Introduction

A 1985 survey by the Soil Conservation Service indicated that eastern redcedar (*Juniperus virginiana*) and ashe juniper (*J. ashei*) had invaded almost 1.5 million acres in Oklahoma by 1950 and 3.5 million acres by 1985 (Snook 1985). The invasion of native plant communities by juniper species has garnered increasing attention throughout much of the Great Plains and the western states. Because these junipers are increasing at an alarming rate and because the invasion is a threat to the sustainability, productivity, and biological diversity of native ecosystems, we thought it prudent to repeat Snook's 1985 inventory of juniper invasion in Oklahoma.

We distributed survey questionnaires to all Natural Resources Conservation Service (formerly SCS) field offices in Oklahoma in the fall of 1994 to determine the extent of juniper encroachment and the control measures used. Respondents were asked: 1) to encircle areas on a map of their county in which eastern redcedar or ashe juniper exceeded 50 trees per acre (i.e., obvious stands), 2) to estimate the land area of rangeland and forestland on which the juniper has invaded in the county, and 3) to estimate the land area on which juniper control measures were applied in the past year. All offices responded to the questionnaire and supplied maps of the distribution of eastern redcedar and ashe juniper in their counties. Several offices in southwestern Oklahoma supplied maps of the distribution of redberry juniper (*J. pinchotii*), but because redberry juniper and other species of juniper (*J. monosperma* and *J. scopulorum* in the Oklahoma panhandle) are more localized within Oklahoma, these species were not addressed in the survey (See Appendix A).

Extent of Eastern Redcedar and Ashe Juniper Populations

Eastern redcedar or ashe juniper was reported in all but nine counties within the state. As in the 1985 survey, eastern redcedar or ashe juniper was concentrated in three regions (Figure 1). Eastern redcedar occurs in a large area across the northwestern part of the state, generally on the northern slopes of the main drainages of the Cimarron, North Canadian, and South Canadian Rivers. The 1985 survey suggested these populations of eastern redcedar were moving eastward along the main river drainages, where they were historically restricted to rough breaks adjoining these rivers. The 1994 survey suggests some populations have coalesced so entire areas between rivers have been invaded by eastern redcedar. Eastern redcedar was noted throughout the central and north central regions of the state, west of the intersection of the

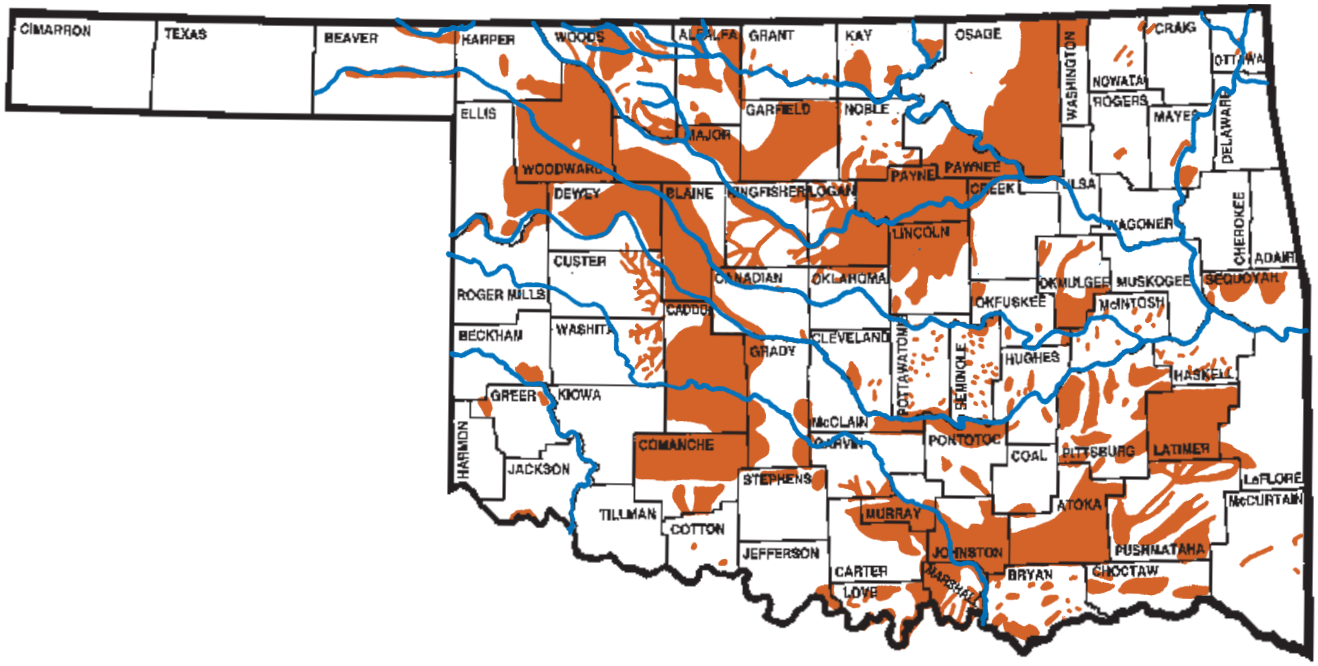

Figure 1. Eastern redcedar and ashe juniper in Oklahoma in 1994. Shaded portions of the map represent areas where eastern redcedar and ashe juniper were located and were compiled from county maps provided by survey respondents.

Arkansas and Cimarron Rivers and westward along the Cimarron. Eastern redcedar, sometimes in a mixture with ashe juniper, also occurs in a large population in south central Oklahoma in and around the Arbuckle Mountains. Scattered populations of eastern redcedar are located in the forested regions of southeastern Oklahoma in cedar glades and as an understory tree in the pine and hardwood forests. None of the populations of juniper in north central, central, south central, or southeastern Oklahoma have increased appreciably in extent.

Comparing the 1985 survey (Figure 2) to the 1994 survey suggests the range of eastern redcedar and ashe juniper has expanded primarily in two regions of the state within the past ten years. Perhaps the most notable increase in extent is evident in southwestern Oklahoma, where only scattered populations were noted in 1985 but where several respondents noted widespread occurrence of eastern redcedar within their counties in 1994. The 1994 survey also suggests the extent of eastern redcedar has increased in northwestern Oklahoma, where by 1994 some of the populations between river drainages had coalesced and had formed one large population occupying much of the available landscape (i.e., rangeland) between drainages. An alternative interpretation of the comparison between surveys, however, is that it is possible junipers had attracted greater attention in recent years, so respondents were more perceptive of juniper in 1994 than in 1985.

Distribution and Control Measures

According to survey responses, eastern redcedar and ashe juniper now occupy over 6 million acres of rangeland and forestland in Oklahoma, which is about 15% of the total land area of the state and almost 30% of the 21.6 million acres in native plant communities (Bernardo 1986). This 79% increase in area in a nine-year period indicates the distribution of junipers is expanding within the three primary population centers of junipers in Oklahoma. Indeed, fitting a curve to the area occupied by eastern redcedar and ashe juniper since 1950 (data for 1950, 1965, and 1975 from Snook 1985) indicates the range of eastern redcedar continues to grow exponentially (Figure 3). Extrapolating the equation presented in Figure 3, it is estimated that junipers will occupy about 9 million acres by the year 2000. The average invasion rate of eastern redcedar/ashe juniper into

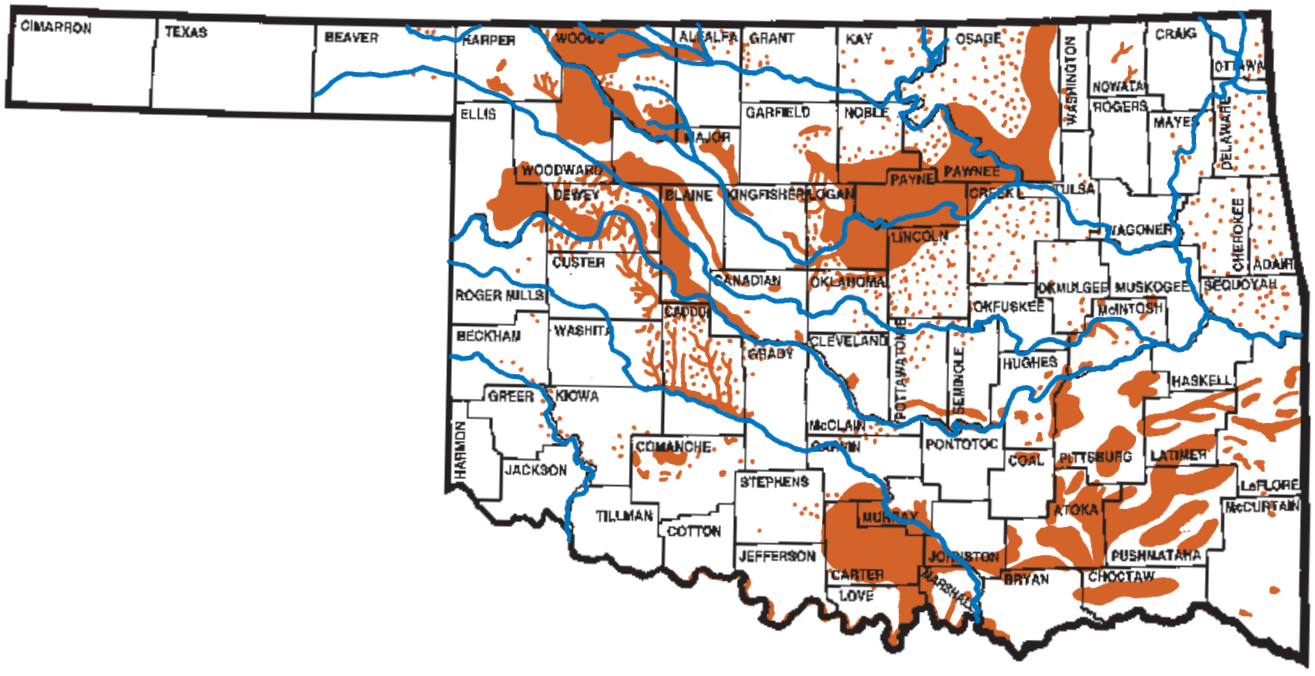

Figure 2. Eastern redcedar and ashe juniper in Oklahoma in 1985 (from Snook 1985). Shaded portions of the map represent areas where eastern redcedar and ashe juniper were located and were compiled from county maps provided by survey respondents.

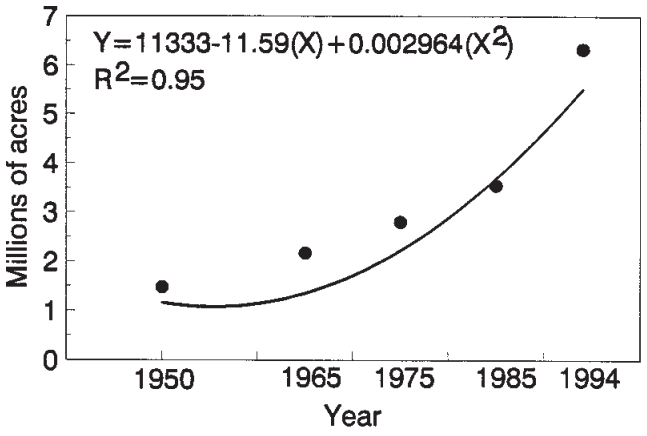

Figure 3. Area (in millions of acres) in eastern redcedar and ashe juniper in Oklahoma in 1950, 1965, 1975, 1985, and 1994 and a curve fitted to the data.

Oklahoma rangeland and forestland was about 280,000 acres per year from 1985 to 1994. More land is prescribed burned for control of eastern redcedar and ashe juniper than all other control measures combined. However, of the 650 thousand acres reported to be prescribed burned in the year before the survey, 550 thousand acres were in Osage County, where much of the rangeland is frequently, if not annually, burned. Hence, it is likely that eastern redcedar control by prescribed burning in most of Osage County is a by-product of prescribed burning conducted primarily to achieve other objectives. It is possible, however, that respondents' estimates of area burned are conservative.

Not including prescribed burning in Osage County, the area treated for eastern redcedar and ashe juniper control amounts to roughly 170 thousand acres each year. Thus, assuming none of these 170 thousand acres represents re-treatment, juniper control is falling behind by roughly 110 thousand acres each year. In view of the exponential increase in area occupied by junipers, it is unlikely that this assumption is completely accurate, and it is more likely that only a small proportion to the total annual increase in area occupied by junipers is treated annually.

Natural Resources at Risk

Eastern redcedar and ashe juniper continue to invade new locations and to increase in abundance in locations previously occupied. The integrity and sustainability of Oklahoma's native plant communities and ecosystems, which are important natural resources, are compromised. With problem stands of junipers occupying almost a third of these plant communities, the environmental and economic benefits derived from these lands are at risk. Control measures have not been keeping pace with an invasion of exponential proportions.

Effects on Native Wildlife Habitat

Invasion of juniper into native plant communities changes habitat structure and composition. Further, it changes the interspersion of the important habitat elements of food, cover, and usable space. This is important because the structure and arrangement of habitat elements provide visual cues to wildlife species that might use a given area. When these cues change the wildlife habitat complex changes; habitats with increasing juniper composition become unsuitable to some species and more suitable to others. This is of concern because wildlife species that historically used many open sites such as native grasslands and shrublands, become decidely disàÿvantaged. As cover and density of eastern redcedar increase, additional food and cover for some wildlife species may be provided or more desirable food and cover plants may be displaced (Rollins and Armstrong 1994). In forested situations, those species that require open midstories such as the declining neotropical migrant, eastern wood pewee, may be strongly disadvantaged. Wildlife species that are considered habitat generalists (i.e., have a broad ecological niche) tend to be favored by juniper encroachment into native grassslands, shrublands or forests. Many of these species consume juniper berries (Chavez-Ramirez 1992). Juniper as a browse is considered to be a marginal food source for white-tailed deer, a habitat generalist (Rollins and Armstrong 1994). The most successful white-

Tallgrass prairie invaded by eastern redcedar.

Greater prairie chicken.

Eastern redcedar in a suburban environment. This is an excellent example of contributory negligence on the part of the homeowner should the house burn down.

tailed deer management programs in Oklahoma also have aggressive prescribed fire and juniper control programs in place.

Recent work in Oklahoma has demonstrated that as little as a 5% increase in juniper cover can preclude the use by grassland endemic songbirds such as the grasshopper sparrow (Chapman et al. personal communication). Native grassland loss is becoming of increasing concern (Boren et al. 1997). Examples of wildlife that decline comensurate with increased invasion of juniper include, Rio Grande turkey, mourning dove, bobwhite quail, greater and lesser prairie chicken and white-tailed deer. In the case of wild turkey, juniper encroachment in riparian areas that were turkey roosts have been implicated in the abandonment of historical roost areas. The use of habitat evaluation guides in native habitats demonstrate these concepts (Bidwell et al. 1991, Bidwell et al. 1995, Masters et al. 1996).

Effects on Endangered or Threatened Plants, Animals, and Ecosystems

The invasion of junipers into native plant communities destroys habitat for endemic species which by their nature are habitat specialists and can exist only under certain narrow habitat requirements (niche). Examples include many birds that require prairie, such as the greater and lesser prairie chicken, neotropical and temporate migrants, and year-round residents. Dense stands of juniper may be at least partly responsible for the local or regional decline of certain endangered species. The black-capped vireo, for example, is often associated with eastern redcedar and ashe juniper communities (Rollins and Armstrong 1994) because its original habitat of deciduous vegetation (low growing oaks) has become over-mature from fire suppression. Thus, juniper may be used where woody deciduous vegetation is over-mature (Grzybowski et al. 1994). Otherwise, juniper is probably not necessary, and juniper cover should be kept well below 10% to maintain black-capped vireo habitat (Grzybowski et al. 1994).

The tallgrass prairie is the most endangered ecosystem in North America (Sampson and Knopf 1994). The remnants of the tallgrass prairie and associated threatened plants such as the eastern and western prairie fringed orchid are compromised by fire suppression and concurrent encroachment by eastern redcedar. Other ecosystems such as bottomland hardwoods and upland post oak-blackjack forests are in a similar degraded state and should receive appropriate restoration efforts.

Effects on Wildland Urban Interface

The invasion of junipers into native plant communities that are also experiencing urban sprawl is a rapidly increasing problem that is being overlooked by zoning laws, urban planners, homeowners, and developers alike. With urban sprawl comes fire suppression, fuel buildup, and an increasing potential for catastrophic wildfires. Other areas of the country have already learned this the hard way by experiencing loss of human life and property.

Eastern redcedar presents a two-edged sword in the wildland-urban interface. On the positive side, eastern redcedar is adapted to many sites,

is drought tolerant, and grows rapidly, so it is a popular species in landscaping (Atkinson 1985, Engle and Kulbeth 1992, Axmann and Knapp 1993). Among its advantages and disadvantages, perhaps the fire hazard presented by eastern redcedar is its greatest potential consequence. Homes in natural grasslands, shrublands, and forests are susceptible to wildfire (Schmidt and Wakimoto 1988). Eastern redcedar can increase the risk of fire damage to homes by serving as ladder fuels to overstory deciduous trees and by serving as a volatile fuel source near the home itself. Eastern redcedar also increases risk to firefighters because of its volatile characteristics.

Effects on Water Quality

Rangelands of Oklahoma normally produce high quality water with negligible sediment loads (Smith et al. 1983, Jones et al. 1985). However, juniper encroachment degrades watershed quality by increasing the amount of bare soil and increasing the potential for erosion (Thurow and Carlson 1994). Although prescribed burning to prevent juniper encroachment may increase nutrient discharge slightly in the short-term, it should not increase sedimentation (Smith et al. 1983, Garza and Blackburn 1985). When juniper-infested grasslands are subjected to mechanical control, sedimentation and water yield both increase, although soil erosion should decrease when herbaceous ground cover following juniper control increases (Bedunah and Sosebee 1986, McCarl et al. 1987, p. 22). Hence, juniper invasion in the absence of maintenance control treatments reduces water quality, either by contributing to increases in bare soil between juniper trees or by eventually requiring soil disturbance with mechanical control.

Juniper has an extensive root system and accesses a greater volume of soil water than herbaceous plants, and are "water wasters" when the supply of soil water is not limited (Thurow and Carlson 1994). In a semi-arid grassland of southwest Texas, an average stand of ashe juniper used about 1.12 acre feet of water annually (Smeins et al. 1994). The combination of less water infiltration and the ability of juniper to extract water from the soil indicate that dense stands of juniper have the potential to reduce the recharge of ground water aquifers.

A healthy prairie and forest ecosystem without juniper.

Effects on Air Quality

The invasion of juniper into native plant communities has increased pollen levels, thus increasing allergic reactions in humans throughout the state. Substantial reductions in air quality may accompany increasing juniper populations. For example, the pollen captured in Tulsa, Oklahoma, in fall and winter originates from populations of redberry juniper (*Juniperus pinchottii*) (a fall pollinator) and ashe juniper (a winter pollinator) in southern and southwestern Oklahoma and Texas (Levetin and Buck 1986).

Effects on Biological Diversity and Ecosystem Management

The invasion of juniper into native plant communities reduces biological diversity by reducing the number of living organisms, their functions, and interactions. Three levels of biodiversity are potentially affected including at the genetic, species, and community levels. Plant communities in Oklahoma developed under a regime of frequent

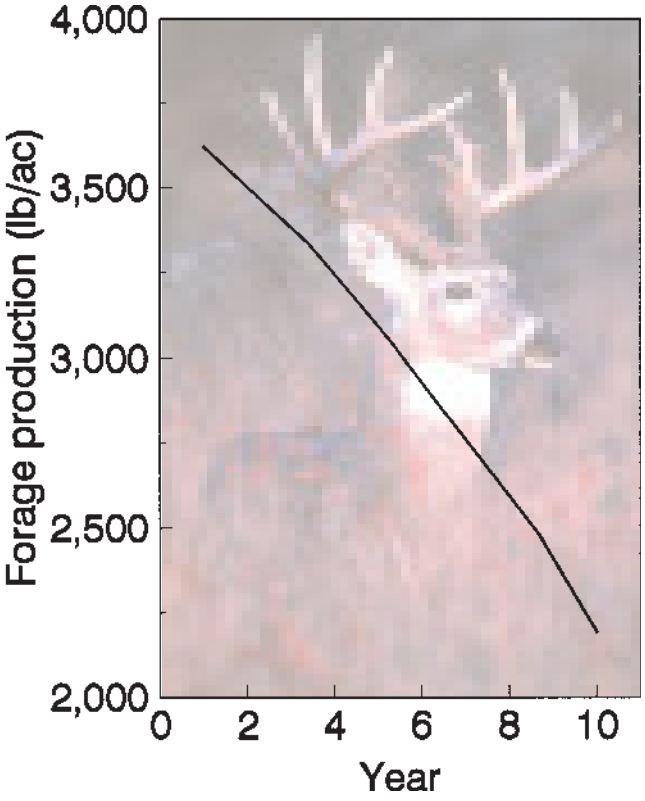

Figure 4. Forage production.

fire. Under such a regime, juniper was an uncommon plant that did not pose a threat to other native plants and animals. The dramatic increase of juniper has led to the reduction in patch size and fragmentation of plant communities creating ecosystem dysfunction (Coppedge et. al., 2000). The conservation and restoration of biological diversity and ultimately ecosystem management requires active management in areas to retain native plant communities. Juniper invasion is in direct opposition to ecosystem management and should be dealt with accordingly. Floristic changes that accompany less than 20 years of shading by invading eastern redcedar indicate that protection from invasion is essential to the continuation of this ecosystem (Gehring and Bragg 1992). Biosimplification is characteristic of a closed stand of juniper and results in ecosystem deterioration.

Effects on Forage Production for Livestock

The invasion of juniper into native plant communities shades out forage plants for wildlife and livestock and reduces stocking rate and carrying capacity. Forage production sharply declines as

In the post oak-blackjack forest, oak is a fire tolerant species, but not with an understory of eastern redcedar. This is an excellent example of contributory negligence on the part of the landowner should fire top kill the oaks.

eastern redcedar trees increase in canopy cover and density (Figure 4). On a range site with the potential to produce 4,000 pounds per acre of forage, a stand of eastern redcedar trees with 200 trees per acre that increases to 470 trees per acre in ten years would produce about 3,700 pounds per acre of forage in the first year, and less than 2,200 pounds per acre of forage in the tenth year (Engle and Stritzke 1992).

Effects on Rangeland Ecological Condition

Other than by plowing, it is almost impossible to drive rangeland into poor ecological condition. However, the invasion of juniper into native plant communities in the Great Plains, has caused the ecological rating to decline (Figure 5).

In bottomland hardwoods, cottonwood is a fire tolerant species, but not with an understory of eastern redcedar. This is an excellent example of contributory negligence on the part of the landowner should fire kill the cottonwoods.

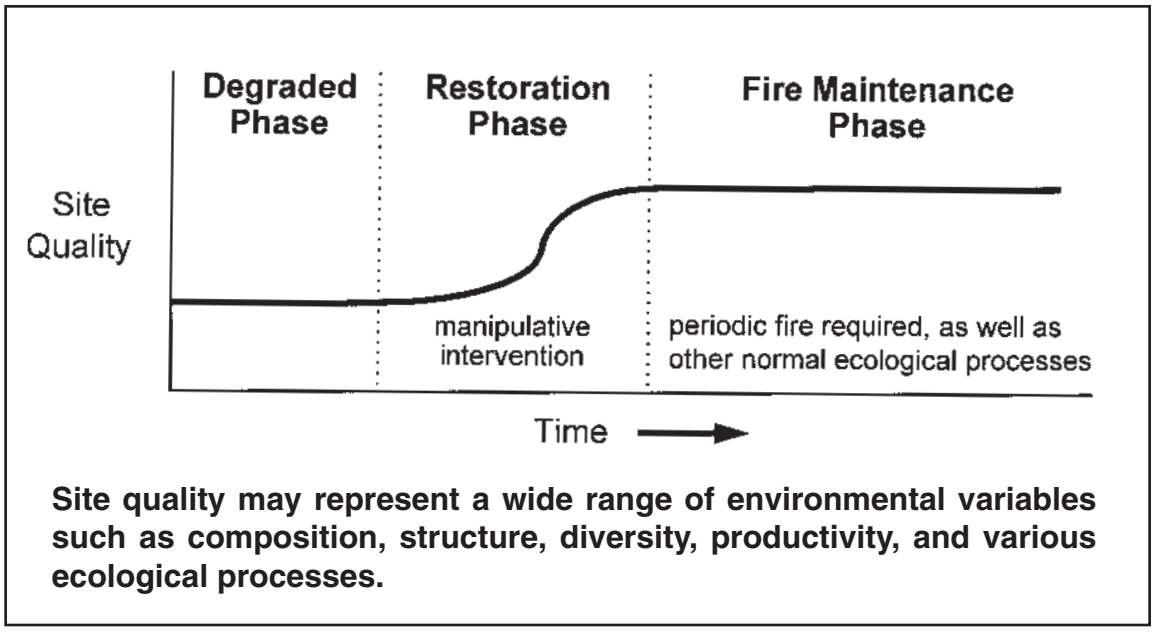

Figure 5. Phases of ecosystem restoration.

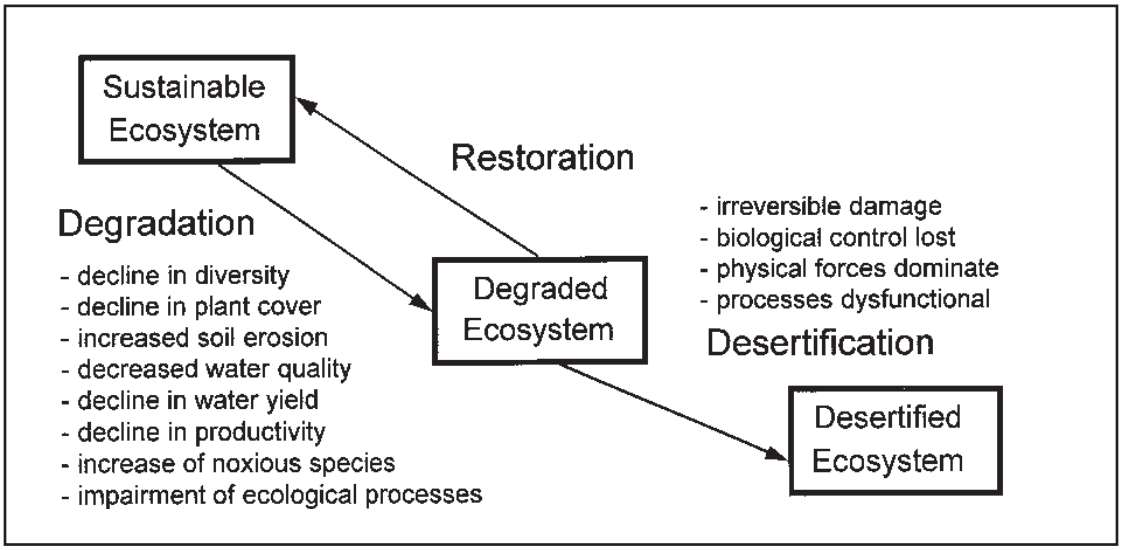

Figure 6. Our choice: Sustainable, degraded, or desertified ecosystems.

Conclusions

We are facing a dilemma with predictable consequences. Are we going to be good stewards of the land and maintain native plant communities or not (Figure 6)? The clock is running, and each year there is a further decline in the condition of Oklahoma's natural resources. The management options are simple and straight forward. One option, doing nothing, has major negative environmental consequences. Conceptually, the problem can be approached from a steady state and transition model (Figure 7) which suggests that without intervention, the ecosystem is locked indefinitely into an unnatural juniper dominated system for both forest and prairie. Our best option is to use a combination of natural ecological processes (i.e., fire) and other human designed (mechanical) management practices to restore prairie, shrubland, and forest ecosystems. Once the threshold is crossed and prescribed fire becomes ineffective (Figure 8), the health of the ecosystem declines rapidly.

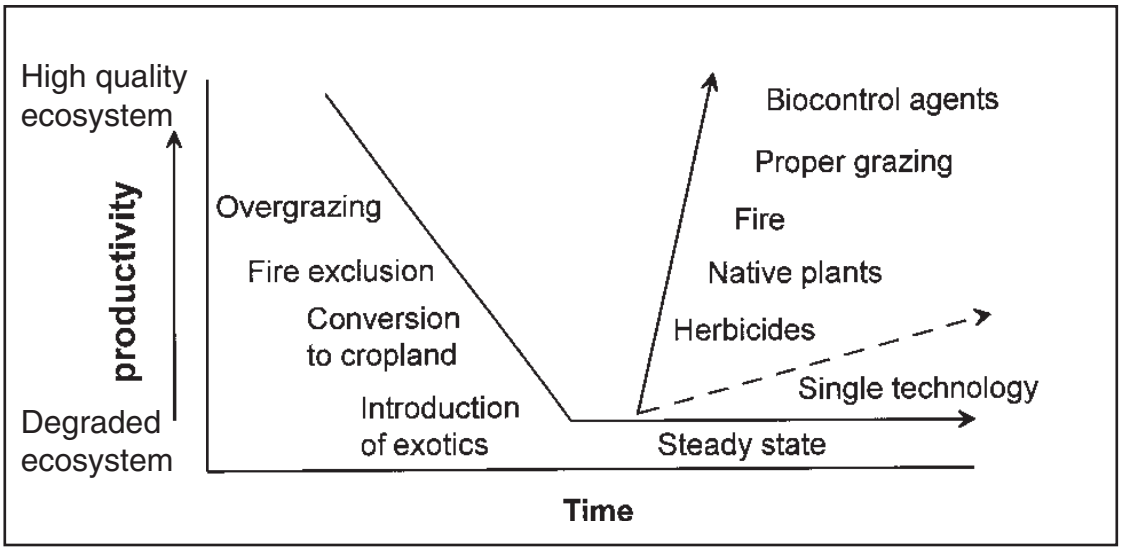

Figure 7. Restoration model.

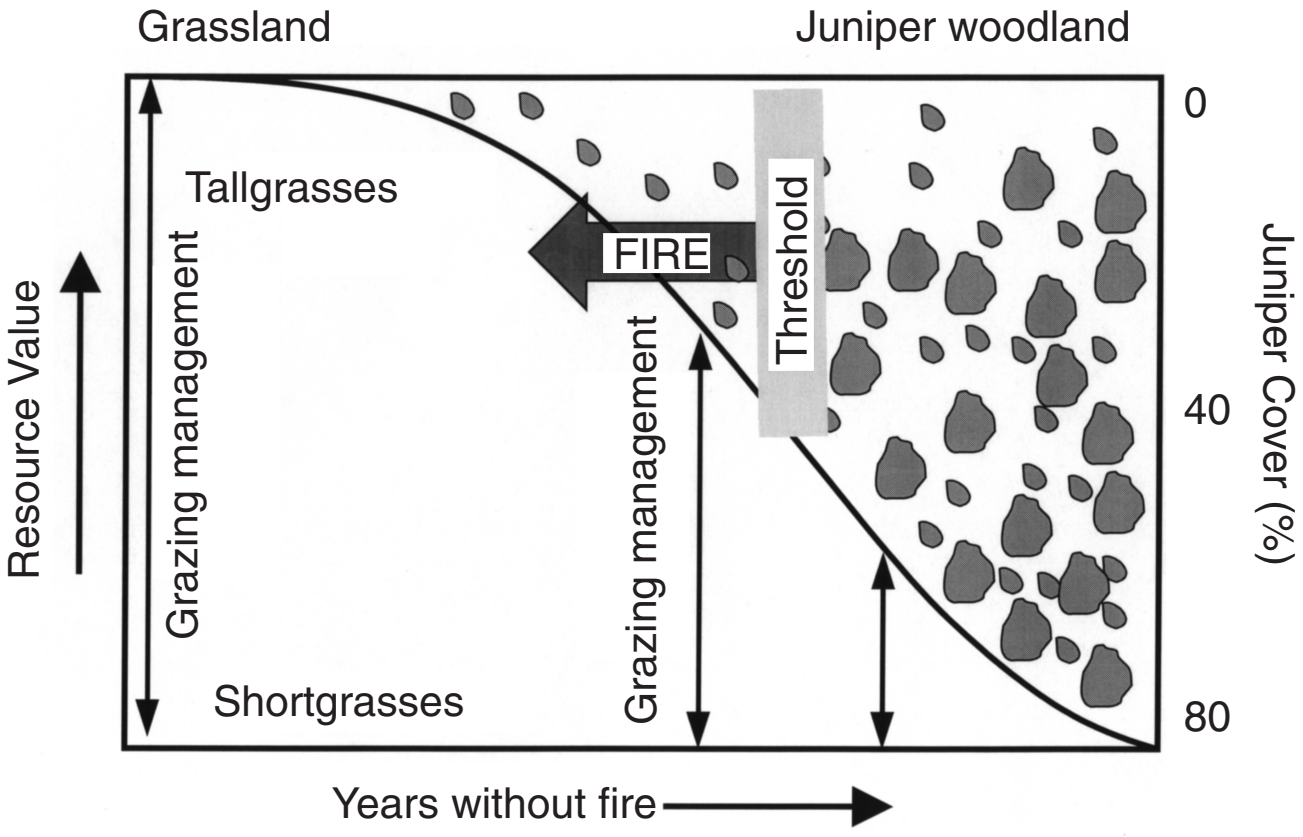

Figure 8. Threshold model for restoration. Grazing management is reduced in effectiveness as juniper cover increases. At low levels of juniper cover, restoration to a grassland is possible using prescribed fire. As juniper cover increases, a threshold is reached beyond which most prescribed fire is effective for ecosystem restoration. Mechanical control or use of a heli-torch (aerial application of fire) will be needed.

Appendix A. Total area (acres) of eastern redcedar or ashe juniper and area (acres) of control treatments in the previous year in Oklahoma's 77 counties in 1994.

County	Total land area	Land with problem cedar		Area treated to control juniper			
		Rangeland	Forestland	Prescribed fire	Mechanical	Herbicide	Manual
Adair	364,000	0	0	0	0	0	0
Alfalfa	557,510	25,000	500	1,000	1,500	200	100
Atoka	628,940	2,500	2,500	250	500	0	0
Beaver	1,129,680	2,000	0	0	0	0	0
Beckham	574,420	2,000	500	300	0	0	0
Blaine	582,210	237,700	0	5,000	1,000	100	1,000
Bryan	568,960	3,000	3,000	500	100	100	100
Caddo	807,950	112,300	3,000	2,300	660	0	165
Canadian	563,080	23,000	8,600	1,150	460	300	2,150
Carter	531,200	47,520	15,840	4,000	160	0	10
Cherokee	483,840	0	0	0	0	0	0
Choctaw	484,670	31,700	5,500	1,200	0	2,500	500
Cimarron	1,166,770	0	0	0	0	0	0
Cleveland	339,930	117,200	78,075	0	0	0	5
Coal	335,900	19,500	0	1,500	0	0	0
Comanche	693,760	140,400	1,000	4,000	600	0	0
Cotton	406,190	240	0	0	0	0	0
Craig	488,820	500	0	0	0	0	0
Creek	614,370	2,000	0	100	100	100	100
Custer	631,100	41,000	0	500	400	0	200
Delaware	452,480	0	0	0	0	0	0
Dewey	621,200	367,861	0	12,000	2,000	0	0
Ellis	781,700	85,000	0	15,000	750	500	50
Garfield	674,310	50,000	0	5,000	600	0	100
Garvin	520,320	6,900	1,800	0	0	0	0
Grady	700,300	5,000	300	0	300	80	50
Grant	644,420	8,000	5,000	1,000	200	0	0
Greer	404,980	7,800	0	200	0	500	0
Harmon	339,110	0	0	0	0	0	0
Harper	656,980	30,000	0	500	0	0	0
Haskell	364,760	15,000	15,000	1,000	5,000	0	200
Hughes	514,580	3,000	0	500	700	0	0
Jackson	492,730	1,700	0	0	0	0	0
Jefferson	482,360	4,000	200	0	0	100	200
Johnston	411,960	356,655	19,373	3,000	600	0	100
Kay	588,360	20,000	25,000	100	0	0	0
Kingfisher	570,420	57,000	0	0	50	1,000	3,000
Kiowa	653,660	0	0	0	0	0	0
Latimer	471,040	67,300	257,878	1,500	500	0	15
LeFlore	1,004,270	13,000	3,000	1,200	500	0	50
Lincoln	612,430	200,000	75,000	200	100	0	400
Logan	472,780	187,800	55,600	200	150	50	50
Love	308,160	15,000	34,000	2,500	100	150	50
Major	607,760	100,000	0	1,000	200	0	0

Appendix A. (continued)

County	Total land area	Land with problem cedar		Area treated to control juniper			
		Rangeland	Forestland	Prescribed fire	Mechanical	Herbicide	Manual
Marshall	228,530	135,000	200	400	200	50	50
Mayes	425,510	500	50,000	0	0	0	0
McClain	360,190	50,000	0	1,000	500	0	500
McCurtain	1,172,410	3,000	650,000	200	2,000	80	80
McIntosh	415,840	153,152	29,131	500	0	100	80
Murray	270,350	75,000	25,000	500	250	100	500
Muskogee	519,380	0	0	0	0	0	0
Noble	472,550	88,320	0	1,600	1,200	10	100
Nowata	359,790	3,000	1,000	100	0	0	0
Okfuskee	399,460	148,677	89,366	3,200	1,500	500	500
Oklahoma	448,000	110,000	10,300	0	0	0	0
Okmulgee	446,940	2,500	90,000	1,000	0	0	5,000
Osage	1,444,570	150,000	0	550,000	1,000	2,752	100
Ottawa	296,960	150	100	0	0	0	0
Pawnee	363,100	175,000	0	2,500	0	0	400
Payne	444,160	200,000	35,000	2,000	10,000	0	1,000
Pittsburg	831,090	202,880	0	900	70	70	0
Pontotoc	455,760	45,000	0	3,000	750	500	250
Pottawatomie	507,770	5,998	3,488	2,939	0	0	750
Pushmataha	906,505	75,000	110,240	200	0	0	100
Roger Mills	716,835	4,560	0	0	0	0	0
Rogers	438,400	52	11	0	0	0	0
Seminole	400,170	5,280	3,120	2,950	0	0	800
Sequoyah	432,450	15,000	118,250	25	205	170	25
Stephens	567,840	10,000	0	1,000	0	0	200
Texas	1,304,660	0	0	0	0	0	0
Tillman	560,890	0	0	0	0	0	0
Tulsa	366,460	0	0	0	0	0	0
Wagoner	360,320	0	0	0	0	0	0
Washington	271,360	7,500	0	2,000	200	0	100
Washita	644,830	4,000	0	60	0	0	0
Woods	826,566	96,000	0	500	200	0	20
Woodward	798,160	330,000	0	3,000	5,000	0	0
TOTAL	43,762,176	4,504,145	1,825,872	646,274	40,305	10,012	19,150

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