Plant Succession Following Chaining of Pinyon-Juniper Woodlands in Eastern Nevada

ROBIN J. TAUSCH AND PAUL T. TUELLER

Highlight: This study was undertaken to determine some of the long-term effects of secondary succession on tree control in pinyon-juniper woodlands by cabling and chaining with "debris in place," a technique used for about two decades. Plant species representative of all the successional stages we observed following treatment exist simultaneously from treatment. These observed changes were primarily changes in relative abundance resulting from differences in the growth rates and competitive abilities of the species concerned. Competitive ability appears directly related to the length of time following treatment that a species is able to maintain an increased growth rate. The trees maintain this increased growth for two to three times as long as any understory species studied. The result is a steady reduction of understory cover and production beyond the fifth to eighth year following treatment, depending on site.

With the expansion of the ranges and density increases of pinyon (*Pinus monophylla* Torr. and Frem.) and juniper (*Juniperus osteosperma* (Torr.) Little) over the last 100 years, a general elimination of the understory has been observed (Blackburn and Tueller 1970; West et al. 1975). This expansion continues even if areas are protected from grazing. Viewed as undesirable by land managers, these changes have led to two basic approaches to tree control: prescribed burning and mechanical treatments. Fire and prescribed burning have been shown to result in an initial significant increase in understory vegetation (Blackburn and Brunner 1975).

A recent study in central Utah of several natural burns of various ages by Barney and Frischnecht (1974) shows the same initial improvement by understory vegetation. However, the trees eventually become re-established and understory suppression resumes. Following fire, the site is occupied by a grass-forb community within 10 years. Around this time shrubs begin to appear that are well established within 20 years. Shrub dominance is usually reached in 30 years. Between 10 and 20, tree seedlings begin appearing on the site, but up to 50 years pass before their presence and impact become significant. In another

20 to 30 years the site is again woodland with a low understory cover.

A common mechanical treatment to effect similar conversion has been debris-in-place cabling and more recently, chaining. The success of the treatments in producing desired changes has varied considerably, depending on treatment and site variations (Aro 1975).

Little information is available on plant succession following these treatments. In eastern Nevada they have been used for about two decades (Cole 1968). Thus, only recently has it become possible to evaluate the long-term vegetation response to this management practice.

Because of its high level of disturbance, the initial impact of the chaining process creates a large area of open habitat. The effectiveness of a debris-in-place treatment in achieving the desired results depends on the rates and patterns by which the site is reoccupied by native and seeded vegetation. This includes the surviving trees. Because of the creation of open habitat, the first expected response by all surviving and seeded plants is an accelerated rate of growth (Aro 1971). In most cases this was what was observed.

This growth acceleration can be attributed to the large reduction in competition for the limited resources, primarily water (Noy-Meir 1973). As the vegetation grows, competition will increase, becoming more intense with time, until all the available resources are again utilized. The length of this period can be expected to vary for different species depending on both the growth rate and ability of the species to reach and utilize the existing resources on a site. On a fully occupied site in water short areas, long-term vegetation composition is primarily determined by competition for the available moisture (Noy-Meir 1973). Success for a vegetation improvement procedure depends on how well the desired species increase on a site and on how well they maintain this increase over time.

Studies done in the period immediately following a treatment have usually shown an increase in both the growth rates and vigor of understory species (Arnold et al. 1964; Aro 1971). This initial response is expected due to the opening up of the habitat, but cannot last. Although the faster growing species occupy the site first this does not necessarily mean they will maintain their dominance. The initial spurt of new growth increases utilization, particularly by game (Terrel 1972; Aro 1975; and Spillett 1975). The real effectiveness of the chaining, however, depends on what type of long-term production and utilization occurs.

The authors are graduate fellow and professor, Renewable Resources Center, University of Nevada, Reno. Tausch's present address is Range Science Department, UMC 52, Utah State University, Logan, Utah.

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Observing the changes in presence and abundance of the various species on treatments of different ages can give insight into the patterns and rates of succession, and into the competitive abilities of the respective species.

Location and Description of the Study Areas

The treatments studied are located in approximately a north-south transect of eastern Nevada. Data were collected primarily during the summers of 1970 and 1971. Earlier data available for some sites from Cole (1968) are also used.

Blythe Springs, the southernmost treatment and only cabling, is located on the west side of the Delamar Mountains 26 km (16 miles) southwest of Caliente, Nev. It has an average elevation of 1,850 meters (6,100 ft). Approximately 190 km (120 miles) north is the Dale chaining, located on the west side of Spring Valley 16 km (10 miles) south of Conner's Pass at a mean elevation of 2,100 m (6,800 ft). Three chainings are located around the Kern Mountains, within a radius of 16 km (10 miles). These are: The South Kern, the North Kern, and the North Kern East chainings. The average elevations vary from 2,070 to 2,130 m (6,800 to 7,000 ft). The most northerly, Spruce Mountain chaining, is on the SSE flank of a mountain of the same name 24 km (15 miles) north of Currie, Nev. Its average elevation is 2,040 m (6,700 ft).

All six chainings are located in similar topographic positions, on the upper edge of bajadas at the base of mountain foothills. No slopes are steeper than can be easily negotiated by the mechanical equipment used (30–40%); annual rainfall on the sites is estimated to be between 330 mm and 430 mm (13 to 17 inches) (Cole 1968). The North Kern site is a sagebrush chaining; all the others are in pinyon-juniper.

Spruce Mountain was chained two ways with a smooth chain (60 lb/link). The other chainings were chained two ways with the Ely chain. Blythe Springs was aerial seeded with crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) following treatment. Spruce Mountain was not seeded. The remaining chainings were seeded with a shrub-grass-forb mixture, which was primarily crested wheatgrass and intermediate wheatgrass (*Agropyron intermedium* (Host.) Beauv.).

Methods

Data were collected on macroplots located to sample all the major vegetation types on each treatment. Whenever the unchained vegetation adjacent to a chained macroplot had the same slope, aspect, and native species composition, unchained vegetation data were collected by the same procedure as a representation of the prechained condition.

Each macroplot consisted of a 152 m (500 ft) baseline. Perpendicular to the baseline were ten 15.2 m (50 ft) randomly located transects. Each transect consisted of (1) ten contiguous 1.5×1.2 m (5×4 ft) macroplots for sampling shrub cover and density and (2) 20 nested 0.3×0.6 m (1×2 ft) macroplots for sampling grass and forb cover. Cover values were obtained with the aid of rings representing 2% and

5% of each size macroplot. Four tangent .001 ha (.00025 acre) circles for deer pellet group density counts were located along each transect. From two random macroplots on four random transects, sagebrush (*Artemisia* spp.) and bitterbrush (*Purshia* spp.) trunk cross sections were collected.

Tree cover and density were determined on two 0.08-ha (1/5 acre) plots centered on the baseline. All pinyon and juniper trees in the plots were individually counted and measured for crown cover. Trunk cross sections were taken from all trees less than 6 inches in diameter, and from a 20% random selection of all larger trees, including the largest, on both plots. The average canopy cover of the tree, shrub, grass, and forb components for each area studied (along with sampled deer-days use per acre) and the age of each area are in Table 1.

Where sample size exceeded 100 cross sections, random samples of 100 cross sections of each tree and shrub species collected were used for ring width measurements. Minimum sample size was 35 for bitterbrush on Spruce Mountain. All other samples exceeded 80 cross sections. For each cross section, all rings that developed following chaining and an equal number prior to chaining were measured to the nearest 0.01 mm with a Craighead-Douglas dendrochronograph. Ring widths of shrubs and trees have been shown to be closely correlated with plant production (Davis et al. 1972). As a result the pattern of ring width changes following chaining can serve as an index of the pattern of yearly production. This pattern was determined by fitting curvilinear regressions to the ring widths over the years sampled.

On each cross section its area at the time of treatment and its total area at the end of the last growing season prior to sampling were measured. By using the data for the average ring width for each year following chaining, the average radius for each cross section was incremented from treatment to sampling and used to compute the cross sectional areas of each section for each year from the area at treatment to the area at sampling. Linear regressions were then used to predict the year to year changes in cross sectional area for the years following chaining. All regressions were accepted at the 1% or 5% level.

As an index of utilization, deer days per acre (DDA) was computed from the average pellet group counts per acre by dividing by thirteen (Neff 1968).

Results and Discussion

Understory Response

A significant increase in both density and cover by most understory species was observed immediately following treatment on both the North Kern and North Kern East chainings (Table 1, Fig. 1).

The density responses of sagebrush (*Artemisia tridentata* Nutt.) and bitterbrush (*Purshia tridentata* (Pursh.) DC.) for 1 year prior and 3 years following treatment on the North Kern sagebrush chaining are illustrated in Figure 1. After a peak the

Table 1. Cover (%) comparison for one cabled and four chained pinyon-juniper and one chained sagebrush area.

Area (year sampled)	Years since treated	Canopy cover						Deer days use/acre
		Pinyon-juniper	Sagebrush	Bitterbrush	Total shrub	Total grass	Forb	
N. Kern East								
1970	1	5.60	.42	.16	.74	.89	.45	1.55
1971	2	5.83	.55	.08	1.40	3.15	1.35	6.15
S. Kern								
1971	3	5.47	.20	.04	.25	4.75	1.75	3.74
Dale								
1970	4	8.15	.015	.01	.19	5.05	.16	.40
N. Kern (sagebrush)								
1971	3	—	4.85	.01	7.77	7.96	4.69	25.05
Spruce								
1971	8	7.66	7.32	.04	7.49	1.78	1.22	23.0
Blythe (cabled)								
1971	12	10.67	7.82	1.73	11.0	.41	.69	3.63

Fig. 1. Density trends (plants per hectare) in sagebrush (*Artemisia tridentata*) and bitterbrush (*Purshia tridentata*) for 1 year before and 3 years after chaining.

first year, density declined. Shrub seedling density declined faster than total density.

Comparing treatments of different ages, the patterns of increase in canopy cover following treatment varied by species for each of the major vegetation groups (Table 1). Maximum cover appears to be reached and full site occupancy approached by forbs in about 2 years. For perennial bunchgrasses, this point appears to be reached in about 3 to 4 years. The larger shrubs take 5 or more years. The time needed for each group is considerably less than that occurring following fire. After a maximum cover has been reached ring widths show that growth rates begin to decline for shrubs.

The site differences of each treatment appear to have a definite influence on the rates but do not appear to alter the general pattern of secondary succession. The specific species involved in each group for a particular site also varies without appearing to alter the general pattern.

Fig. 2. Shrub ring width regressions for sagebrush (*Artemisia nova* Hull. and Clem.) and bitterbrush plus deer days use per acre (DDA) following chaining at Spruce Mountain.

Fig. 3. Shrub ring width regressions for sagebrush (*Artemisia tridentata*) and bitterbrush (*Purshia glandulosa* Curran.) plus deer days use per acre (DDA) following cabling at Blythe Springs.

Fitting curvilinear regression to the average ring widths of sagebrush and bitterbrush for the years following treatment illustrates this pattern. On the Spruce Mountain chaining (Fig. 2), located further north than Kern Mountain, the ring width pattern peaks sooner than the peak cover data on Kern Mountain. Farther south at Blythe Springs (Fig. 3) the ring width peak occurs 1 to 3 years later than the peak cover data on Kern Mountain. After 8 years at Spruce Mountain and 12 years at Blythe Springs, the age of the respective treatments at sampling, the average ring widths, and the average shrub production increases have diminished to the beginning level. The data for the years in which deer days use per acre are available are also plotted on Figures 2 and 3. On both treatments the patterns of utilization and ring widths were similar as utilization and average ring width increase and decrease together.

Tree Response

The initial impact of treatment on tree density and cover is shown in Table 2. These values are the average of all the paired plots from all of the areas studied. Although the method and size of chain used varied between treatments, there was no significant difference in tree removal between treatments. The more recent chainings were done with heavier chains but actually had a slightly higher survival rate than the older chaining and cabling. Part of this appears to be due to the initial density differences (Table 3).

Both treatments were much less effective on juniper than pinyon on all sites. The relative reduction of tree cover averaged 84% when averaging both species and treatments, while the relative reduction in density was well under 60% of that on the adjacent untreated sites. In the untreated vegetation sampled adjacent to the treated areas, $\frac{1}{3}$ of the tree density contributed over $\frac{2}{3}$ of the tree cover. This indicates that $\frac{1}{3}$ of the original density is still sufficient for dominance of the site.

Table 2. Average density and cover reduction by comparison to adjacent untreated plots for simple leaf pinyon (*Pinus monophylla*), Utah juniper (*Juniperus osteosperma*), and the average of both trees combined.

Species	Percent reduction	
	Density	Cover
Pinyon	72.2%	95.1%
Juniper	39.2%	70.8%
Average	57.5%	83.9%

Table 3. Average tree density (plants per hectare) surviving treatment on three chainings.

Tree species	Spruce Mountain	South Kern	North Kern East
Pinyon	116	155	324
Juniper	363	397	689

A curvilinear regression was also fitted to the average yearly ring widths of the trees (Figs. 4 and 5). Neither species of trees on both the Spruce Mountain and Blythe Springs sites shows the substantial decline in ring widths observed in the shrubs. It appears that the sites were fully reoccupied by the understory as their response to treatment had nearly ended. The same situation had not occurred for the tree species at the time of sampling.

The increase in resource competition experienced by the shrubs was not greatly affecting the trees. Some reduction in the rate of increase is evident in pinyon. This appears to indicate that the trees are much better competitors for available resources. Because of the larger size and slower growth rates in pinyon and juniper, it takes them two to three times longer to reach full site occupancy (full utilization of resources) than it does for the larger understory species. There appears to be, in general, a direct relationship between the size of a plant species, its rate of growth, and the time necessary to regain full site occupancy. Other site factors, not determined in this study, also appear to influence the rate of site occupancy.

Plant Succession and Competitive Interaction

To further analyze the apparent competitive ability of the two conifers, curvilinear regressions were computed between the total tree cover and the total understory cover as groups (Fig. 6). All the unchained macroplots were combined for the first analysis (curve 2). The chained macroplots from Blythe Springs (curve 1) and Spruce Mountain (curve 3) were similarly analyzed.

The formula for these regressions has the basic form:

$$S \times S_0 e^{-kT}$$

where S = the understory cover (%) determined from the amount of tree cover, S_0 = the total cover (%) of the understory species possible when no trees are present, k = a competition constant, and T = the amount of tree cover (%).

The results indicate a negative geometric reduction of the understory cover for each unit increase in tree cover. At Blythe Springs this rate is 8%; for the combined untreated macroplots it is 12.9%; and at Spruce Mountain it is 16%. This geometric rate of understory decline with tree cover increase appears to be

Fig. 4. Tree ring width regressions following chaining at Spruce Mountain.

Fig. 5. Tree ring width regressions following cabling at Blythe Springs.

inversely related to the rate of site reoccupancy by the conifers. Similar curvilinear relationships between tree and understory have been found in other areas (Jameson 1967; Clary 1963; Beale 1973; and Ffolliott and Clary 1975).

The average post-treatment tree ring widths were 1.09 mm for Spruce Mountain, 1.4 mm for Blythe Springs, and 1.64 mm for Kern Mountain. These averages represent an index of the growth rate for each site. For all sites they represent approximately a 400% increase over the pretreatment average.

Because the dynamics of plant succession following treatment is dominated by the regrowth of surviving trees, these regression results also make possible a general estimate of the understory cover for any level of tree cover on a chaining. For the eastern Nevada area studied, any increase in the proportion of resources available to the understory resulting from the treatment appears to be essentially eliminated by the time the tree cover reaches between 12% and 15%.

A determination of the rate and pattern of the regrowth of the trees in reaching this cover gives an estimate of treatment effectiveness. On each tree from Blythe Springs the measured ring widths were prorated to the average radius of each area for each cross section.

The area of each cross section was then incremented by the appropriate amount from the year of chaining to the year of sampling for a measured 12-year increase in basal area. In addition, the average ring widths were summed by year for both trees and curvilinear regressions were fitted to this data. The curves were extrapolated for three more years and the resulting

Fig. 6. Curvilinear regressions of tree cover (T) and total non-tree cover (S).

estimated ring widths used to project basal area increase to 15 years following chaining.

Using all cross sections for each tree species, linear regressions were computed to determine the effectiveness of using the area of the cross sections of one year to predict the area of the next year. The area at the time of treatment was used to predict the area of year one, year one was used to predict year two, year two to predict year three, etc. until year 14 predicted year 15. This resulted in 15 linear regression equations for each species that have R^2 values ranging from .96 to .97 for pinyon and .95 to .97 for juniper ($P \leq .01$).

The accuracy of these equations has several implications on predicting and measuring the growth and production of the tree species. For any one season's growth, the resulting cross sectional or basal area of a tree is highly correlated to the area at the start of the growing season. The constant determining the basal area increase seems to be controlled by the growing conditions existing each year. The high correlation between cross sectional areas from year to year indicated that a high correlation also exists between the amount of cross sectional area added and the total area at the beginning of the growing season for each year. Dimensional analysis of woody plant size and shape with growth has demonstrated that the ring area added is directly proportional to the sapwood area (Tausch and West 1975). On trees surviving treatment nearly all the cross sectional area is sapwood because of the accelerated growth and initial small size.

A comparison of the basal area to the crown cover of 74 individual trees of each species by regression analysis also gives significant results with R^2 equal to .61 for juniper and .71 for pinyon ($P \leq .05$). Payne (1974) has recently shown cover to also be a good predictor of production. Significant correlation between basal area increases and understory decline have been described by others (Jameson 1967; Clary 1969; Beale (1973; and Ffolliott and Clary 1975). Basal area increase, particularly the yearly basal area, is directly related to production, more so than cover, and makes a better predictor of production (Tausch and West 1975).

Using the regression values between tree cover and basal area, the 30 regressions predicting basal area increase were converted to predict crown cover increase. Using this relationship, the estimated crown cover of each year for any year could be predicted from the crown cover of the previous year. The data are available on all macroplots for all six treatments studied.

The final regression equations, developed from data collected on the Blythe Springs cabling, were tested with 2 years' data available from the Spruce Mountain chaining. Using these equations, the crown cover of each tree measured in 1970 was incremented to an estimated level for 1971 and an average tree cover for the chaining was computed. Because the average ring width at Blythe Springs was larger than at Spruce Mountain, an overestimate was to be expected. The estimated 1971 tree cover was 7.77%; the cover actually sampled was 7.64%. Using the estimated 1971 tree cover and the regression equation in Figure 6, an estimated 1971 shrub cover value of 9.82% was computed. The shrub cover sampled in 1971 was 10.01% (Table 4).

These data indicate that the understory cover is declining as the tree growth continues, and that this tree growth can be reliably estimated from the basal area increases of the trees.

A program was written, incorporating the regression equations for crown cover, and applied to the data collected on two of the Kern Mountain chainings to predict tree regrowth. Kern Mountain had a greater average ring width than Blythe Springs,

Table 4. Sampled cover (%) of tree and understory for 1970 and 1971 and the cover (%) predicted for 1971 from 1970 values on Spruce Mountain.

Group	1970 sampled	1971 sampled	1971 predicted
Tree	6.57	7.64	7.77
Understory	12.15	10.01	9.82

indicating the results should be an underestimate. Computations were stopped when the tree cover exceeded 15%.

On the South Kern chaining, the simulation reached this cover in 12 years following chaining. On the North Kern East chaining, this cover was reached in 10 years. On Spruce Mountain the simulation time needed was 14 years. The differences in time were caused primarily by the differences in surviving tree density on these chainings (Table 3). An inverse relationship exists between the surviving tree density and the effectiveness of the treatment. Natural reseeded by the trees appeared to be quite slow. After 12 years only 1% of the trees sampled on the Blythe Springs cabling were post-treatment seedlings. Two-thirds of these were pinyon.

Summary and Conclusions

In summary, the pattern of growth forms occurring in succession following a debris-in-place treatment was essentially the same as that found by Barney and Frischknecht (1974) following fire. The peaks in abundance of the various stages occur faster, however, due to the existence of individuals of all successional stages from the beginning. Chaining or cabling is not as severe a disturbance as fire and allows for a much higher plant survival rate. Many of the surviving plants have established root systems. Species representing all successional stages, although occurring simultaneously after treatment, dominate at different times. Differences in the growth rates of the species representing the different stages of succession results in their reaching maximum abundance at different points in time.

During the first 1 or 2 years following treatment, the site is dominated by annual and perennial forbs. Where seed sources are available (native or seeded), perennial grass dominance begins the second year and reaches its maximum abundance around the fourth year. An increase in shrubs, again where propagules are available, follows closely behind the grasses and reaches its peak 1 to 3 years later. The increase in the tree species is slow but steady from the time of treatment, and trees appear to redominate the eastern Nevada sites studied in less than 15 years. This tree increase is primarily responsible for the decline in understory abundance and deer utilization observed after about the fifth year following treatment.

The specific understory species representing each group involved in succession varies from site to site depending on the species present, as does each site's specific rate of succession. The rate at which a species or species group reaches its peak is approximately inverse to the mature size of the species or average mature size of the species in the group.

The historical increase in tree abundance in pinyon-juniper woodlands is a problem that is possibly greater than previously realized. Along with other important ecological considerations on the size, shape, and location of the treatment (Terrel 1972; Terrel and Spillett 1975), any treatment not successfully removing nearly all the trees in the treated areas will have a short life expectancy. The incroachment of trees into many areas formerly without trees indicates some factor or factors were previously keeping the trees out of these areas. From the pattern

and rates of succession following fire described by Barney and Frischknecht (1974) and the growth dynamics described in this study, it appears that fires, no more frequent than 50 to 60 years, could have successfully kept the trees out of these formerly non-tree areas.

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Biochemical Calcium Cycling of *Andropogon scoparius* Michx. in Two Contrasting Soil Types, by Steven Scobee Waller, PhD, Range Science. 1975.

Techniques of dry ashing plant material and column extracting soil material were developed to convert ^{45}Ca to a chloride salt. Calcium-45 recovery efficiency was approximately 90% for plant material and 95% for soil. Movement and distribution within *Andropogon scoparius* Michx. tillers, clones, and associated ecosystems were investigated in greenhouse and field studies using ^{45}Ca as a tracer. Two contrasting soil types, Heiden-Hunt clay and Tabor fine sandy loam, were utilized. Calcium-45 introduction was achieved by both foliar and soil application techniques.

Initial movement of foliar applied ^{45}Ca was rapid in greenhouse-grown tillers. Movement from point of introduction was basipetal and acropetal with activity observed in every tiller compartment and the soil within 1 hour following isotope introduction. Temporary redistribution was observed between leaf and sheath (major compartments of accumulation) during 100.5 hours following isotope introduction. Over time, ^{45}Ca was immobilized and accumulated in the leaf, sheath, and senescent material. Calcium in the sheath was remobilized and transported to developing seed culms.

Field studies indicated ^{45}Ca distribution within clonal tillers was similar to that observed in greenhouse-grown tillers. Over 56% of

foliar applied ^{45}Ca had been transferred from clay-grown clones to the soil compartment while 11% was in the associated vegetation compartment after 4 months. The sand soil compartment contained over 63% of the total applied activity with 8% in the associated vegetation compartment. At the end of the second growing season, the soil compartment contained about 85% of the applied ^{45}Ca , regardless of soil type. An active calcium cycle on the clay ecosystem was not identified, while a rapid cycle was documented on the sand ecosystem.

Total ^{45}Ca uptake by little bluestem clones following soil application was positively correlated with foliage production during the growing season, and both were positively correlated with precipitation. Total uptake and concentration were greater in sand-grown clones than clay. Magnitude of foliage concentration was inversely related to stable soil calcium in the soil. However, maximum ^{45}Ca uptake at the end of the growing season did not exceed 0.20% of that applied on either soil type. Thus, the soil compartment was the principal sink and was the rate-limiting compartment in the grassland ecosystem of both soil types.