubs in a size class was calculated. Then a regression was developed with percentage survival as the dependent variable and plant size as the independent variable.

RESULTS

Average survival differed by planting year. Survival after the first growing season for all plots averaged 92% in 1993, 42% in 1994, 88% in 1995, and 41% in 1996 (Table 1). The years with poorer survival (1994 and 1996) were associated with poor nursery stock. Flooding of the nursery beds occurred for at least a half day and injured the shrubs used for the 1994 plantings. A late lifting date apparently caused poor condition of shrubs in 1996. Unfortunately, nursery stock condition was confounded with planting year, which resulted in confounding of stock condition with seed source and weather. The confounding of the year effect and seed source did not appear to be a problem because the local and non-local collections both had one good year and one poor year of survival. The average first-fall survival was 67% for the non-local sources and 65% for the local source. Spring and summer of 1993 and 1995 were cooler and had more precipitation than in 1994 and 1996. See the sidebar for average temperature and precipitation for April through September for a weather station in the region (Klamath Falls).

	Year			
	1993	1994	1995	1996
Temperature °C (°F)	19.1 (66)	22.2 (72)	19.4 (67)	21.1 (70)
Precipitation mm (in)	31.3 (1.23)	14.0 (0.55)	30.5 (1.20)	23.9 (0.94)

TABLE 1

Mean percentage survival and standard error (in parentheses) and initial plant size of antelope bitterbrush by planting year and browse protection category (with or without Vexar).

Planting Year	Percentage survival					Initial plant height (cm)	Initial plant diameter (mm)
	1st fall	2nd fall	3rd fall	4th fall	5th fall		
1993	92 (1)	67 (3)	61(3)	49 (3)	44 (3)	15.3	4.3
No Vexar	90 (2)	62 (4)	57 (5)	40 (4)	36 (4)	15.0	4.3
Vexar	93 (1)	71 (4)	65 (4)	57 (4)	51 (4)	15.7	4.3
1994	42 (4)	23 (4)	18 (3)	15 (3)		8.9	2.6
No Vexar	40 (5)	19 (4)	15 (4)	11 (3)		9.0	2.6
Vexar	46 (5)	31 (5)	25 (5)	23 (5)		8.8	2.6
1995	88 (2)	62 (4)	53 (4)			17.3	4.5
No Vexar	86 (3)	50 (4)	38 (4)			17.2	4.6
Vexar	89 (2)	74 (4)	68 (4)			17.4	4.5
1996	41 (3)	28 (2)				10.6	7.0
No Vexar	37 (3)	25 (3)				10.7	7.5
Vexar	44 (4)	30 (3)				10.5	6.5
All No Vexar	**62**	**39**	**36**	**26**			
All Vexar	**70**	**53**	**55**	**44**			

On a year-to-year basis, taller plants had greater survival than shorter seedlings (Table 1). Initial plant size also affected survival within planting years (Figure 1, Table 2). Logistic regression consistently indicated that plant size had a statistically significant effect on survival (Table 2). A 1-cm increase in height tended to increase survival by 1% to 2%, while a 1-mm increase in root-collar diameter increased survival 1% to 10% (Table 2).

Plant survival and vigor scores were greater for the plants protected with Vexar compared with those without Vexar. Improved survival persisted over time for each planting year (Table 1). Vexar increased survival (1997 data) between 5% and 30% (Table 1). The improvement from Vexar on vigor scores was a function of improved survival, and to some degree, to improved vigor of the surviving plants. Vigor scores of surviving plants in the fall of 1997 were significantly higher ($P < 0.001$) for the 1993 and 1995 planting years (data not shown). Vigor scores of live shrubs in 1997 with and without Vexar for the 4 planting years averaged 3.2 vs. 2.9 for the 1993 plantings, 3.3 versus 3.1 for the 1994 plantings, 3.7 versus 3.3 for the 1995 plantings, and 3.3 versus 3.2 for the 1996 plantings.

The increase in survival was not solely a function of browse protection. Twenty-five transects had no evidence of browse the first summer yet there was a statistically significant increase ($P = 0.02$) in survival in the browse-protected plots (65% survival in the protected and 60% survival in the unprotected plots). This difference cannot be attributed to protection from browsers since no browsing occurred.

Plant height was consistently greater when plants were protected with Vexar (Table 3). The difference in height between plants with and without Vexar increased with time, partly because Vexar protected the plants from browsing. Up through the second spring, plants with Vexar were less browsed than those without Vexar. After the second spring, however, no difference appeared between the intensity of browsing because, by this time, many stems of the shrubs were poking through and above the Vexar mesh and were available to browsers (Table 4).

Survival after the first growing season was well correlated with survival up to 3 y later (Table 5). The correlations were strongest when taken over all planting years because there was a wider range of first-fall survival. The 1993 data poorly correlated because of the distribution of the data; 26 of the 65 subplots had 100% survival the first fall.

Equations were developed to predict survival the spring after the first, second, and third growing seasons using first-fall survival as the independent variable. Neither planting year, nor its interaction with first-fall survival, were significant. The equations were as follows:

% survival, spring after the 1st growing season = 0 + (0.86 x first-fall survival), $r^2 = 0.72$

% survival, spring after the 2nd growing season = –15 + (0.85 x first-fall survival), $r^2 = 0.49$

% survival, spring after the 3rd growing season = –10 + (0.70 x first-fall survival), $r^2 = 0.39$

First-fall vigor scores were better correlated with subsequent survival than percentage survival (Table 5). Vigor score represented more data because it includes a crude measure of plant health in addition to survival (dead plants were scored as 0). Planting years varied in their correlations, but all had the same trend of decreasing correlations as time of separation increased. A significant year-by-vigor interaction indicated that one single equation using vigor could not predict subsequent survival for all 4 y; each year needed a separate prediction equation.

The June and July survival and vigor scores were also correlated with subsequent survival, but correlations were weaker than the first-fall data with subsequent survival (data not shown).

DISCUSSION

Condition of the seedlings received from the nursery appeared to be the most important factor affecting survival of bitterbrush seedlings. Planting stock appeared undamaged in 1993 and 1995. Many of the seedlings in the 1994 planting stock were subjected to a flood in June 1993, with seedlings under water for a minimum of one-half day. Flooded stock had significantly poorer survival (32%) than the nonflooded stock (53%). The 1996 planting stock was severely browsed in the nursery and was lifted after bud burst. Lifting dormant planting stock has been recommended for decades (Olson 1930) and only dormant shrubs are to be used in shrub restoration plantings (Tiedemann and others 1976).

Plant size is one measure of the condition of planting stock. Examination of size-class data for each year demonstrated a consistent trend of increasing survival for larger plants in most years (Figure 1). Regardless of plant size, 1994 and 1996 nursery stock did not survive well. For any given year, however, minimum specifications for reasonable survival of bitterbrush seedlings appear to be root-collar diameter ≥ 4 mm (0.16 in) and height ≥ 14 cm (5.6 in). Brown and Martinsen (1959) also showed the need for larger stock in the establishment of bitterbrush and suggested a minimum height of 30 to 46 cm (12 to 18.4 in) for 2-0 stock. The forestry literature has many examples that show larger planting stock results in higher survival and faster initial growth rates (for example, Sluder 1979; Long and Carrier 1993; Randall and Johnson 1998; South and Mitchell 1999). In addition to seedling size, other attributes in forestry tree seedlings have been effectively used to assess seedling quality (see Ritchie 1984; Duryea 1985).

Vexar improved survival, vigor scores, and height each year (Tables 1 and 4), in part because of reduced browsing. Browse protection increased absolute survival 10% to 20%. Up through the second spring, plants with Vexar were browsed less

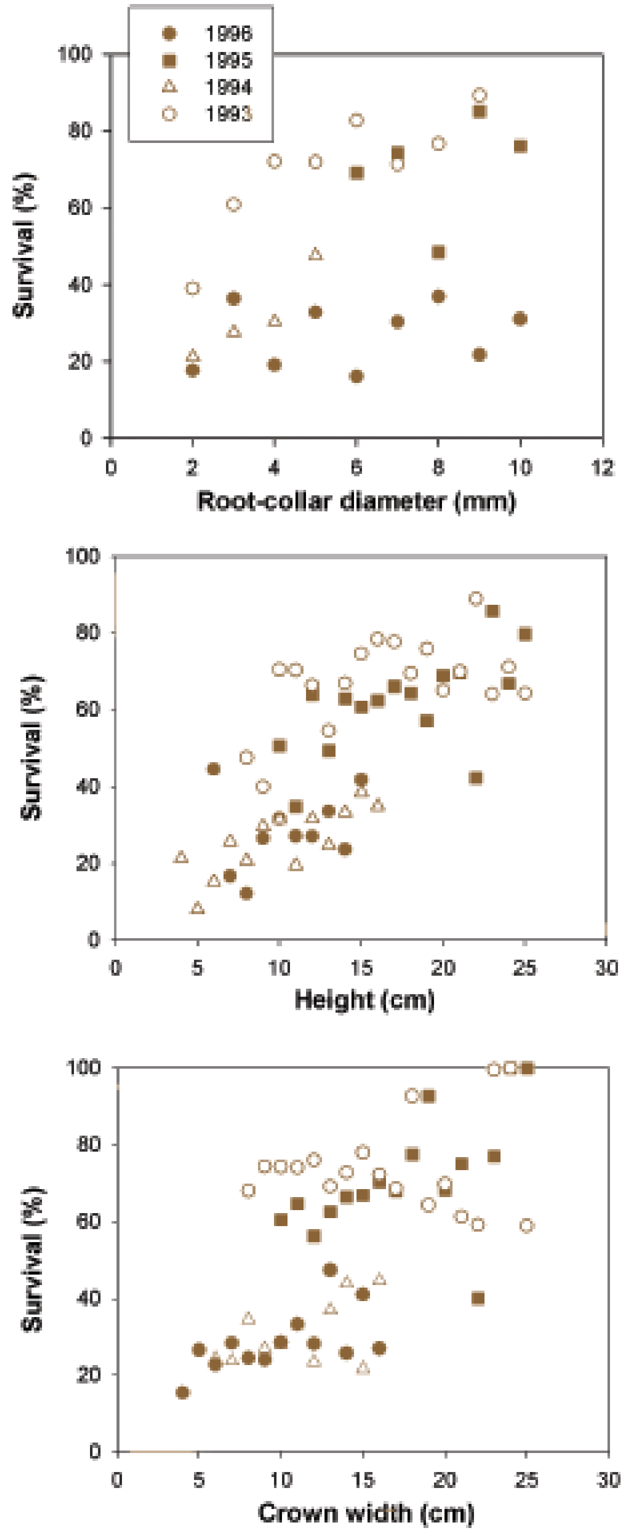

Figure 1. Percentage survival after the second growing season as a function of initial root-collar diameter, plant height, and crown width.

TABLE 2

Regression coefficients (b) of survival percentage regressed on size class and the probability (p) that size class affected survival based on logistic regression using individual shrub data for antelope bitterbrush.

	First fall		Second fall		Third fall		Fourth fall		Fifth fall	
Trait	b	p	b	p	b	p	b	p	b	p
Height										
1993	1.18	0.001	1.56	0.001	1.41	0.001	1.20	0.001	1.09	0.001
1994	1.27	0.007	0.99	0.005	0.31	0.052	0.77	0.019		
1995	1.00	0.002	1.15	0.001	1.28	0.003				
1996	1.76	0.002	1.51	0.009						
Diameter										
1993	3.18	0.001	4.83	0.001	5.30	0.001	4.39	0.001	4.28	0.001
1994	7.62	0.001	8.64	0.001	7.04	0.001	8.27	0.001		
1995	1.21	0.029	2.10	0.013	1.90	0.008				
1996	2.08	0.045	0.09	0.515						
Crown width										
1993	0.64	0.002	1.21	0.001	1.54	0.001	0.31	0.001	0.27	0.001
1994	2.03	0.001	1.65	0.006	1.60	0.004	0.73	0.042		
1995	0.97	0.071	0.95	0.025	0.96	0.016				
1996	1.35	0.156	1.23	0.097						

TABLE 3

Average antelope bitterbrush plant height (cm) and standard errors (in parentheses).

Planting year / Vexar	First fall	Second fall	Third fall	Fourth fall	Fifth fall
1993	18.2 (0.2)	28.7 (0.4)	40.5 (0.7)	45.6 (0.9)	51.3 (1.1)
No Vexar	17.8 (0.2)	24.3 (0.5)	33.0 (0.7)	35.6 (1.1)	41.7 (1.4)
Vexar	18.7 (0.3)	33.0 (0.7)	47.8 (0.9)	53.8 (1.2)	58.7 (1.4)
1994	20.9 (0.7)	26.8 (1.0)	35.6 (0.5)	47.4 (1.0)	
No Vexar	17.9 (0.7)	22.5 (1.1)	29.0 (1.8)	40.1 (2.5)	
Vexar	26.0 (1.4)	31.9 (1.6)	42.8 (2.3)	54.5 (2.8)	
1995	17.1 (0.2)	29.0 (0.6)	46.4 (1.0)		
No Vexar	16.3 (0.3)	21.7 (0.7)	32.9 (1.2)		
Vexar	18.0 (0.4)	34.0 (0.8)	54.1 (1.0)		
1996	10.5 (0.4)	23.0 (0.8)			
No Vexar	10.2 (0.6)	21.1 (1.1)			
Vexar	10.8 (0.5)	24.6 (1.3)			
All No Vexar	15.6	22.4	31.6	37.8	41.7
All Vexar	18.4	30.9	48.2	54.1	58.7

TABLE 4

Mean and standard error (in parentheses) of percentage live antelope bitterbrush browsed and statistical significance of browsing difference.

Planting year	First fall	Second fall	Third fall	Fourth fall	Fifth fall
1993					
No Vexar	9.2 (2.0)	34.1 (5.4)	22.3 (5.4)	30.6 (5.8)	43.8 (6.7)
Vexar	0.2 (0.2)	17.9 (3.4)	17.1 (3.6)	32.7 (5.9)	41.9 (6.4)
1994					
No Vexar	15.0 (3.0)	5.8 (4.9)	23.5 (10.5)	40.0 (11.0)	
Vexar	6.3 (1.8)	7.1 (3.0)	22.2 (7.0)	60.7 (11.9)	
1995					
No Vexar	3.8 (2.7)	34.6 (9.0)	69.4 (10.3)		
Vexar	0.4 (0.4)	21.1 (6.5)	78.0 (8.9)		
1996					
No Vexar	10.3 (4.6)	15.7 (6.7)			
Vexar	7.9 (3.4)	10.7 (3.9)			
All No Vexar	9.3	26.8	33.3	32.6	43.8
All Vexar	2.4	16.5	38.1	38.0	41.9
Significance	0.001	0.001	0.298	0.072	0.172

than plants without Vexar. After the second spring, however, the intensity of browsing (Table 4) was similar because shrubs had grown outside their Vexar cylinders. Dealy (1970) and Clements and Young (2000) also showed improved survival with protection from browsing. Although reducing browsing may increase photosynthetic leaf mass the first year, this increased leaf mass from browse protection may not be the reason for increased survival. In 1993, a year with relatively good survival, 25% of the plants lost all of their leaves in June. Initially, we believed that the leaf loss represented high mortality, but most of these plants developed new leaves within a month.

The fact that the Vexar-protected plants had improved survival the first fall in unbrowsed whole-plots (65% versus 60%) suggests factors other than browse protection were involved in the increased survival. Vexar may have improved the microclimate around each plant. Increased shading could have reduced temperatures and evapotranspiration and increased relative humidity. Temperatures between 60 °C and 70 °C (140 °F and 158 °F) were measured near the soil surface in the first year after the fire (Cassidy 1997). Thus, shading could have reduced solar radiation and reduced soil temperature. Sexton (1998) reported greater survival and growth of shrubs in areas with more tree crown cover (more shade) than in areas with less crown cover on this same burn.

Factors to be weighed when deciding to use browse protection such as Vexar are the additional planting costs, whether using Vexar will allow planting less habitat per year and therefore require more years for planting, the probability of achieving acceptable stocking, the alternative of increasing planting density, and the cost of replanting when survival is unacceptable. Establishing new shrubs from replanting may be more difficult than initially establishing shrubs soon after a burn because competition from other shrubs, grasses, and forbs increases each additional year after a fire.

Based on the 1997 data, the absolute increase in survival from browse protection varied from 5% (1996 planting) to 30% (1995 planting). The percentage increase in survival varied from 20% (1996 planting) to 109% (1994 planting). Averaged over all 4 planting years, browse protection increased survival percentage by more than one-half (28% for unprotected as compared with 43% for protected). Therefore, if the cost of browse protection is less than one-half the cost of planting the seedlings, it may be a worthwhile investment. Currently the material costs of browse protection range from 15 to 30 US cents per enclosure, and 1+0 bitterbrush plants can be purchased for 30 to 40 US cents per seedling. The labor costs of planting shrubs and putting up Vexar must also be considered. At these prices, whether to protect plants is not an obvious decision. Improvement in survival from browse protection varied considerably. Better prediction of the effect of browse protection on seedling survival for a given site would allow better selection of the course of action. Unfortunately, the present study provided no strong insights into which types of sites would benefit most from browse protection.

Another possible strategy to maximize the effectiveness of limited resources would be to establish refugia or hubs over extensive areas (Bainbridge and Virginia 1990) and in subsequent years to plant more intensively between these sites as

TABLE 5

Correlations of first-fall survival and vigor with subsequent survival (correclations are statistically significant at P = 0.01, unless otherwise noted).

Trait / Planting year	1st spring survival (after 1st growing season)	2nd fall survival	2nd spring survival	3rd fall survival	3rd spring survival	4th fall survival	4th spring survival	5th fall survival
SURVIVAL								
All years	0.90	0.80	0.69	0.70	0.63	0.59	0.18 ns	0.16 ns
1993	0.56	0.49	0.40	0.44	0.31*	0.30*	0.18 ns	0.16 ns
1994	0.88	0.76	0.67	0.69	0.69	0.64		
1995	0.79	0.52*	0.53*	0.44*				
1996	0.89	0.71						
VIGOR								
All years	0.89	0.80	0.69	0.71	0.67	0.65	0.31*	0.27*
1993	0.60	0.59	0.50	0.59	0.41	0.41	0.31*	0.27*
1994	0.96	0.89	0.82	0.81	0.83	0.81		
1995	0.79	0.38+	0.37+	0.26 ns				
1996	0.93	0.72						

Significance: ns = not significant at $P = 0.10$; * = significant at $P = 0.05$; + = significant at $P = 0.10$.

resources allow. Shrub habitat islands that result from escaping a burn have shown ecological benefits with regard to species richness (Longland and Bateman 2002); therefore, when working with a limited budget, a reasonable management strategy would be to purposely establish shrub hubs (islands).

Surviving the first growing season is a relatively good indicator of subsequent survival. Vigor scores had higher correlations with subsequent survival for each planting year, but they required different regression equations each planting year to estimate subsequent survival because a significant planting-year-by-vigor-score interaction existed. Survival at the end of the first growing season is easier to assess than vigor, and it appears adequate for predicting subsequent survival.

Management Implications

Ensuring that large, well-conditioned plants are received from the nursery is the most important aspect to control when establishing antelope bitterbrush with 1+0 bareroot seedlings. Poorly conditioned seedlings will establish poorly and there may be a need to replant. Vexar tubing increased survival and height growth of bitterbrush in this study, and it may be appropriate to use Vexar if the economics and logistics are thoroughly examined and shown to be of benefit.

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