

Rate of Increase of Redberry Juniper (*Juniperus pinchotii*) Canopy Cover in Western Texas: Ecological and Economic Implications

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Abstract—Redberry juniper (*Juniperus pinchotii*) is a major problem on Texas rangelands, yet little is known about the rate it is increasing. This study estimated long-term rates of change of redberry juniper canopy cover on undisturbed sites and adjacent sites that were either chained or grubbed at five locations in western Texas. Juniper cover was estimated from positive transparencies of aerial photographs by the line intercept method using a 10-X monocular lense with a vernier. Juniper cover increased at an average rate of 0.37 percentage unit year⁻¹ (range 0.12 to 0.59) on undisturbed sites from the mid 1950s or early 1960s to the late 1990s (34 to 41 years). Following chaining or grubbing treatments during 1970 to 1978, juniper cover increased at an average rate of 1.00 percentage unit year⁻¹, which was significantly faster than the average rate of 0.5 percentage unit year⁻¹ on untreated rangeland for the same time interval. Juniper cover returned to pre-treatment levels in an average of 20.6 years (range 11 to 29) following mechanical control. The annual increment in herbaceous production was predicted at -2 to -4 kg ha⁻¹ (-1.8 to -3.6 lb acre⁻¹) for sites or periods where juniper cover was increasing at low rates and at -15 to -23 kg ha⁻¹ (-13 to -21 lb acre⁻¹) where juniper cover was increasing at high rates. Data from this study suggest that initial or maintenance control practices should be installed before juniper cover exceeds about 12 percent.

Redberry juniper (*Juniperus pinchotii*) infested about 4.7 million ha (12 million acres) of rangeland in Texas in 1982 (Soil Conservation Service 1985), and it is rapidly increasing in abundance and expanding its geographical range (Ansley and others 1995). Only about 34 percent of annual rainfall reaches mineral soil beneath mature redberry junipers because of interception by the tree canopies and litter layers (Thurow and Hester 1997). Mature junipers severely impact the herbaceous vegetation beneath, and on some soils for

considerable distances beyond, their canopies (Dye and others 1995), thus, forage production declines as juniper canopy cover increases (Johnson and others 1999; McPherson and Wright 1990). Knowledge on the rate of increase of redberry juniper cover is critical to better understanding its ecology, assessing the economic feasibility of control programs, and scheduling initial and maintenance control practices. The main objective of this study was to determine the rates of increase of redberry juniper cover on undisturbed and mechanically treated rangeland in western Texas. Our hypothesis was that juniper cover increases faster following mechanical control than on undisturbed rangeland. A secondary objective was to apply the knowledge on the rate of juniper cover increase to estimate the temporal effects of redberry juniper cover changes on herbaceous production.

Materials and Methods

Redberry juniper woodlands were studied at five locations across the northern and western Edwards Plateau of Texas (fig. 1) along an average annual rainfall gradient from 46 to 62 cm (18.1 to 24.5 inches). Two 16.2-ha (40-acre), juniper-infested sites, one with and one without a history of prior mechanical control that were in close proximity and on the same soil, were selected at each location. Other criteria for site selection were that (1) redberry juniper was the dominant overstory species, (2) there were no other large, evergreen plants that could be mistaken for junipers on aerial photographs taken during winter, (3) maintenance juniper control treatments had not been applied to treated plots subsequent to the initial mechanical control treatments, (4) past management was typical for the region, and (5) topographical or man-made features facilitated precise location of the sites on large-scale aerial photographs.

The soils at all study sites were shallow, with rapid surface runoff, and low to very low water availability. Juniper control treatments included two-way chaining at three sites (1970 in Coke County, 1972 in Irion County, 1978 in Reagan County), one-way chaining in 1971 in Crockett County, and grubbing in 1976 in Nolan County.

Positive transparencies of all available aerial photographs (scale 1 cm = 79 m) (1 inch = 660 ft) of each site were purchased from the USDA Farm Services Agency Aerial Photography Field Office in Salt Lake City, Utah. The earliest photographs were taken in 1955 and the latest in

In: McArthur, E. Durant; Fairbanks, Daniel J., comps. 2001. Shrubland ecosystem genetics and biodiversity: proceedings; 2000 June 13-15; Provo, UT. Proc. RMRS-P-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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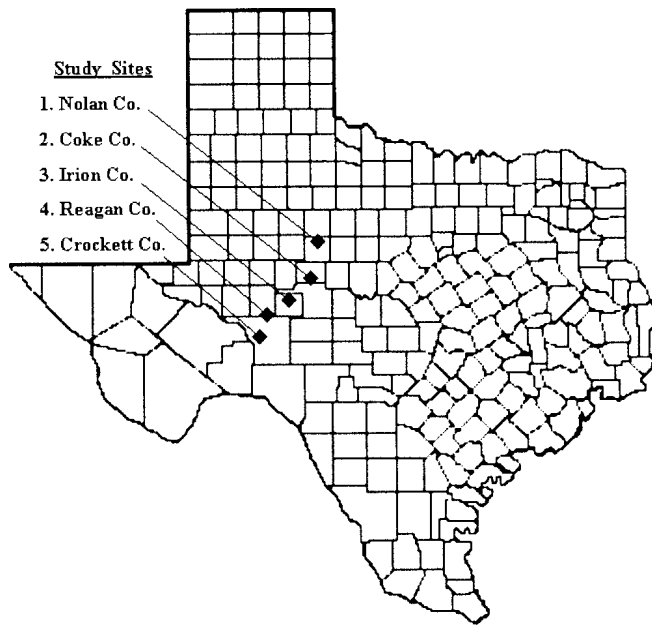


Figure1—Locations of redberry juniper study sites in the Edwards Plateau, Texas.

1997. All photographs were taken in winter and redberry juniper plants or clusters were evident on the photographs as dark or black areas within the grey matrix of dormant grasses and bare ground. A 10-X hand lense with a vernier was used to estimate juniper cover by the line intercept method (Bonham 1989) on each aerial photograph of each study site, while the positive transparency was on a light table. The center one-hundred 0.1-mm (0.0039-inch) increments of the vernier were used for line transects. Forty-five line transects, equivalent to 79 m (259 ft) in length, were sampled on each aerial photograph of each site. The mean canopy cover for each photograph of each site was calculated. Redberry juniper cover on each study plot was estimated in the field by the line intercept method in July 1999 for comparison with estimates from the most recent (1996 or 1997) aerial photographs. Ten 152.4-m (500-ft) line transects were sampled on each 16.2-ha (40-acre) plot. The mean canopy cover was calculated for each plot.

The rate of change of juniper cover (percentage units year⁻¹) for each site was calculated by dividing the percentage point change in cover from photograph A to photograph B by the number of years that had lapsed between the two photographs. Live juniper cover remaining subsequent to chaining or grubbing was assumed to be about 1 percent, based on our observations of commercial chaining and grubbing operations in the region.

Analysis of variance was used to determine if the estimates of juniper cover for each site from the most recent aerial photographs and from field sampling in 1999 were significantly different. Variation among subsamples within each plot ($n = 45$ for aerial photographs; $n = 10$ for field sampling) was utilized as the estimate of error. Data on juniper cover from each study site were subjected to analysis of variance to determine if juniper cover changed significantly during the time interval between photographs.

Variation among subsamples within treatments was utilized as the estimate of error. Means were separated by LSD at $P \leq 0.05$. Analysis of variance was also used to test for differences in rates of change of redberry juniper canopy cover post treatment on chained or grubbed sites and for this same time interval on untreated plots. Locations ($n = 5$) were utilized as replications in this analysis.

We used our estimates of the rates of change of juniper cover to estimate juniper cover for each year between the earliest and latest photographs for each undisturbed site. These yearly juniper cover values were then used in the natural log model of the relationship between annual herbage production and redberry juniper cover developed in the Edwards Plateau by Johnson and others (1999) to estimate the decline in total herbaceous production as a function of time. This production function is defined as:

$$Y = e^{7.1626024 - 0.000441X^2}$$

where Y = annual herbage production in kg ha⁻¹, e is a transcendental number 2.718282, X = redberry juniper canopy cover (percent), and $r^2 = 0.9054$.

Results and Discussion

Cover Estimates From Photographs Versus Field Sampling

Estimates of juniper cover from 1996 or 1997 aerial photographs and from field sampling in 1999 were similar for seven of the 10 study sites, but field estimates were significantly ($P \leq 0.05$) lower than those from photographs for three sites (data not shown). Visual estimates of juniper cover on the photographs of these three sites by two observers were in close agreement with the means obtained from the photographs using the 10-X monocular lense method. We concluded that ten 152.4-m (500-ft) line transects were not an adequate sample size for field sampling on these three sites because the juniper was spatially arranged either in patchy or striated patterns. We feel confident that the 10-X monocular lense method provided acceptable estimates of redberry juniper cover on all 10 of our study sites.

Juniper Canopy Cover Changes

Undisturbed Rangeland—Juniper cover decreased or remained relatively static for several years after the mid 1950s on untreated sites where the initial cover was >30 percent (see graphs for Irion and Coke County sites in fig. 2). In contrast, juniper cover steadily increased, usually at increasing rates, on undisturbed rangeland where the initial canopy cover was ≤ 14 percent (see graphs for Crockett, Nolan, and Reagan County sites in fig. 2). These differences suggest that, following the drought of the 1950s, intraspecific competition may have suppressed juniper growth and seedling recruitment on rangeland with heavy juniper cover, whereas adequate resources were available for juniper growth and seedling recruitment on rangeland with light juniper cover.

The rate of juniper cover increase on undisturbed rangeland escalated over time from the mid 1960s through the late 1990s at most sites (fig. 2). Terminal rates of canopy cover

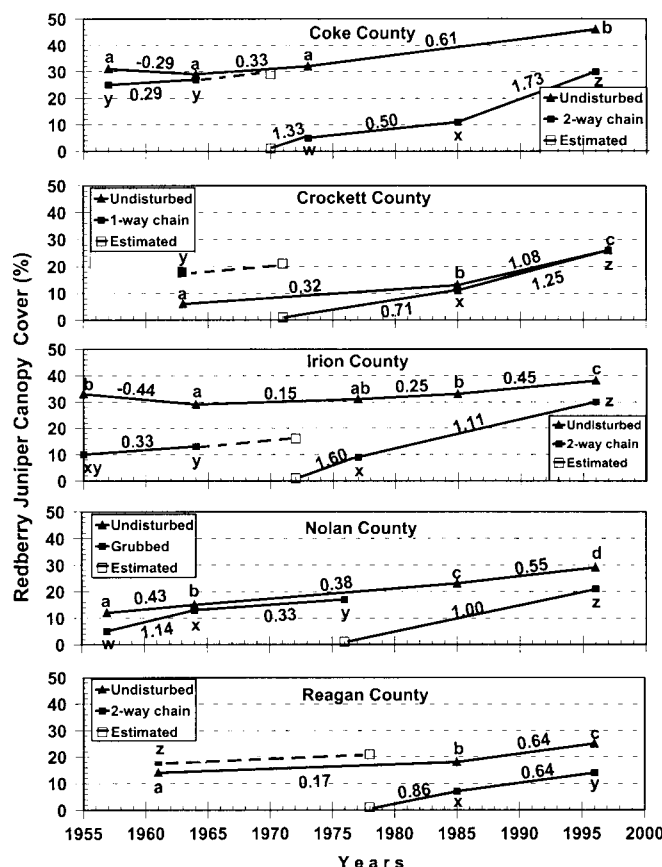


Figure 2—Redberry juniper canopy cover (percent) during 1955 to 1997 on undisturbed rangeland and adjacent sites subjected to chaining or grubbing in Coke, Crockett, Irion, Nolan, and Reagan Counties, Texas, estimated from aerial photographs. Numbers between data points are the rates of canopy cover change (percentage unit year⁻¹). Means within a line accompanied by different lower case letters are significantly different at $P \leq 0.05$.

change on undisturbed rangeland varied from 0.45 percentage unit year⁻¹ in Irion County, where cover was approaching 38 percent, to 1.08 percentage unit year⁻¹ in Crockett County, where cover was approaching only 26 percent (fig. 2). The Crockett County undisturbed site supported only 11 percent juniper cover in 1985, which was much less than was present on the other undisturbed sites. This suggests that the environment of the Crockett County site during 1985 to 1996 was capable of supporting more juniper cover, whereas juniper populations on the other undisturbed sites were more mature, and perhaps approaching equilibrium with their environments.

The long-term rates of change of juniper cover over 34- to 41-year periods on the five undisturbed sites averaged 0.37 percentage unit year⁻¹ (range 0.12 to 0.59). The undisturbed site in Irion County, which supported the greatest initial juniper cover (33 percent) (fig. 2), had the lowest long-term rate of change (0.12 percentage unit year⁻¹). The undisturbed site with the lowest initial juniper cover (6 percent) exhibited the greatest long-term rate of change in juniper cover (0.59 percentage unit year⁻¹) (see Crockett County site

in fig. 2). Soulé and Knapp (1999) reported that western juniper (*J. occidentalis* spp. *occidentalis*) cover increased at rates of 0.08 percentage unit year⁻¹ on an ungrazed site and at 0.11 to 0.18 percentage unit year⁻¹ on grazed sites during 1951 to 1994 in central Oregon where average annual precipitation was 25 cm (9.8 inches). The faster development of redberry juniper woodlands in western Texas may be a function of greater annual rainfall or to inherent differences among these two species in growth rate, seed production, recruitment rates, or the age at which these species reach reproductive maturity.

Mechanically Treated Rangeland—Redberry juniper canopy cover increased at an average rate of 1.00 percentage unit year⁻¹ over the 18- to 26-year periods following chaining or grubbing (range 0.72 in Reagan County to 1.21 in Irion County). During this same time interval, the canopy cover of undisturbed juniper increased at 0.50 percentage unit year⁻¹, which was significantly ($P \leq 0.001$) lower than the average rate following mechanical treatments. Short-term rates of cover change (between photographs) subsequent to mechanical treatments ranged from 0.5 to 1.73 percentage unit year⁻¹ (fig. 2). Juniper cover increased at similar rates on sites two-way chained, one-way chained, and grubbed.

The more rapid development of juniper cover following mechanical treatments can be attributed to three factors. Redberry juniper seedlings and saplings are often very abundant in the understory of mature junipers in the Edwards Plateau (Dye and others 1995; Ueckert and Whisenant 1982), and these small plants are not effectively controlled by chaining or grubbing. Removal of mature junipers by chaining or grubbing reduces the interference of mature junipers with the growth of these juvenile plants, and they grow very rapidly. On some sites, chaining only removes the aboveground growth of many redberry junipers, and these plants resprout from the basal caudex, then grow very rapidly because of their extensive root system (McPherson and Wright 1989). Also, the soil disturbance and juniper debris created by chaining or grubbing provides seedbeds for juniper seed germination and safe sites for juniper seedling establishment.

Interrelationship of Juniper Cover, Herbage Production, and Time

Linear and polynomial models with r^2 values >0.998 explained the decline in annual herbage production over time in response to increasing redberry juniper cover on our five untreated range sites (fig. 3). Annual herbage production was predicted to decrease at increasing rates over time at the Crockett, Nolan, Reagan, and Irion County study sites, and to decrease at a slightly decreasing rate over time at the Coke County site. The annual increment in herbage production was low (-2 to -4 kg ha⁻¹ year⁻¹) (-1.8 to -3.6 lb acre⁻¹ year⁻¹) for sites and periods when juniper cover was increasing at low rates (0.15 to 0.32 percentage unit year⁻¹), intermediate (-11 to -14 kg ha⁻¹ year⁻¹) (-10 to -12 lb acre⁻¹ year⁻¹) when juniper cover was increasing at intermediate rates (0.45 to 0.61 percentage unit year⁻¹), and high (-15 to -23 kg ha⁻¹ year⁻¹) (-13 to -21 lb acre⁻¹ year⁻¹) when juniper cover was increasing at the highest rate (1.08 percentage unit year⁻¹). The natural log production function predicted

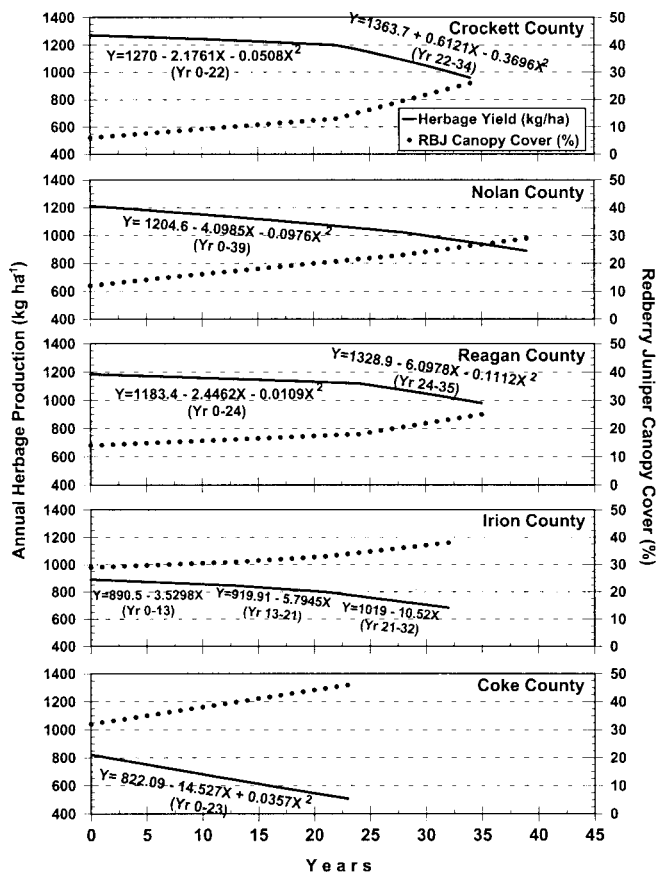


Figure 3—Relationships between annual herbage production (kg ha⁻¹) (Y) and time (years) (X) for undisturbed redberry juniper study sites in Crockett (1963 to 1997), Nolan (1957 to 1996), Reagan (1961 to 1996), Irion (1964 to 1996), and Coke (1973 to 1996) Counties, Texas. The trend lines were developed by integrating our estimates of annual redberry juniper canopy cover (percent) into a natural log model of the relationship between annual herbage production and redberry juniper canopy cover developed in the northern Edwards Plateau, Texas, by Johnson and others (1999). Functional forms were fitted to the trend lines that had r^2 values >0.998. Annual juniper canopy cover (dotted line) is included in each graph for reference only.

that herbage production on our five untreated sites had decreased by an average of 272 kg ha⁻¹ (243 lb acre⁻¹) (range 204 to 320 kg ha⁻¹) or 26 percent (range 17 to 38 percent) from the mid 1950s or 1960s to the late 1990s.

Management Implications

The threshold from grasslands, in which graminoid-driven successional processes predominate, to redberry juniper-dominated woodlands is crossed when sufficient numbers of junipers become established and reach reproductive maturity. At this point, juniper-driven successional processes, including (1) a major reduction in diversity, density, basal

area, and productivity of the herbaceous understory, (2) an influx of subsidiary woody and succulent species, (3) further reduction in fire frequency and intensity, and (4) a high incidence and rate of juniper seedling establishment, begin predominating (Dye and others 1995). Data presented in this paper document the rates at which redberry juniper woodlands can develop and recover following chaining or grubbing, and predicted rates at which herbage production concomitantly declines. This study substantiates the conclusion of Dye and others (1995) that conversion of juniper woodlands back to grasslands will not only require initial reclamation treatments, but also sustained use of followup maintenance control practices and proper grazing management. Our data show that annual herbage production on undisturbed rangeland declines slowly as redberry juniper cover initially reaches 12 to 18 percent, rapidly as juniper cover increases from 19 up to 29 percent, and slowly on some sites, but fairly rapidly on other sites, after juniper cover exceeds 29 percent. We suggest that initial or maintenance redberry juniper control practices should be installed before redberry juniper cover exceeds about 12 percent, in other words, before annual herbage production begins declining at peak rates.

Knowledge of the rate woody plant canopy cover changes is essential for determining the economic feasibility of control projects. In a recent study of the economic feasibility of redberry juniper control using two-way chaining as the initial treatment and periodic prescribed burning as maintenance treatments, Johnson and others (1999) utilized empirical linear rates of juniper cover change of 1.6, 2.5, and 5 percentage units year⁻¹ across a range of untreated juniper cover of 10 to 30 percent and subsequent to two-way chaining and prescribed burning. Their study showed that net present values of juniper control treatments increased from \$67 to \$130 ha⁻¹ (\$27 to \$53 acre⁻¹) and that the optimal burning cycle decreased from 9 to 5 years as the rate of juniper cover change increased from 1.6 to 5 percentage units year⁻¹. The slower rates of juniper canopy cover increase that we report here for untreated and mechanically treated rangeland suggest that the net present value of controlling juniper with chaining and periodic burning would be positive, but substantially less than \$67 ha⁻¹ (\$27 acre⁻¹), and that the optimum burning interval would be substantially longer than 9 years. More recently and based on data from our study, SoRelle (2000) used rates of redberry canopy cover increase of 0.12, 0.37, and 1.08 percentage unit year⁻¹ for undisturbed stands and rates of 0.5, 1.0, and 1.73 percentage unit year⁻¹ subsequent to initial or maintenance control practices in his study of the economic feasibility of redberry juniper control. The net present value to a cattle producer for controlling redberry juniper using two-way chaining as the initial treatment and hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione) individual plant treatments for maintenance control increased from about \$34 to \$56 ha⁻¹ (\$14 to \$23 acre⁻¹) as the rate of juniper cover increase without treatment increased from 0.12 to 1.08 percentage unit year⁻¹. The net present value of juniper control decreased from about \$54 to \$25 ha⁻¹ (\$22 to \$10 acre⁻¹) when the rate of canopy cover increase following treatment increased from 0.5 to 1.73 percentage unit year⁻¹.

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