United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
CO 80526

**General Technical
Report RM-258**

Desired Future Conditions for Piñon-Juniper Ecosystems

**August 8-12, 1994
Flagstaff, Arizona**

Shaw, Douglas W.; Aldon, Earl F.; LoSapio, Carol, tech. coords. 1995. Desired Future Conditions for Piñon-Juniper Ecosystems; proceedings of the symposium; 1994 August 8-12; Flagstaff, Arizona. Gen. Tech. Rep. RM-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 226 p.

Abstract

The purpose of this symposium was to assist the USDA Forest Service, other federal land management agencies, and the Arizona State Land Office in managing piñon-juniper ecosystems in the Southwest. Authors assessed the current state of knowledge about the piñon-juniper resource and helped develop desired future conditions.

USDA Forest Service
General Technical Report RM-258

February 1995

Desired Future Conditions for Piñon-Juniper Ecosystems

August 8-12, 1994
Flagstaff, Arizona

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Welcoming and Opening Remarks

Jose Salinas[1] and Chip Cartwright[2]

Jose Salinas...

Good Morning! I am pleased to join the rest of the speakers this morning in welcoming each of you to this week's 1994 Piñon-Juniper Symposium—Desired Future Conditions for Piñon-Juniper Ecosystems.

I, too, want to thank our co-sponsors:

- Northern Arizona University
- University of Arizona
- Bureau of Indian Affairs, Phoenix Area Office
- Society of American Foresters

Equally important, I want to thank Doug Shaw and the Steering Committee that coordinated this symposium. Doug has been coordinating the P-J Initiative for a little over two years.

I want to thank the other agency coordinators also.

There are always behind-the-scene players that are part of a successful program. I want to recognize my Regional office watershed staff:

- Penny Luehring
- Debby Potter
- Chic Spann
- Wayne Robbie
- Penny Fabian
- Barney Lyons

And two staff people who helped with symposium but stayed in Albuquerque to keep the office in operation—Gena Velasquez and Theresa Sanchez.

A key partner and supporter in the P-J watershed restoration program is Gerald Henke, Regional Director for Range Management.

Of course, we are very pleased to have our Regional Forester, Chip Cartwright, with us this morning. Chip will be properly introduced in a moment.

I also want to thank the Coconino National Forest for hosting us as well as for hosting our field trip.

I understand more than 200 people signed up for this symposium. I think this in itself is a success and we have not even begun!

We have people representing several Regions. Our presenters include research, Forest Service managers, program leaders, people with specific expertise, academia, members of other agencies, people representing tribal governments, members of the ranching community, and private industry. And the list goes on and on.

The agenda consists of scientific papers, papers on human and social relationship within the P-J ecosystem. We also have a series of presentations of on going projects. Plus, we have several posters on display and a couple of videos on P-J.

Based on the information I have shared with you, I think all of you will agree with me that the title of the symposium—Desired Future Conditions for Piñon-Juniper Ecosystems—is very appropriate.

So why are we all here this week? For one thing, not all is well with our P-J woodland ecosystems. There are over 7 million acres of P-J on national lands in the Southwestern Region alone. But the real concern is that nearly 50% of this land base represents watersheds in unsatisfactory condition. This condition is not unique to this region nor to the Forest Service. For the same condition exists on other federal lands, Indian land and private lands. This condition also extend to all the states surrounding us, including Mexico.

Our P-J ecosystem was never in this type of condition—in other words, these unsatisfactory conditions are not natural. We, man, through our past management practices, have created unbalance among the components of the ecosystem—the biological, the physical and the human aspects. We can no longer continue to contribute to the problem. We must work together—the research scientist, the land manager and the user—be state, federal or private, we must work together in seeking solutions. This may include joint projects under partnership or it could mean technology transfer. It may include changing present land management practices. It will mean being more responsive to the needs of the land and the people who are part of that ecosystem.

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Definitely, a scientific-based ecosystem management program is the appropriate approach.

Deteriorating watersheds are not a problem that belongs to the project leader in a remote Ranger District. It is your problem. It is my problem. It is a social and economic problem. It is our problem—yours and mine together.

I am proud to announce that the Southwestern Region has increased its funding for watershed restoration work in the last two years by more than 38%. I am proud to announce that every Forest in the Region has a P-J demonstration project. And I am proud to announce nearly all of the 69 Ranger Districts in the Region have identified some kind of watershed restoration demonstration project. There has been a tremendous amount of commitment by our field personnel and our partners. Our management practices are being reassessed to be in balance with the watershed capability. We are making better use of our soil inventory data as well as research data. We are all doing a good job—but we must do better if we are to get in front of the many pressures, problems and issues facing our P-J ecosystems.

When it is all done, water quality and soil productivity will be the determining factors to the health and well being of our nation or any nation. We have a lot at stake if we are to remain a strong nation and one of leadership and balance between people and the environment.

If I could have only one outcome from this symposium, it would be that our partnerships in P-J watershed restoration would increase in number and strength. These partnerships could be based on technology transfer, research, joint projects, and promotion of ecosystem management principles.

In summary, I encourage each of you to participate in symposium as much as possible. And to have an enjoyable and productive week. Thank you.

* * * * * *

Chip Cartwright...

Welcome to this 1994 symposium on Piñon-Juniper management. I'm glad you are here to share information about these important southwestern ecosystems. Being new to the Southwestern Region, I'm glad to be here to learn a little about how we are implementing ecosystem management principles in the Piñon-Juniper. I want to stress a few points about ecosystem management in these brief opening comments. First ecosystem management as we know it is adaptive to changes in our knowledge about the system. Second humans and their interactions with the other ecosystem components are part of ecosystem management, and we are stressing involvement of all stakeholders in management. Third, ecosystem management is based on sound science, and forth ecosystem management must involve strong partnerships.

The Piñon-Juniper is vast; it stretches in some form from west Texas to the Santa Ynez Mountains of Southern California and from Oregon deep into Mexico. The story of these woodlands extends back through historic, prehistoric, and geologic time. The history of the Piñon-Juniper is a documentation of humanities' changing relationship with its environment. It starts with a relationship in which human fate was determined by the bounty of its un-manipulated environment, and extends through relationships in which people dramatically modify their environment to meet the needs and wants of growing populations.

The purpose of this symposium is to share information that will be useful in directing human relationships with this ecosystem in the future. Our goal for this relationship should be ecosystem sustainability. We understand no ecosystem is a simple thing, but P-J, with so many links to people and cultures, is particularly complicated. Ron Lanner describes this complexity well in the introduction to his book on the Piñon Pine, "Every tree, like every other living organism, is at the center of its own four-dimensional spider web: tug on this strand or that and see what quivers, what falls, what comes in or goes out, what lives or dies, what grows fat-and when."

Much has been said in the last decade or so about managing Piñon-Juniper. Bill Hurst, Regional Forester from 1966-1976, said there were more symposiums about-but less done about—P-J, than on any other species he could remember. Why do we continue to talk a lot and act little? Perhaps it is because we don't understand or take seriously the importance of this ecosystem to current human needs and past and current human beliefs and perceptions. Or perhaps we cannot reach a common agreement on how to manage an ecosystem that is so highly variable and has so many ties to so many different cultures.

Societal values and perspectives about the environment change and evolve continuously. The human domination era, of most western societies, was replaced early in the 20th century by the conservation and multiple-use era. Some societal values and perceptions are shifting again, as we enter the 21st century. In response to this shift the Forest Service is looking more holistically at natural systems as systems that integrate biological, physical, and human dimensions. We have a heightened concern for the long term sustainability of systems, not just the multiple-uses that can be realized from these systems. This evolving approach to land stewardship is frequently referred to as "ecosystem management".

Along with the evolution of attitudes about ecosystem management is an increased sensitivity to the importance of stakeholders in the management of public lands.

The Region recently completed work to help us define principles for ecosystem management. A human dimension study group is publishing a short document containing eight human dimension principles for ecosystem management. A scientific study team recently published a document titled, "An Ecological Basis for Ecosystem Management" which contains six guiding principles for ecosystem management.

Both documents have the following common principle, "Humans are an integral part of today's ecosystems and depend on natural ecosystems for survival and welfare; ecosystems must be sustained for the long-term well-being of humans and other forms of life". In the past, our efforts to assess the physical/biological aspects of ecosystems have been separate from our efforts to assess the human dimension aspects of ecosystems. We are working hard to understand how these two aspects can be integrated.

According to Eugene Odum, "Ecology is the study of the structure and function of nature, it being understood that mankind is part of nature". The culture, family heritage, lifestyles and livelyhoods of people are linked with the ecosystems of which they are a part. Peoples past, present, and future values and desires influence ecosystems. Ecosystems affect people's physical, mental, spiritual, social, cultural, and economic well-being. Understanding these relationships establishes a basis from which integrated ecosystem management can contribute to sustaining human life as well as healthy ecosystems.

As I mentioned earlier we are becoming much more sensitive to the needs of stakeholders in our efforts to implement ecosystem management. How do we integrate the needs of such a diverse spectrum of people into an ecological approach to Piñon-juniper management. Some people consider the P-J "public enemy number one", while others consider the P-J as "our very life! They are part of us." Still others have a long tradition of using P-J for daily needs such as cooking and heating.

We also have the needs of the biological part of this system to understand, how much can we harvest with out adversely affecting the needs of the Piñon jay? And the physical part must be integrated. How do we protect or restore soil productivity, a basic consideration to all other needs?

We must look to the people for answers to these and many other questions. We know people want to be involved, but we also know people must be sensitive and knowledgeable to be effectively involved. It is a basic human dimension principle that sustainable ecosystem management requires an ecologically knowledgeable population.

We also look to scientists for answers. Scientific information helps us better understand the range of choices for actions and the consequences of following one path instead of another. Scientists can provide the citizen-manager partnership with some of the information required to make informed decisions. Research will assist in better understanding ecosystem functions and inter-relationships and all scales and times. Research will also assist in better understanding stakeholders and the values and motives that drive their behavior. We must seek a more complete understanding of the social and cultural dimensions of ecosystems, including the changing perceptions, needs, and values of people.

Adaptive management is a term currently used to describe an evolving management strategy for ecosystems. In such a strategy ecosystems like the P-J and related ecosystems will be managed according to a working hypothesis which continues to change and adapt to new information and experience. To make this management strategy effective we must monitor and evaluate management to see if we are achieving the desired results and if the results we originally desired are still desired.

The P-J is vast and the problems are wide spread in the Southwest. We have goals for the National Forest part of P-J that include maintaining or improving soil productivity, meeting water quality standards, maintaining or improving visual and biological diversity, protecting habitat needs for threatened and endangered species, and historic and prehistoric cultural values. But our goal also includes management that is sensitive to lifestyles as well as ecosystem needs. But the P-J involves more than just National Forest. All the stakeholders in this vast system must join in partnerships to describe and move toward shares visions and goals. We are actively seeking such partnerships. We have a partnership with two great universities, a professional society, and another agency to organize this symposium. But our partnerships must expand to include others that have entirely different visions for the P-J. Our partnerships must change to collaborative partnerships with shared visions and also shared responsibilities for bring those visions into realization.

I hope this symposium is successful in sharing the latest in scientific information. I also hope this symposium is successful in bring together stakeholders in a way that will lead to partnerships and most important sustainable ecosystem management in the P-J.

Western Juniper Woodlands: 100 Years of Plant Succession

Rick Miller[1], Jeffrey Rose[2], Tony Svejcar[3], Jon Bates[4], and Kara Paintner[2]

Abstract.—During the past 100 years there have been dramatic increases in western juniper (*Juniperus occidentalis* spp. *occidentalis*) in the western U.S. Evidence for the increase come from descriptions of explorers and early settlers, old photographs, ring counts of existing trees, and pollen cores taken from pond sediments. A number of factors may have contributed to the western juniper expansion. Most probable among the contributing factors are: 1) reduction or removal of Native American populations that actively used fire as a vegetation management tool; 2) removal of fine fuels, and thus a decline in fire frequency as a result of heavy livestock grazing between 1880 and 1930; and 3) mild temperatures and above average precipitation during the late 1880s and early 1900s. Because young juniper (<50 yr. old) do not survive fires, most factors causing a reduction in fire frequency will tend to favor western juniper.

INTRODUCTION

One of the most pronounced changes in plant community dynamics in the western U.S. has occurred in the juniper and piñon-juniper woodlands, a major vegetation type characterizing the Intermountain Region. These woodlands, sometimes described as pygmy forests, currently occupy 17 million ha throughout this region (West 1988). *Juniperus occidentalis* ssp. *occidentalis* Hook. (western juniper) is considered the Northwest representative of the piñon-juniper zone in the Intermountain Region (Franklin and Dyrness 1973) and occupies over 1 million ha (Dealy et al. 1978) in eastern Oregon, southwestern Idaho and northeastern California (Cronquist et al. 1972). This subspecies of *J. occidentalis* is found primarily north of the polar front gradient (Neilson 1987) (parallel to the Oregon and Nevada border, Latitude 42°) where temperatures are cooler, summer precipitation decreases, and winter precipitation increases (Mitchell 1976).

Relict juniper woodlands, tree-age class ratios and historical documents generally indicate western juniper woodlands, prior to Euro-American settlement, were open, sparse and savannah-like (Burkhardt and Tisdale 1969, Vasek and Thorne 1977, Miller and Rose 1994, EOARC data files). In southeast Oregon and northeast California, where soils are primarily derived from igneous material, the majority of old trees established prior to settlement are located on the shallow soil low sagebrush flats and rocky ridges where fine fuels were insufficient to carry a fire (Vasek and Thorne 1977, EOARC data file). Densities of presettlement trees on these harsh sites generally ranged from 8 to 20 per ha (EOARC data file). Old growth stands in the ash-pumice zone of Mt. Mazama and Newberry Crater in central Oregon are more extensive (personal observation by authors). During the last 100 years, western juniper has increased both in distribution and density throughout its range. Expansion has been most dramatic in the deeper more productive

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soils of open meadows grasslands, sagebrush steppe communities, aspen groves, and riparian communities (Eddleman 1987, Miller and Rose 1994, Miller and Wigand 1994, Young and Evans 1981).

In central Oregon in 1825, Ogden observed only occasional junipers (reported as cedars) growing on the hillsides, while traveling through the Crooked River drainage in central Oregon (Rich et al. 1950). Today, these hillsides are covered by dense juniper woodlands. In a nearby area, J.W. Meldrum's 1870 survey notes describe a gently rolling landscape covered with an abundance of perennial bunchgrasses and a wide scattering of juniper trees (Caraher 1977). Today, juniper densities on this site vary between 125 and 250/ha. Near Silver Lake Oregon, juniper density increased from 17/ha in 1890 to over 400/ha by 1970 (Adams 1975). The majority of trees established between 1902 and 1936. On another site in central Oregon where junipers were absent prior to 1880, densities reached 1018/ha by 1980 (Eddleman 1987). David Griffiths, a representative from the Department of Agriculture, was sent to tour and evaluate the condition of the western rangelands around the turn of the century. He observed only scattered stands of juniper on Steens Mountain in southeastern Oregon (Griffiths 1902).

Western juniper began increasing in both density and distribution in the late 1800s in central and southeastern Oregon, northeast California, and southwest Idaho (Eddleman 1987, Miller and Rose 1994, Young and Evans 1981). In much of central Oregon and portions of northeastern California, peak establishment occurred between 1890 and 1930. In southeastern Oregon, juniper expansion began in the 1880s, however, establishment progressed slowly during the early 1900s; the rate increased later into the century as trees reached reproductive maturity (Eddleman 1984, Miller and Rose 1994). Current densities of trees less than 100 years old on the more productive low sagebrush and mountain big sagebrush communities on Steens Mountain average 338/ha (Miller and Rose 1994). In stands where juniper has invaded and completely replaced aspen trees on Steens Mountain, densities of mature juniper trees ranged from 725 to over 2,000/ha (Miller and Rose 1994). The oldest juniper trees in these stands were less than 90 years old. Although western juniper is a long-lived species, the oldest tree reported in Oregon is 886 years old (Holmes et al. 1986). The majority of present day woodlands in eastern Oregon are less than 100 years old (USDI-BLM 1990).

Seed dissemination occurs primarily through movement by water across the land surface, particularly on frozen soils (Eddleman 1984), and through bird, coyote and rabbit dispersal (Gabrielson and Jewett 1970). The Townsend solitaire (*Myadestes townsendii*) (Lederer 1977, Poddar and Lederer 1982), the American robin (*Turdus migratorius*), Steller's jay (*Cyanocitta stelleri*) and scrub jay (*Aphelocoma coerulescens*) are primary avian vectors of juniper seed dispersal in the Great Basin (Gabrielson and Jewett 1970).

The factors most frequently associated with the recent expansion of juniper species throughout the west are climate, fire, and grazing. The combined affect of climate and fire were likely the cause of juniper expansion and retraction during prehistoric times (Miller and Wigand 1994), but are climate change and altered fire regimes fully responsible for the expansion of western juniper woodlands during the last 100 years? Following the end of the Little Ice Age in the mid 1800s, winters became more mild and precipitation increased above the current long term average between 1850 to 1916 in the northern Great Basin (Antevs 1938, Graumlich 1985, Holmes et al. 1986). Mild conditions and increased precipitation during the late 1800s and early 1900s, which promotes vigorous juniper growth (Earle and Fritts 1986, Fritts and Xiangdig 1986), increased the potential for juniper establishment. In central Oregon, juniper establishment primarily occurs during years of good tree ring growth, with few trees establishing in years of marginal tree ring growth (Adams 1975). However, these conditions would also have increased the potential for fire due to the increased production of fine fuels; grasses and forbs.

Reduced fire frequency has been one of the factors attributed to the expansion of juniper throughout the west (Burkhardt and Tisdale 1976, Young and Evans 1981). Before settlement, fire frequencies in mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*) communities varied from 15 to 25 years (Burkhardt and Tisdale 1976, Martin and Johnson 1979, Houston 1982). Western juniper less than 40 to 50 years old are easily killed by fire (Burkhardt and Tisdale 1976). Fire probably maintained both shrubs and trees at low densities and often restricted trees to the harsh sites which produced little contiguous fuel.

Reduction of fire frequencies during settlement was probably due to a decline in Native American-set fires and the reduction of fine fuels through livestock grazing. The effects of fire suppression during the late 1800s and early part of this century were minimal, not becoming a factor until after WWII. Native American-caused fires augmented lightning fires in the more mesic sagebrush communities (Agee 1993). Fire was used to improve forage for game, maintain or increase the yield of certain wild edible plants and increase seed production. However, the influence of Native Americans declined as early as the late 1700s. By the close of the eighteenth century, native populations throughout the Intermountain Region were reduced 80 percent by European diseases such as smallpox, measles, venereal disease and possibly typhus (Thompson 1916, Cressman 1981). Despite their decline in population, Peter Skene Ogden noted abundant evidence of Native American set-fires in the Harney and Malheur lakes region during the middle 1820s.

Settlement of the region by European Americans in the late 1800s and early 1900s, lead to a reduction of fine fuels through grazing high densities of domestic livestock (Griffiths 1902, Burkhardt and Tisdale 1976). Possibly the greatest influence livestock had on the expansion of juniper throughout the West was the reduction of fine fuels resulting in a decrease in fire return intervals. In 1901, on his trip from Nevada to eastern Oregon, Griffiths (1902) stated; "No open-range lowland was seen on the whole trip which had much feed upon it excepting that consisting of the tough and persistent salt grass. On the whole trip of three days we found no good feed, except in very steep ravines." Removal of fine fuels was probably of particular importance during the wet and mild climate conditions of the late 1800s and early 1900s initiating the development of western juniper woodlands.

Competition appears not to be a factor inhibiting western juniper seedling establishment (Burkhardt and Tisdale 1976, Eddleman 1987, Miller and Rose 1994). Ecological condition of a plant community does not appear to influence seedling establishment. However, an increase in sagebrush would increase the number of safe sites for juniper seedling establishment. The majority of juniper seedlings are usually found beneath sagebrush canopies (Burkhardt and Tisdale 1976, Eddleman 1984, Miller and Rose 1994).

A more recent argument attributes the expansion of piñon-juniper woodlands in the southwest to increased atmospheric CO_2 concentrations (Johnson et al. 1990). Bazzaz et al. (1985) reported cool season (C_3) plants respond more favorably to increased CO_2 levels than do warm season (C_4) plants. In the southwest, increased atmospheric CO_2 may increase growth of C_3 junipers at the expense of associated C_4 grasses in the understory. In the northern portions of the juniper zone (e.g., western juniper) understory species are also C_3 forbs and grasses. However, water use efficiency has been shown to be enhanced more in woody than in herbaceous cool season plants (Polley et al. 1993).

CONCLUSION

Since the turn of the century western juniper has rapidly increased in distribution and density. Although western juniper has fluctuated during the prehistoric past, several factors appear to be different between past and present expansion (Miller and Wigand 1994). The present expansion differs from past increases, in that it has occurred during a period of increasing aridity. In the past, increasing aridity generally increased the fire frequencies and caused a decline in western juniper dominance. During the past 70 years aridity has increased, but human activities have greatly reduced fire frequencies.

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Soil Loss in Piñon-Juniper Ecosystems and Its Influence on Site Productivity and Desired Future Condition

Malchus B. Baker Jr.[1], Leonard F. DeBano[2], and Peter F. Ffolliott[3]

Abstract.—Piñon-juniper woodlands are widespread throughout the western United States and have provided habitat and a variety of products for human use in recent and historical times. Site productivity of piñon-juniper woodlands depends on a wide range of complex processes which dynamically interact over various time and space scales. The hydrology of piñon-juniper ecosystems is relatively complex, because it is controlled by interactions among precipitation regimes, geomorphological settings, and edaphic conditions. Superimposed on the natural system is a wide spectrum of past land uses, and misuses. The present and past hydrologic environment has also been characterized by extreme spatial and temporal variation. Water and wind erosion are primary processes that influence site productivity. In this paper, a limited amount of experimental data on water and wind erosion is presented for southwestern piñon-juniper woodlands. A conceptual model is presented for describing water and wind erosion and is used to illustrate their dependency on mean annual precipitation for vegetated and disturbed (bared) sites. This model emphasizes the importance of plant cover density on soil loss and subsequent site productivity. Soil loss is a crucial factor affecting productivity because nutrient enriched materials are lost from the site during water and wind erosion. Decreases in site productivity resulting from soil loss make it more difficult to attain ecological goals necessary for achieving different desired future conditions. It is imperative, therefore, that management practices implemented on piñon-juniper woodlands minimize soil losses and associated reductions in site productivity.

INTRODUCTION

piñon-juniper woodlands, similar to those found throughout the Southwest, are one of the most extensive vegetative type in the western United States (Evans 1988). These woodlands provide a wide range of valuable products and benefits such as fuelwood, fence posts, Christmas trees, piñon nuts, forage for livestock grazing, and critical habitat for a large number of game and nongame animals, including some rare and endangered species. Some products produced in these woodlands (e.g. piñon nuts and firewood) have played a significant role in sustaining past human occupancy and cultures, as well as providing useful products to present day society.

Site productivity of piñon-juniper woodlands depends on a wide range of complex processes which interact dynamically over time and space. Although site productivity can be viewed simply as the capacity of a soil to support plant growth (Powers 1991), this concept encompasses several

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complicating factors, including the effects of soil erosion. Because soil erosion historically was a common occurrence in piñon-juniper woodlands (both naturally and in response to human activities), it is important to understand how these losses may affect site productivity and, ultimately, the overall sustainability of these woodlands. Equally important are the effects that changes in site productivity may have on the desired future condition (both physio-biological and socio-economic dimensions) of these woodlands. The objectives of this paper are to: (1) present a conceptual framework for describing erosion processes; (2) discuss the impacts of soil losses on site productivity; and (3) to relate erosion and site productivity information to expected changes in the desired future condition of southwestern piñon-juniper woodlands.

CHARACTERISTICS OF PIÑON-JUNIPER WOODLANDS

Physical and Biological Environment

Piñon-juniper woodlands in the Southwest are found on foothills, low mountains, mesas, and plateaus between 1,300 and 2,200 meters elevation (Brown 1982, Clary et al. 1974, Gottfried 1992). These woodland communities occupy elevations between the more xeric lower elevation brush and grass-dominated vegetation types and more mesic higher elevation montane forests. Piñon pine tends to become dominate at higher elevations, whereas, junipers are more common at the lower elevations. The distributions of piñon-juniper woodlands reflect ecological amplitude and responsiveness to available soil water and temperature regimes, rather than to any general topographic relationship.

The stand structure of piñon-juniper woodlands is relatively simple. In general, undisturbed stands are uneven-aged. Piñon tends to dominate the smaller size classes in these stands, while junipers are the major component of the larger size classes. Even-aged stands frequently develop as a result of fire and tree removal operations. The piñon-juniper ecosystems, however, have very heterogeneous overstory-understory relationships. Moir and Carleton (1987) recognized over 70 habitat types in Arizona and New Mexico piñon-juniper woodlands.

Piñon-juniper woodlands are found on a variety of soils that are derived from diverse parent materials including intrusive and extrusive igneous rocks, sedimentary rocks, and mixed alluvium (Springfield 1976). Soil depths vary from shallow to moderately deep, and soil textures range from coarse, rocky, and porous sandy loams to fine compacted clays. Fertility levels of the soils are generally low to moderate.

Hydrologic Environment

The hydrology of piñon-juniper ecosystems is complex, because it reflects a wide range of interactions among precipitation regimes, geomorphological settings, and edaphic conditions. It is further complicated by a wide spectrum of past land uses, and misuse. Hydrologic scenarios vary from a desirable combination of low-intensity rainstorms, good vegetative cover, and permeable soils, to a potentially hazardous situation on areas with steep slopes, sparse vegetative cover, and impermeable soils that are often subjected to high-intensity rainstorms. A heterogeneous vegetative cover makes it difficult to generalize watershed characteristics and potential hydrologic functioning; and variations in soils, with their different infiltration rates, further complicate the hydrology.

Climatic variability has also been a key factor affecting past and current community dynamics in piñon-juniper woodlands (Betancourt et al. 1993). Paleoecological data collected on a wide range of sites throughout the Southwest suggest that droughts have been a common and regular occurrence during the last 40,000 years. Measured precipitation in piñon-juniper woodlands range from 300 to 440 mm, with local areas receiving 500 mm, or more (Hibbert, 1979). Summer convective storms can account for over half of the total annual precipitation.

Erosion and Soil Loss

Soil losses by both water and wind erosion are an integral part of piñon-juniper ecosystems because precipitation required for a dense protective vegetative cover is marginal. This delicate balance between erosional processes and the conditions required for an acceptable vegetative cover make these ecosystems particularly sensitive to both natural disturbances and improper land use practices. Imbalance can reduce vegetative cover and accelerate soil loss. Because a well maintained plant cover reduces soil losses, it is a cornerstone of land management activities.

Most storms cause little or no overland flow from sites having good ground cover, gentle slopes, and permeable soils (Baker 1986, Clary et al. 1974, Springfield 1976). However, high-intensity, short-duration storms can produce significant runoff events, particularly when they occur on steep slopes having a sparse ground cover and soils with low permeability. Historically, high rates of runoff and sediment have been attributed to overgrazing by livestock, fire, or other past misuse (Evans 1988; Wood and Javed 1992).

Water erosion on piñon-juniper woodlands in the arid Southwest generally can be characterized as an unsteady, or episodic process, that transports sediment from a source area, across a landscape, and through a channel system with intermittent periods of storage (DeBano 1977). Results obtained from studies in the Southwest provide some information on the relative magnitudes of soil losses associated with different management activities. For any site condition, runoff, erosion, and sediment production are related to precipitation events that move intermittently stored material downstream. After 9 years of piñon-juniper watershed studies on basalt-derived soils in central Arizona, the largest sediment yield recorded was 2200 kg/ha from a six-year-old, cabled watershed during an intense rainstorm—estimated recurrence interval of 100 to 150 years (Clary et al. 1974). Based on the knowledge of the influence of treatment intensities, age since treatment, and storm frequencies on sediment losses, it was concluded that maximum potential sediment yields were in the range of 2240 to 4880 kg/ha/year for watersheds with similar physical characteristics and climatic regimes (Clary et al. 1974).

Runoff studies on small plots, using both natural and simulated rainfall, have provided additional information on the amounts of sediment moved during runoff from sites receiving different treatments. Under natural rainfall events, course sediment losses from plots where slash was piled and burned exceeded those of control plots by about four-fold (100 kg/ha from controls compared to over 400 kg/ha on burned slash plots) (Wood and Javed 1992). Loping and scattering slash without burning it had little effect on sediment production. Similarly, sediment concentrations were lower in runoff water from control plots than from those that had been burned. Total sediment yields from dry soil rainfall simulator runs (rainfall simulation on dry soil) on piñon-juniper sites in New Mexico and Arizona ranged from 368 kg/ha (per simulation) on high cover plots to 2211 kg/ha on plots that had been scraped bare (Bolton et al. 1992).

Significant movement of soil by wind can also occur in piñon-juniper woodlands, particularly following prescribed burning of fuelwood slash. Mean sediment amounts collected in samplers located 1 meter above the ground during a summer season (May 15 through October) were as high as 17.9 kg/m^2 (Baker and Jemison 1992). At 0.05 m above the soil surface as much as 1164 kg/m^2 of soil and ash material were collected. These measurements of windborne material represent quantities of sediment caught at points in a vertical profile on the site sampled and not the total amounts that were removed from the site.

A CONCEPTUAL FRAMEWORK FOR SOIL LOSS

A model initially developed by Marshall (1973) and later extended by Heathcote (1983) to describe water and wind erosion can be used to illustrate erosional processes in piñon-juniper woodlands (Figure 1). This model emphasizes the dependency of water and wind erosion on mean annual precipitation for vegetated and bare sites. It also provides a useful framework for discussing the nature of wind and water erosional processes and their controlling factors.

In figure 1, curve labeled $water_{veg}$ represents water erosion under natural vegetation cover—normal erosion (Marshall 1973). Water erosion increases from a low value at the arid extreme of mean annual precipitation to a peak erosion rate in the semi-arid rainfall range (400 mm). Here, rainfall is not great enough to sustain a complete vegetation cover all year, but is sufficient to cause erosion of the bare soil. With additional precipitation, vegetation cover increases and water erosion decreases (Schumm and Harvey 1982). The curve labeled $water_{bar}$ represents water erosion rates in the absence of natural vegetation, e.g. vegetation loss due to overgrazing or burning. Here, erosion continue to increase in excess of normal erosion rates (curve $water_{veg}$) in the humid range. The opportunity for reducing water erosion below the maximum rate (curve

$water_{bar}$) is quite low at the arid and semi-arid end of the scale, but increases markedly at the humid end.

In contrast, normal wind erosion, curve $wind_{veg}$, decreases exponentially as precipitation increases because the presences of even a moderately sparse vegetation cover can reduce the wind force at the soil surface. Wind erosion, in the absence of vegetation (curve $wind_{bar}$), remains at a relatively high level until enough precipitation is available to keep the surface soil moist and reduce wind erosion. The shape of curve $wind_{bar}$ depends upon the amount of rainfall and its distribution. Curve $wind_{bar}$ would fall more steeply if the increasing precipitation is distributed more evenly or if it coincides with the summer months. Conversely, the curve would be less steep if the precipitation is mainly confined to the winter months. Unlike water erosion, the greatest opportunity for reduction of wind erosion occurs in the semi-arid range of annual precipitation—i.e. at the greatest divergence between the two wind erosion curves ($wind_{veg}$ and $wind_{bar}$) or about 200 to 500 mm.

In situations where both wind and water erosion occur under a vegetation cover, there is a compensating effect between the two erosional processes, while under bare soil condition the erosional effects are additive. For example, combined water and wind erosion from vegetated surfaces ($w+w_{veg}$) starts out high because of the high wind erosion potential but decrease rapidly until about 250 mm of mean annual precipitation is reached, and then reaches a secondary peak at about 400 mm of precipitation (Figure 1). With additional increases in precipitation, vegetative cover increases and water erosion decreases. In contrast, on a bare surface, combined rates of wind and water erosion ($w+w_{bar}$) start out at high rates of erosion or sediment yield and remain high at all levels of mean annual precipitation (wind erosion essentially ceases above 950 mm of rainfall).

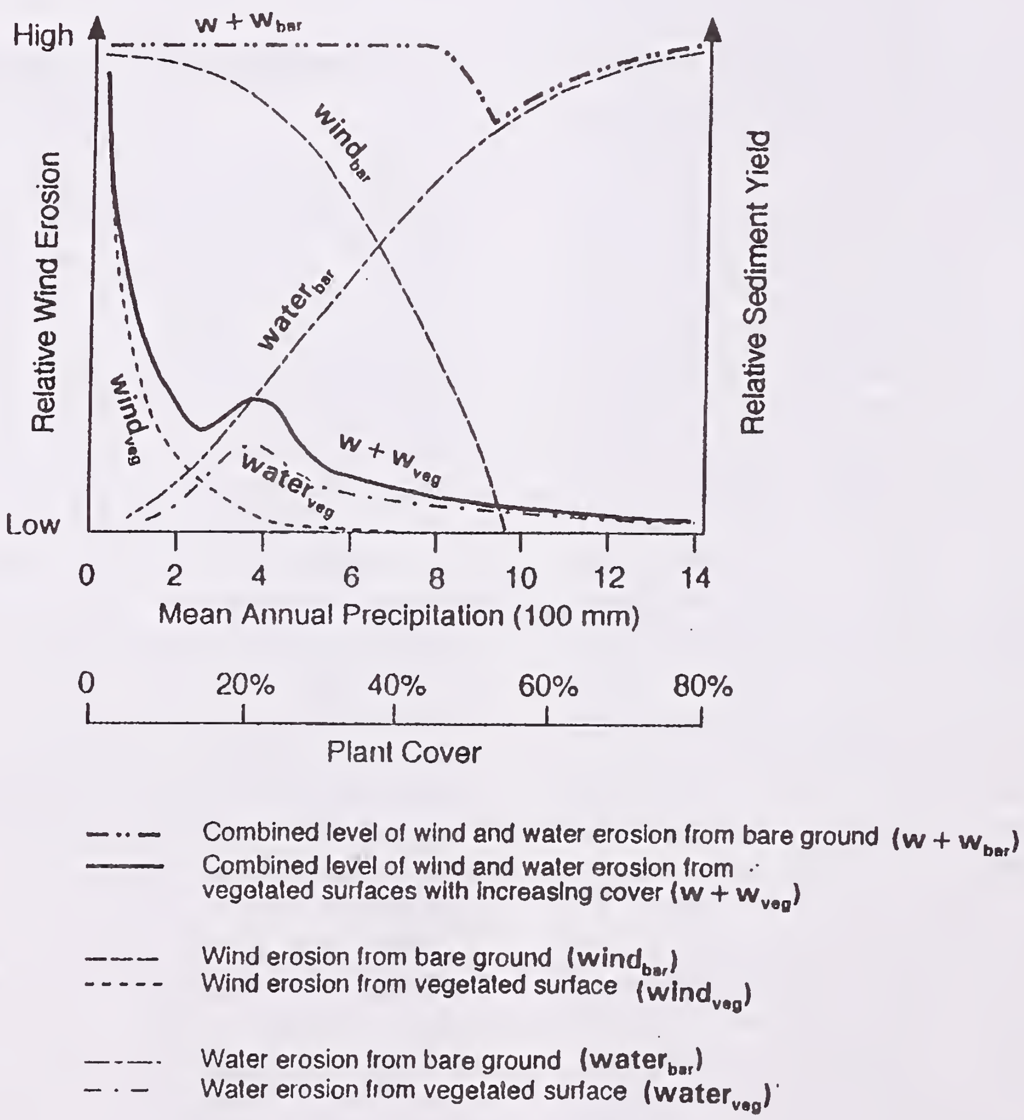

Figure 1.—Conceptual model illustrating relative wind erosion and sediment yield as a function of mean annual precipitation on bare and vegetated surfaces (adapted from Heathcote 1983).

This model clearly illustrates that any management practices or natural occurrences that reduce plant cover (i.e. grazing, tree removal, fire, or drought), substantially increases both water and wind erosion. These effects are additive if a protective plant cover is lacking. It also highlights the importance of wind erosion in the management of piñon-juniper woodlands, an erosional process which has been largely ignored in the past.

OTHER FACTORS AFFECTING EROSION

The model presented in Figure 1 is overly simplistic because it includes only annual precipitation (used as a surrogate for plant cover); consequently other important soil properties and site characteristics are needed to further refine this model. The importance of other factors was recognized when the Soil Loss Equation (USLE) and the Wind Erosion Equation (WEE), two commonly used equations to predict soil loss by water and wind, respectively, were developed.

The USLE predicts annual soil loss caused by rainfall impact and overland flow (Elliot et al. 1991) according to the following relationship:

$$A = RKLSCP$$

where: A = annual soil loss (kg/ha); R = rainfall erosivity; K = soil erodibility; L = slope length; S = slope steepness; C = cover management; and P = supporting practice (conservation). The USLE was developed for agricultural croplands and, therefore, has limited value for predicting soil loss from dissimilar ecosystems. Although the C and P factors have been replaced in the original USLE with a vegetative management (VM) factor (Dissmeyer and Foster 1985), these equations need further validation before being useful for estimating water erosion on piñon-juniper woodlands.

Wind erosion equations; such as in the WEE (Woodruff and Siddoway 1965), consider additional site factors which influence wind erosion:

$$E = f(ICKLV)$$

where: E = annual soil loss (kg/ha); I = soil erodibility index (vulnerability to wind erosion); C = climatic factor; K = soil surface roughness; L = median unsheltered travel distance for wind across a field; and V = vegetative cover.

Although additional information on soil properties and site characteristics would increase the applicability of the model shown in Figure 1 on piñon-juniper woodlands, the inherent spatial and temporal variability in the properties and characteristics throughout these ecosystems will continue to limit the precision of predictive models. However, models do provide a conceptual framework that is useful when considering erosional processes within the context of piñon-juniper management. The framework brings both water and wind erosion into a more balanced perspective and creates an awareness of the importance of wind erosion.

INFLUENCE OF SOIL LOSS ON SITE PRODUCTIVITY

Relating soil loss to decreases in site productivity is not a simple task because productivity depends on recent soil losses and is strongly affected by past uses and erosional history of a site. In order to have a minimum effect on soil productivity, soil losses must not exceed rates of soil formation. Although it is difficult to quantify rates of soil formation, in arid and semiarid environments this process is a very slow (DeBano and Wood 1990). Soils generally contain 80 to 90 percent of the total ecosystem nitrogen and phosphorus (Powers 1991). Not only is the soil a major nutrient reservoir, but nutrients are also concentrated in the litter and humus layers which are vulnerable to wind and water erosion and to management practices that affect the soil surface. Therefore, annual soil losses exceeding a few millimeters can result in disproportionate losses in nutrients that will ultimately cause a reduction in site productivity (Bolton et al. 1991 and DeBano 1991). The capability to reduce accelerated soil loss to assure long-term site productivity is one of the greatest challenges confronting managers of piñon-juniper ecosystems.

Understanding the effects of wind and water erosion on site productivity requires an understanding of how soil loss affects plant growth and the subsequent productivity of plants through time. Unfortunately, these relationships are not well known in many cases. We simply do not have sufficient information about the reduction of site productivity that has resulted from past soil losses in the piñon-juniper woodlands. As pointed out by Dregne (1990), our understanding of the permanent effects of soil loss on site productivity in most natural ecosystems is based largely on anecdotal information. Nevertheless, it appears that serious soil loss has occurred on many piñon-juniper sites in the past and, as a consequence, have resulted in significant and permanent reductions in site productivity. As suggested by Figure 1, these reductions in site productivity are more likely to occur on areas having low densities of plant cover because of increased water and wind erosion.

Quantifying reductions in site productivity resulting from soil loss is further confounded by the inherent variability of rainfall patterns in the piñon-juniper woodlands. Paleoecological studies confirm that both wide spatial and temporal fluctuations occurred in piñon-juniper woodlands in the past (Betancourt et al. 1993). Therefore, the present day growth of trees and shrubs, and the production of forage plants, are undoubtedly sensitive to shifts in rainfall amounts, distributions, and timing. However, reductions of site productivity due to soil loss can also occur simultaneously, but are more subtle and long-term, and, therefore, can easily be confounded with natural rainfall variability.

DESIRED FUTURE CONDITION

The desired future condition for piñon-juniper woodlands in the Southwest has been defined in terms of human-value, economic, and ecological goals (USDA-FS 1993). Human-value goals consider hunting and fishing conditions, recreation experiences, and sustenance activities such as cutting firewood or fence posts, gathering Piñon nuts, or grazing livestock. Ecological goals in any desired future condition must be based on individual site potential (soil, vegetation, and climate) as described in USDA Forest Service Region 3's current ecological classification systems. Ecological goals for piñon-juniper ecosystems can range from grassland, to savanna, to open-canopy Piñon-juniper woodlands, to uneven-aged piñon-juniper forests. Management activities should, therefore, be designed to achieve these ecological goals.

Within the human-value goals, the implementation of management practices must be based on providing a sustainable level of the goods and services that are desired by the public. Therefore, management practices must recognize these ecosystems for their valuable uses, products and benefits, a visually desirable mosaic of landscape elements that maintains a wide range of plant and animal diversity, and the uniqueness of threatened, endangered, and sensitive plant and animal habitats (USDA-FS 1993).

Ecological goals can only be achieved by managing for a healthy productive ecosystem. It is imperative, therefore, that the practices implemented maintain piñon-juniper woodlands in a condition where soil loss and the reduction of site productivity are minimized. An important component of this effort must address intensifying the need for sustaining and improving a protective plant cover. Within this context, however, it is important to recognize inherent variability from soil-to-soil and site-to-site which is caused by interactions among precipitation regimes, geomorphological settings, and edaphic conditions. As a consequence, regional guidelines on the effects of soil loss on site productivity and desired future condition may not be applicable to site specific conditions, but instead require validation on the more important critical areas.

CONCLUDING COMMENTS

Demands on the piñon-juniper ecosystems are expanding and intensifying. New and innovative management practices are needed to respond to these demands in order to maintain and improve productivity. It is also important that investigative efforts continue to quantify the magnitudes of soil loss through the actions of water and wind, and better quantify the effects of soil losses on site productivity and consequent land condition. Failure to recognize changes in site productivity could jeopardize achieving proposed desired future condition.

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Plant Species Composition Patterns with Differences in Tree Dominance on a Southwestern Utah Piñon-Juniper Site

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Abstract.—Fourteen plots covering the range from scattered small trees to full tree dominance were sampled from a single site in southwestern Utah. The rate of reduction in understory cover with increasing tree cover was less than the rate of reduction in total understory leaf biomass with increasing tree leaf biomass. Differences were primarily due to changes that occurred in the crowns of the shrubs. Shrub leaf biomass was rapidly reduced as tree leaf biomass increased, but this initially coincided with minimal loss in shrub crown area or height. Forb leaf biomass initially declined but then increased with increasing tree leaf biomass. A tradeoff occurred between shrubs and forbs at later stages of succession on this site. The grasses were not so affected. Rank by natural logarithm of abundance curves for the plots had several straight lines, reflecting strong dominance by the growing trees. Species interactions within the understory can affect the patterns of understory composition as tree dominance increases.

INTRODUCTION

An historical increase in spatial extent and in tree dominance in piñon and juniper woodlands has been documented throughout the southwest (Everett and Koniak 1981, Tausch et al. 1981, Vaitkus and Eddleman 1991). The result has often been dramatic reductions in the production and diversity of the associated understory communities (Gottfried and Severson 1993, Pieper 1990, West 1984a, 1984b, West et al. 1978). This has often reduced the suitability of the affected sites for many species of wildlife and for livestock grazing (Short and McCulloch 1977, Tausch and Tueller 1977). Associated alteration of the hydrologic regimes has the potential to change nutrient cycling, increase soil loss, and reduce soil productive potential (Gottfried and Severson 1993, Wilcox 1994). The observed increases in tree dominance have been variously attributed to many causes with the most important including livestock grazing, fire control, and climate change, but these influences have received mostly localized study (Evans 1988). Many causes can be involved in the observed changes with the relative importance of differences in plant community data varying with location. An understanding of all aspects of piñon-juniper community ecology is necessary to select the correct areas and tools for successful management (Suminski 1993).

Regardless of the causes behind the widespread increase in tree dominance, the result has led to many past attempts to reverse the trend (Tausch and Tueller 1977, Gottfried and Severson 1993). Past attempts usually have had only limited short-term success and most have had even less, or no, long-term success (Tausch and Tueller 1977, Clary 1989). Clearly, past results show that adequate knowledge of the processes and mechanisms of succession (Evans 1988) and the influences of history and climate (Betancourt et al. 1990) that affect management success in these

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woodlands is lacking. One area where detailed information is lacking is in how increasing tree density affects the competitive dynamics and productivity within the understory communities. This study looked at changes in dominance and diversity within an understory community over a range of tree dominance levels on one site at one point in time (inferred succession in space). We attempted to keep all the factors influencing the understory community, other than changes in tree dominance, as uniform as possible over all sampled plots.

STUDY SITE DESCRIPTION

The site used for this study is on the east flank of Indian Peak in the Needle Range of southwestern Utah, in the lower third of the piñon-juniper belt at the site, and on the upper third of a bajada. It is nearly level (two degree slope to the east-northeast) and at an elevation of about 2000 m (6550 ft). Fourteen plots covering a range of tree dominance from a few seedling trees to total tree dominance were contiguously clustered within an area approximately 150 m by 200 m in size (Tausch and West 1988). This area is within a small burn that occurred about 140 years prior to sampling in 1975. Woodlands were present over the entire site at the time of the fire and current differences in tree dominance appear due to differential rates of seedling establishment from differing distances from seed sources. A small lightning caused fire of about 0.1 ha occurred near the site the year prior to sampling. Such events may have also occurred within the sampled area at other times in the past, contributing to local variation in the timing of tree establishment. Establishment patterns and age-class distributions of the trees by species on this site have been reported elsewhere (Tausch and West 1988).

Soils were very uniform over the entire site with approximately 20 to 22 cm of A horizon topping an Argillic B horizon. A partially cemented C horizon is also present at 28 to 30 cm. Approximately 95 percent of the root biomass was observed to be in the top 25 cm of the soil. The soil has been identified as a Fine-Loamy Mixed Mesic Xerollic Paleargid (Tausch and West 1988). Precipitation for the winter and spring preceding sampling was slightly above normal based on climatic data for the Desert Range Experiment Station located north of the study site (Tausch 1980).

Field Sampling

Sampling was done at, or just after, the peak in plant production on the site. All but one of the 14 macroplots sampled were 20 by 50 m in size and placed with the long axis upslope. The last macroplot was 9 by 22 m in size and was the largest area remaining where the nearest trees, other than seedlings less than 0.5 m tall, were more than their height away from the edge of the plot. This was to sample the understory with as little tree influence as possible. The understory in the 9 by 22 m macroplot was totally sampled using nine transects 1 by 22 meters in size divided into 11, 1 m by 2 m microplots. The understory in the 20 m by 50 m plots was sampled using five randomly located 1 by 20 m transects placed perpendicular to the long axis of the macroplot. Each transect was divided into ten 1 by 2 m microplots for sampling.

Each individual plant of all understory shrub and perennial forb species rooted in each microplot were measured for the longest crown diameter, the crown diameter perpendicular to the longest and foliage height (Ludwig et al. 1975, Tausch 1980, Tausch and Tueller 1990). Foliage height is the height of the crown containing green leaves. Measurements were to the nearest centimeter for shrubs and the nearest millimeter for forbs. When plants had two or more sections to their crowns, each section was individually measured. Basal diameter measurements used for the perennial grasses (all bunch grasses) were to the nearest milimeter and excluded parts that were dead. Foliage height of bunch grasses was determined by raising all the culms to a vertical position and measuring the average height of their leaf-bearing portions to the nearest milimeter. After measurement, the leaf biomass of each individual of each species in the microplots of the 9 by 22 m macroplot was collected.

Annual grasses and forbs were small, only infrequently encountered, and contributed only trace amounts to the macroplot leaf biomass. Crown measurements were not taken and biomass samples were not collected. The percent crown cover of annuals was estimated using an estimation ring representing one percent of the microplot. Their cover, however, rarely exceeded trace levels, even for cheatgrass (*Bromus tectorum*).

Every tree rooted in each of the macroplots was measured by species for the longest crown diameter, the diameter perpendicular to the longest, total height of the living crown, and total tree height (Tausch and Tueller 1990). Measurements were to the nearest centimeter for trees up to two meters tall and to the nearest five centimeters for trees taller than two meters. Tree sampling included a thorough search of each plot for all seedlings present. A trunk crossection was taken from each tree as close to the ground as possible, but above the root crown, and labeled. When a tree had multiple trunks that branched less than 10 cm above the ground, a section was taken from each trunk present. In addition to the general tree sampling in the plots, a random sample of 12 juniper and 16 piñon with mature foliage had their total leaf biomass collected (Tausch 1980). Tree leaf biomass samples were stratified to cover the age-classes present (Blackburn and Tueller 1970). The number of burned snags and stumps in each macroplot was also recorded.

Data Processing and Analysis

The crown diameters of the understory species were used to compute a crown area and this was used to determine percent cover by species in the macroplots. The two crown diameters and the foliage height were used to compute a crown volume by individual and species using the formula for one half of an ellipsoid (Tausch 1980). The leaf material collected from the 9 by 22 m macroplot, and the collected tree leaf material, were oven dried at 50° C for 96 hours and weighed by plant and species. The crown volume and leaf biomass data for the individuals of each understory species were used to compute dimensional equations for predicting leaf biomass from crown volume (Tausch 1989). These equations were used to estimate the leaf biomass by individual and species in the other 13 macroplots using the measured crown volumes (Table 1).

The sapwood and heartwood areas were determined for each tree cross- section collected (Tausch 1980). Regression analysis was used with the 12 juniper and 16 piñon to determine a relationship between sapwood area and leaf biomass each tree species (Tausch and Tueller 1988, 1989, DeRocher and Tausch 1994). Sapwood areas for the trees in each macroplot were converted to estimated leaf-biomass using these equations.

Piñon was removed from the sampled area by the last fire (all but three trees) and accounts for most of the density of tree seedlings established following the fire (Tausch and West 1988). For this reason the pattern of overstory to understory changes over time was approximated by computing a leaf biomass-weighted average age for the piñon of each plot. This weighted age was obtained by multiplying the age of each piñon by its leaf biomass. The sum of these products on each plot was divided by the total piñon leaf biomass. The result is an estimated age for the piñon dominating each plot.

Table 1.—Regression analyses results between leaf biomass (Y) and sapwood area cm^2 (S), crown volume dm^3 (V), and stem length cm (L) for plant species used in the biomass analyses. Formula without an intercept or coefficient of determination value hd too few individuals for a regression analysis. The slope given is the average grams of leaf biomass per dm^3 of crown volume.

Species	Size Range (cm^2)	Regression Formula	r^2
Juniperus osteosperma	770<=S<=5	Y=92.18S1.0934	0.96
	5<S	Y=79.01 + 108.6S	0.94
Pinus Monophylla	0<S<=20	$Y=84.16S^{1.07}$	0.98
	20<S	Y=325.3 + 125.9S	0.97
Artemisia arbuscula	all V	$Y=7.40V^{0.793}$	0.93
Artemisia tridentata wyomingensis	all V	$Y=6.84V^{0.808}$	0.88
Chrysothamnus vicidiflorus	0<V<=8	$Y=2.98V^{0.887}$	0.87
	8<V	Y=8.27 + 1.30V	0.99
Ephedra nevedensis	all V	Y=0 + 3.45V	
Ephedra viridis	all V	Y=0 + 3.39V	
Opuntia rhodantha	all V	Y=0 + 5.81V	
Achnatherum hymenoides	0<V<=0.2	$Y=6.30V^{0.753}$	0.88
	0.2<V	Y=0.254 + 7.75V	0.64
Elymus elymoides	all V	Y=0.0249 + 15.2V	0.83
Hesperos comata	0<V<=0.6	$Y=9.48V^{0.869}$	0.94
	0.6<V	Y=0.225 + 10.27V	0.94
Arabis holboellii	all V	Y=0 + 6.17V	
Astragalus lentiginosus	0<V<=0.05	$Y=2.40V^{0.723}$	0.89
	0.05<V	Y=0.0280 + 4.8658V	0.97
Astragalus purshii	all V	Y=0 + 12.09V	
Astragalus tetrapterus	0<V<=0.05	$Y=2.40V^{0.723}$	0.89
	0.05<V	Y=0.028 + 4.87V	0.97
Chaenactus douglasii	0<V	$Y=8.26V^{0.852}$	0.94
Eriogonum ovalifolium	0<V	Y=0 + 9.90V	
Penstemon confusus	0<V	$Y=3.99V^{0.551}$	0.69
Phlox longifolia	0<L	Y=0.0237 + 10.5L	0.90

Leaf biomass data were combined into species groups of trees, shrubs, perennial grasses, perennial forbs, and total understory for regression analysis. Some individual species data were also used for regression analysis. Natural logarithms of individual species leaf biomass data were used to plot species abundance by rank curves for each of the macroplots (Digby and Kempton 1987, May 1975, Whittaker and Niering 1975). The shape of these curves reveals the form of competitive interactions. Curves for each plot were compared for additional information on how increasing tree dominance may change competitive interactions within the understory.

RESULTS AND DISCUSSION

Leaf Biomass Relationships

The sapwood area to leaf biomass relationships of the two trees (Table 1) gave high coefficient of determination values consistent with similar analyses for other tree species and these species in other locations (Tausch and Tueller 1988, DeRocher and Tausch 1994). Results for the crown volume to leaf-biomass relationships (Table 1) are equivalent to those for other studies (Ludwig et al. 1975, Tausch and Tueller 1990, Tausch et al. 1994). For rare species with four or fewer individuals per plot, regression analysis was not used. An average weight of leaf biomass per cubic decimeter of crown volume was determined instead. These equations in table 1 have a zero intercept and no coefficient of determination value.

Overstory/Understory Dynamics

A comparison of total tree cover to total understory cover over the sampled plots revealed a slightly convex relationship (Fig. 1A). The loss of understory cover with increases in tree cover was less at lower tree cover than at higher tree cover. The tree-understory relationship on the basis of total leaf biomass, however, is concave (Fig. 1B). The decrease in understory leaf biomass is greater at lower tree leaf biomass levels than at higher levels. This latter pattern has also been observed by others (Arnold et al. 1964, Pieper 1990). The maximum leaf biomass sampled for the trees was nearly ten times the maximum sampled for the understory. On other sites the differences between the overstory and understory total leaf biomass ranged from 8 to over 20 times over a range of site production potentials (Tausch and Tueller 1990).

The reasons for the pattern in understory leaf biomass decline is evident by looking at the shrubs, which account for over 90 percent of the understory cover and biomass. The change in average shrub crown area with increasing tree dominance (Fig. 1C) was linear. Changes in shrub density were also linear to slightly convex, similar to figure 1a. Changes in average shrub leaf biomass, however, (Fig. 1D) were strongly non-linear. The greatest losses came with the initial increases in tree dominance. Almost half the foliage height can be lost with little loss in crown area or total height. The loss of leaves within the shrub crown comes primarily from a reduction in the foliage height, or the depth of leaves in the crown. Overall, the average shrub in the most tree dominated plots were reduced by over 60 percent in average leaf biomass over the range of tree dominance sampled.

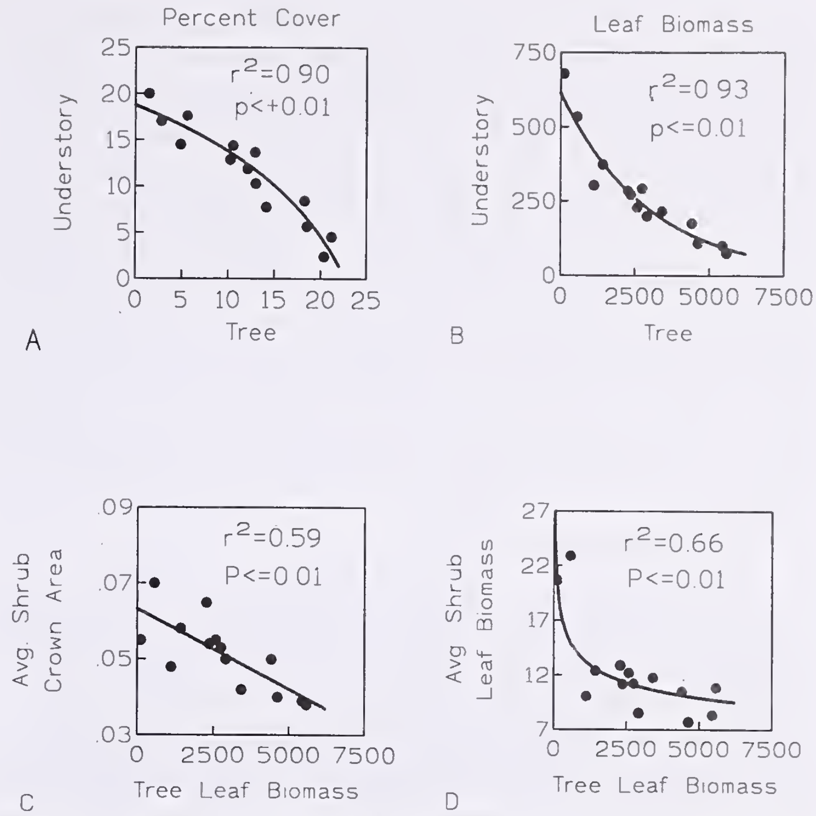

Figure 1.—Regression analyses results for: A) a comparison of total tree cover and total understory cover; B) total tree leaf biomass and total understory leaf biomass; C) total tree leaf biomass and average shrub crown area; and D) total tree leaf biomass and average shrub leaf biomass for 14 plots on a southwestern Utah study site.

The pattern of these changes over time can be approximated by plotting both tree total leaf biomass and understory total leaf biomass against time as represented by the leaf biomass weighted average age of piñon (Fig. 2). The actual pattern of understory loss with increases in tree dominance would probably have some differences if a single site were actually followed over time. For the first fifty years of the reestablishment of trees following the last fire, tree seedlings were mostly part of the understory. When the total tree leaf biomass exceeded the highest total understory biomass sampled, the increase in tree leaf biomass accelerated. By the time the tree leaf biomass was about one fourth of the maximum value sampled for the trees, or three to four times the maximum observed for the understory, the understory total leaf biomass was down by nearly half. On this site, significant reduction in understory productive potential occurred at relatively low levels of tree dominance.

Over the next 30 to 40 years figure 2 indicates a continued rapid increase in tree size and dominance to essentially total site occupancy. At the point where the trees are at about half the maximum leaf biomass observed on the site, the understory leaf biomass is at about one fourth of the maximum observed. This reduction in understory production from increasing tree dominance early in the sere is generally not apparent from casual observation of the community. The changes are not visually evident because the reduction in the leaf biomass is concentrated within the crown and for a period of time coincides with little change in either the crown area or the height of the shrubs.

The patterns of variation in grasses and forbs over changes in tree dominance differs from that observed for the shrubs. Both total and average grass leaf biomass on this site have a linear decline with increases in the tree dominance (Fig. 3A, 3B). With the loss of an average of about 40 percent of its maximum observed value over the range of tree dominance, the decline for the average grass leaf biomass was less than for the shrubs. The perennial grasses represent a relatively constant proportion of the understory of around 2 percent (randomly varying from 1 to 3 percent) over the entire range of tree dominance sampled.

Forbs had a strong non-linear response to changes in tree dominance (Fig. 3C). Total forb leaf biomass initially declined over the first third of the range of tree dominance, and then increased to about three times its initial value. The lowest values for forbs coincides with piñon weighted age of about 70 to 75 years, or about the point of the maximum rate in the increase in tree dominance in figure 2. At greater levels of understory reduction, a

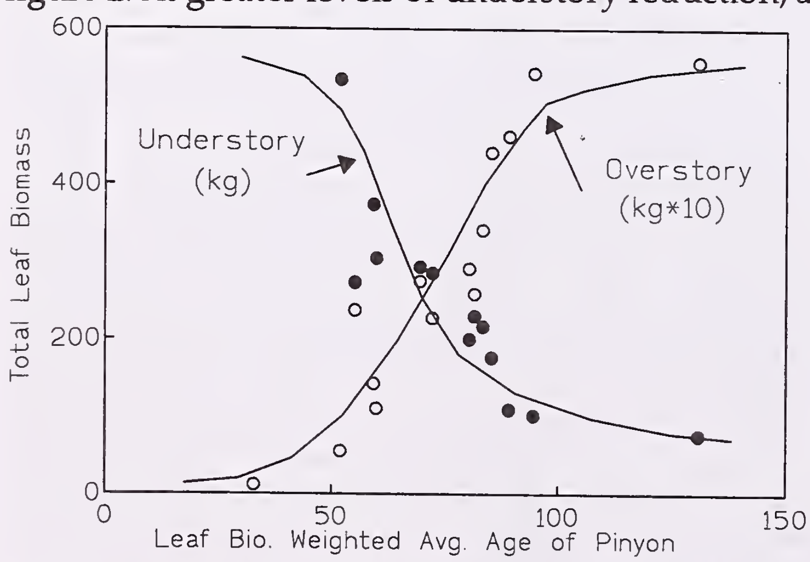

Figure 2.—Comparison of both the total tree leaf biomass (open circles, kg*10) and total understory leaf biomass (closed circles, kg) over time as indexed by the range in the leaf biomass weighted average age of piñon for 14 plots on a southwestern Utah study site.

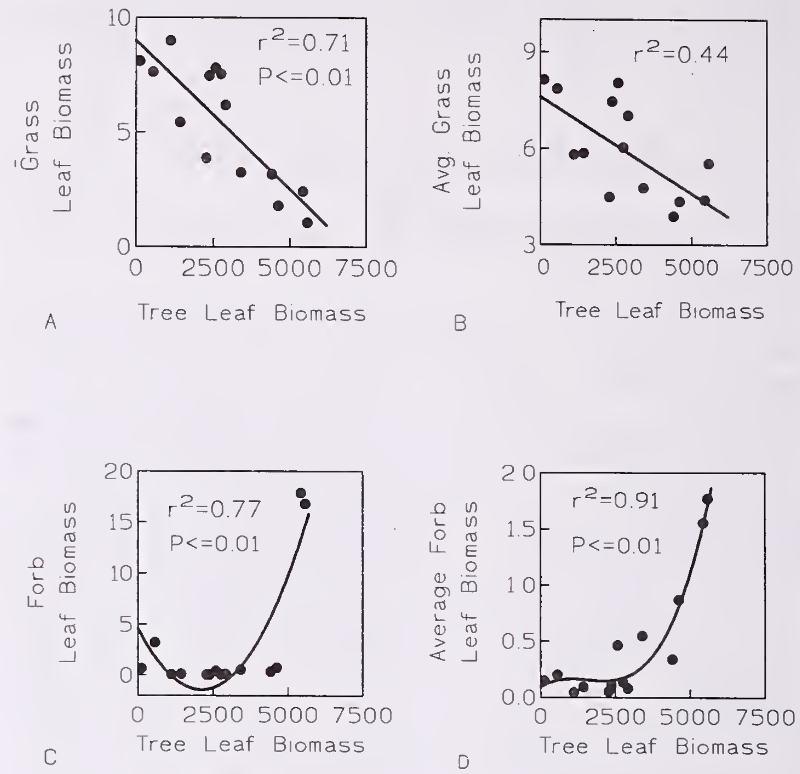

Figure 3.—Regression analyses for A) total tree leaf biomass and total grass leaf biomass; B) total tree leaf biomass and average grass leaf biomass; C) total tree leaf biomass and total forb leaf biomass; and D) total tree leaf biomass and average forb leaf biomass for 14 plots on a southwestern Utah study site.

release of the forbs appeared to occur on the site studied. A few kilometers north of this study site, and on steeper slopes away from water and roads, Yorks et al. (1994) found up to a three-fold increase in perennial grass cover on tree dominated plots from 1933 to 1989. Pieper (1990) observed an increase in two grass species with increasing canopy cover in New Mexico woodlands.

The leaf biomass of the average forb also had a slight decline at first, but then increased at the highest levels of tree dominance to nearly ten times the initial value (Fig. 3D). Changes in forb density are approximately a mirror image of the relationship for average forb leaf biomass.

The pattern of change in the forbs appears to be due primarily to the reduction in the shrubs. Shrubs and forbs show a tradeoff at the higher levels of tree dominance (Fig. 4A). While shrubs decrease over the range of tree dominance from over 97 percent to about 77 percent of the total understory, forbs increase from about 1 percent to over 20 percent (Fig. 4A).

In addition to the overall change in abundance, inter-species dynamics are evident within the forbs that reflect changes in the patterns of relative species dominance over the range of increasing tree dominance (Fig. 4B). One species of Penstemon actually increased in dominance within the forb group during the initial period of rapid overall understory decline but then declined at the highest levels of tree dominance. A locoweed increased linearly along with the increase in tree dominance while long-leaf phlox exponentially decreased.

It is evident from the results for all the understory groups that the trees have considerable impact on the species composition, relative dominance, and on the productivity of the understory as their level of dominance increased. This impact was also reflected in the rank by abundance curves (Fig. 5). Data for the macroplots are arranged in this figure from the lowest total tree leaf biomass on the left to the highest on the right. When several influences have random affects on a community composed of a heterogeneous assemblage of species, the resulting rank by abundance curve will have a log-normal form. This is the most common type of distribution found in plant communities (May 1975). The first two plots in figure 5 approximate the log-normal type of distribution.

When a community is influenced primarily by a single dominant factor resulting in a situation where niche-preemption is occurring among the species present, a log-series distribution is the result. This type of distribution can be theoretically derived by assuming that a dominant species is able to establish into the community and preempt a proportion of the resources on a site. This results in readjustments in resource use that cascades down through the less dominant species in a similar fashion. A log- series distribution is a relatively straight line when the natural logarithm of abundance is plotted against rank, as in figure 5.

Several of the more tree-dominated plots in figure 5 show essentially a straight line distribution

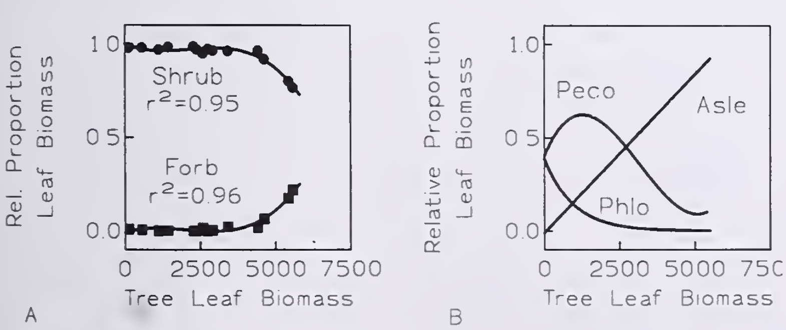

Figure 4.—Regression analyses results for A) relative composition of total shrub leaf biomass and total forb leaf biomass in the total understory leaf biomass over the range of total tree leaf biomass for 14 plots on a southwestern Utah study site; B) relative composition of the leaf biomass of three forb species, *Astragalus lentiginosus* (Asle, r^2=0.79), *Penstemon confusus* (Peco, r^2=0.70), and *Phlox longifolia* (Phlo, r^2=0.72) in the total forb leaf biomass over the range of total tree leaf biomass for 14 plots on a southwestern Utah study site.

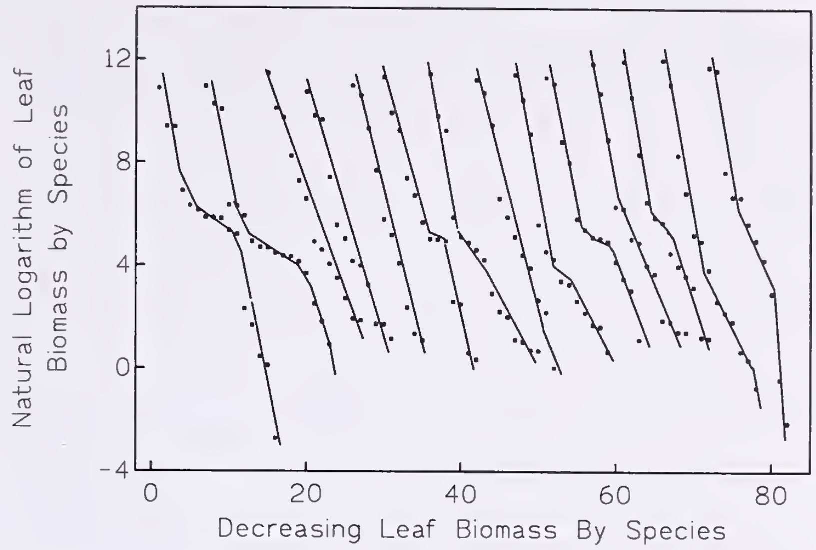

Figure 5.—A comparison of the dominance diversity curves for 14 plots on a southwestern Utah piñon-juniper study site. Species are ranked by abundance of total leaf biomass within each plot. Plots are staggered along the X-axis from the lowest total tree leaf biomass on the left to the largest total tree leaf biomass on the right. The Y-axis is the natural logarithms of the leaf biomass of the individual species.

in their rank-abundance plots. Such a straight line distribution was also found by Whittaker and Niering (1975) for pigmy conifer-oak woodlands on the Santa Catalina Mountains of Arizona. Even for the lines in figure 1 for the higher levels of tree dominance that are not straight, there is a much weaker tendency toward the log-normal distribution than in the first twoplots. Many factors could be involved in the variation in the curves. Possibilities include variation in the spatial distribution or patchyness of the trees, variation in the size class distribution of the trees, and variation in the relative dominance of piñon and juniper.

CONCLUSIONS

Regression analysis results, plus the patterns in Figure 5, both indicate that on the site studied, the use of the limited available resources by the trees as they increase in dominance has a major impact on the competitive dynamics of the understory community. Effects on the shrubs and the forbs were greater than on the perennial grasses. Species and species groups affected, and the resulting patterns, apparently vary with site and understory community. To be effective, management must work within the community ecology of the woodland sites of interest, including all the species present, and including the history of use and change on the site as well as its current status.

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Acid and Alkaline Phosphatase Dynamics in Soils of a Piñon-Juniper Woodland

Susanne Krämer[1]

Abstract.—Plant roots and soil organisms increase phosphorus availability by releasing acid and alkaline phosphatase. Organic phosphorus compounds are hydrolysed into plant-available forms through the action of these enzymes. Phosphatase is of particular importance under conditions of low phosphorus availability which is commonly found in piñon-juniper soils. Acid and alkaline phosphatase activities (mg *p*-nitrophenol released g^{-1} soil h^{-1}) were studied at two research sites in northern Arizona. At monthly intervals, soil samples were collected underneath *Juniperus monosperma* canopies and in interspace areas dominated by *Hilaria jamesii*. In both juniper and interspace soils, alkaline phosphatase activities were significantly higher than acid phosphatase activities. Alkaline phosphatase activity ranged from 57.3 to 167.2 μg *p*-nitrophenol g^{-1} soil hr^{-1} and was similar to values reported for acid farmfield and grassland soils. Acid phosphatase activity varied between 9.3 and 29.5 mg *p*-nitrophenol g^{-1} soil h^{-1} and corresponded to values in *Juniperus occidentalis* and a range of western coniferous forest soils. The results indicate that soil microbes are the dominant producers of phosphatase in the studied piñon-juniper soils.

INTRODUCTION

Traditionally, most nutrient cycling studies in forests and rangelands have focused on the measurement of nutrient pool sizes and the return of nutrients from plants to soil in litterfall. Only recently have we turned our attention to the dynamics of nutrient fluxes and the underlaying processes by which the supply of nutrients to plants is sustained.

Phosphorus availability may be the most limiting factor to plant growth in many terrestrial ecosystems (Attiwill and Adams 1993, McGill and Christie 1983, Vitousek and Howarth 1991). In natural ecosystems dominated by perennials much of the plant demand for phosphorus is met by cycling of phosphorus in organic matter (Halm et al. 1972, Attiwill 1980, Attiwill and Adams 1993). Phosphatase enzymes are a good indicator of the organic phosphorus mineralization potential and biological activity of soils (Cole et al. 1977, Speir and Ross 1978). Phosphatase measured in soils reflects the activity of phosphatase bound to soil colloids and humic substances, free phosphatase in the soil solution, and phosphatase associated with living and dead plant or microbial cells (Nannipieri et al. 1990, Skujins 1976). Phosphatase activity is related to soil and vegetation conditions (Herbien and Neal 1990, Ho 1977, Neal 1973), responds to changes in management (Adams 1992, Clarholm 1993, Pang and Kolenko 1986), and is reasonably correlated with seasonal changes in soil temperature and moisture (Harrison and Pierce 1979, Speir and Cowling 1991).

Phosphatase activity has been studied in various agricultural and forest soils. However, very limited information exits on phosphatase dynamics in semiarid rangeland soils. The present study determined acid and alkaline phosphatase levels in a piñon-juniper woodland of northern Arizona and compares it to values reported for soils from a range of ecosystems. Possible relationships of

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phosphatase activity levels to various soil and vegetation characteristics are discussed.

MATERIALS AND METHODS

Two study sites were established in a one-seed juniper/galleta (*Juniperus monosperma/Hilaria jamesii*) dominated woodland of the Colorado Plateau in northern Arizona. The sites were located about 30 miles northeast of Flagstaff at Wupatki National Monument at an elevation of 1650 m. The climate at Wupatki National Monument is semiarid with 54% of the total annual precipitation occurring during thunderstorms in July, August, and September (fig. 1) (Sellers and Hill 1974). Longterm average precipitation at the visitor center (1492 m elev.) is 188 mm (Sellers and Hill 1974).

Soils for the analysis of pH, loss on ignition, and texture were collected during August 1993. Prior to sampling, each study site was subdivided into three equal sized rectangular plots. In each plot, soil subsamples were collected from 5 to 15 cm depth from 10 randomly located areas under both juniper trees and in interspace areas. Subsamples were composited within plots. Soils were air dried and passed through a 2 mm sieve. Standard analysis techniques were used for soil pH (1:1 soil/$CaCl_2$), loss on ignition, and texture (Bouyoucos hydrometer) (Klute 1986, Page et al. 1982). Soil textural classes follow the USDA classification scheme (Gee and Bauder 1982). The depth of cinders and litter covering the soil surface was measured to the nearest half centimeter at three random locations in each interspace and tree plot used for phosphatase analysis. Variations in soil properties between sites, trees, and interspace areas were analyzed with *t*-tests at the 0.05 level.

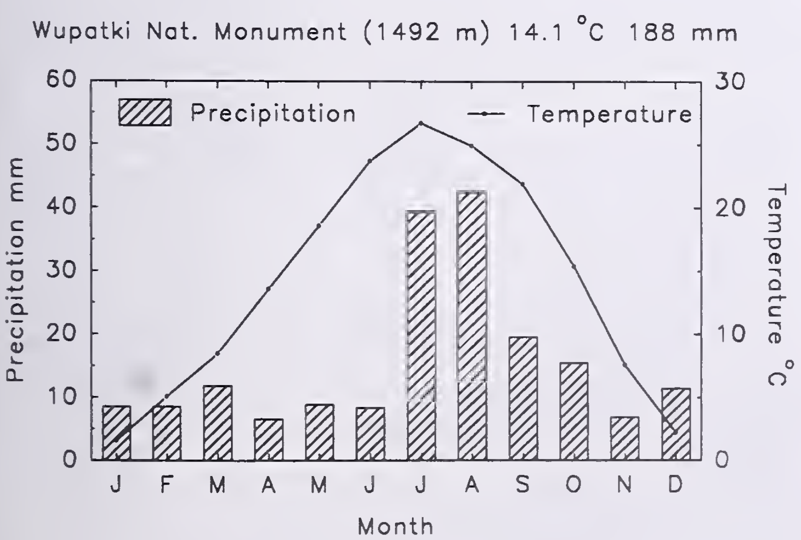

Figure 1.—Longterm precipitation and temperature averages (1941-1970) at Wupatki National Monument (Sellers and Hill 1974).

Tree canopy cover was determined at 10 random locations with a spherical densiometer (Lemmon 1956). Understory cover of dominant herbaceous species was estimated in 20x50 cm plots. At each site, 30 plots were read at 1 m intervals along 5 transects. Cover was estimated based on Daubenmire cover classes (Daubenmire 1968). Canopy and understory cover differences between sites were compared with *t*-tests at the 0.05 level.

Within each study site, four juniper and four interspace plots were randomly selected for the study of soil phosphatase. Soil was collected from 0 to 20 cm depth at monthly intervals from September 1993 to June 1994. At each plot, 3 randomly located subsamples were obtained with a core sampler lined with a 2.5 cm diameter butyrate sampling tube. Samples in juniper plots were collected at approximately half the distance between the tree trunk and canopy edge. Sampling tubes were capped and transported to the laboratory on ice. At the laboratory, the 5 to 15 cm core sections were passed through a 2 mm sieve and composited within sample plots. Sieved samples were stored in polyethylene bottles at 4° C.

Field moist soil samples were analyzed for acid and alkaline phosphomonoesterase activity with a buffered disodium *p*-nitrophenyl phosphate tetrahydrate solution (Tabatabai 1982, Schinner et al. 1991). Results were calculated in µg *p*-nitrophenol released per gram dry soil per hour at 37° C. A hierarchical ANOVA (Zar 1984) was used to test differences in acid and alkaline phosphatase activity, juniper and interspace plots, and between sites within sampling dates.

RESULTS AND DISCUSSION

Soil and vegetation characteristics varied considerably between study sites (table 1 and 2) although the sites were located within 500 m of each other. Soils were alkaline and ranged from pH 7.4 to 7.9 in interspace plots, and 7.9 to 8.0 in juniper plots (table 1). At site 1, soil pH was significantly lower in interspace than juniper plots ($P \leq 0.01$). Both interspace and juniper soil pH levels were significantly lower ($P \leq 0.01$) at site 1 than site 2.

Soil organic matter estimated by percent loss on ignition was between 3.4 and 4.1% and did not differ significantly within or between study sites (table 1).

Site 1 soils were of a sandy loam texture with significantly less sand ($P \leq 0.05$) in interspace (54.3%) than juniper plots (63.6%) (table 1). Soils at site 2 were finer textured and classified as loam.

Both study sites are covered with black cinders from the eruption of Sunset Crater. Cinder cover was significantly deeper at site 1 than site 2, and under juniper trees as compared to interspace areas (P £ 0.05). Interspace plot cinder cover was 3.2 cm at site 1 and 1.6 cm at site 2 (table 1). Under juniper trees, cinders are mixed with tree litter. Average cinder/litter depth for juniper plots was 8.6 and 4.3 cm for site 1 and 2, respectively (table 1). Rocks and plant residue on the soil surface act as a mulch and can significantly decrease evaporative loss of soil moisture, and decrease soil temperature fluctuations (Brady 1984). These factors may be critical in determining aboveground vegetation and belowground soil phosphatase characteristics associated with the study sites.

One-seed juniper and galleta were the dominant plant species on both study sites. Juniper canopy cover was 8.2% at site 1 and 3.5% at site 2 (table 2). Galleta cover was significantly higher ($P \leq 0.05$) at site 1 (7.0%) than site 2 (4.5%) (table 2).

Acid phosphatase activities ranged from 13.3 to 29.5 µg *p*-nitrophenol g^{-1} h^{-1} in juniper soil and from 9.3 to 33.4 µg *p*-nitrophenol g^{-1} h^{-1} in interspace soil (fig. 2). Acid phosphatase levels found in this study are similar to values reported for western juniper (*Juniperus occidentalis*), a range of coniferous forest soils, and fescue/ryegrass (*Festuca* spp./*Lolium* spp.) pasture (fig. 3) (Ho 1979). Acid phosphatase activity in low pH soils of eucalyptus (*Eucalyptus diversicolor*), Douglas fir/red alder (*Pseudotsuga menziesii*/*Alnus rubra*), red alder,

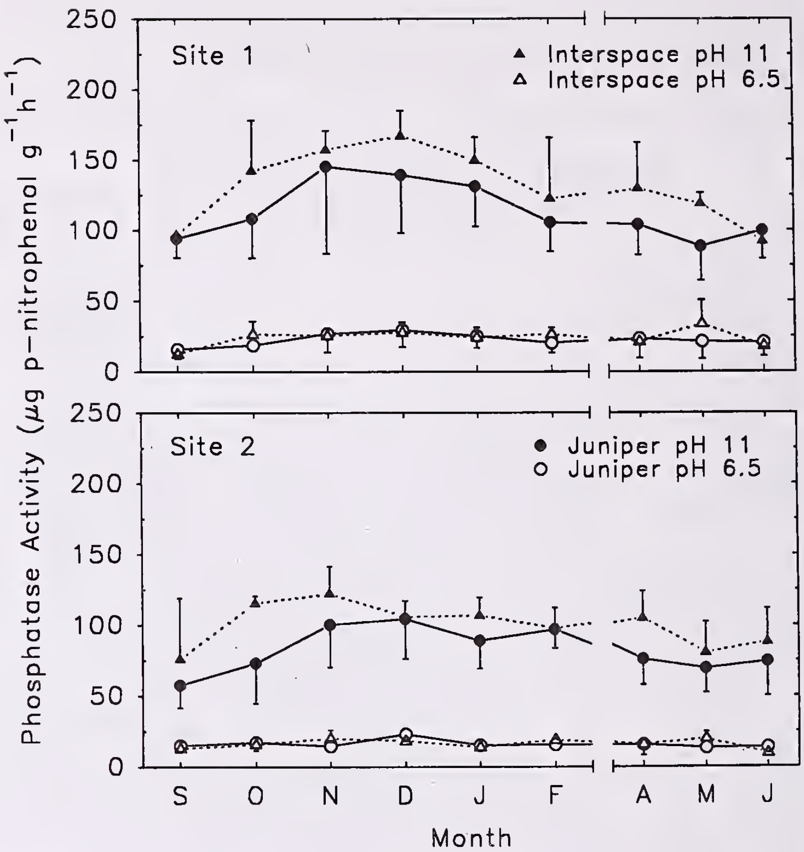

Figure 1.—Longterm precipitation and temperature averages (1941-1970) at Wupatki National Monument (Sellers and Hill 1974).

mixed oak (*Quercus* spp.) forest soils, and acid farmfields was considerably higher than levels found in this study (fig. 3) (Adams 1992, Eivazi and Tabatabai 1977, Herbien and Neal 1990, Ho 1979).

Alkaline phosphatase activity varied between 57.3 and 145.4 µg *p*-nitrophenol g^{-1} h^{-1} in juniper soil and 75.9 and 167.2 µg *p*-nitrophenol g^{-1} h^{-1} in interspace soil (fig. 2). These values are similar to alkaline phosphatase activities reported for grassland and acid farmfield soils (fig. 3) (Eivazi

Table 1.—Chemical and physical soil characteristics of research sites. Lower case letters indicate significant differences between interspace and juniper soils within study sites. Numbers indicate significant differences in interspace or juniper soils between study sites.

	Site 1		Site 2	
	Interspace	Juniper	Interspace	Juniper
pH	7.4 a1	7.9 b1	7.9 a2	8.0 a2
Loss on ignition (%)	3.6 a1	3.4 a1	3.6 a1	4.1 a1
Texture	sandy loam	sandy loam	loam	loam
% Sand	54.3 a1	63.6 b1	48.2 a1	50.6 a2
% Clay	20.0 a1	14.1 a1	21.4 a1	20.2 a1
Cinder/litter depth (cm)	3.2 a1	8.6 b1	1.6 a2	4.3 b2

Table 2.—Cover of dominant plant species at research sites. Values are means ± SE. Lower case letters indicate significant differences between sites. TR = trace (< 0.5%).

	Cover (%)	
Species	Site 1	Site 2
Juniperus monosperma	8.2 (±22.7) a	3.5 (±5.7) a
Hilaria jamesii	7.0 (±2.1) a	4.5 (±1.1) b
Sporobolus cryptandrus	TR	TR
Aristida arizonica	TR	-
Stipa neomexicana	TR	-
Sitanion hystrix	-	TR

and Tabatabai 1977, Herbien and Neal 1990). Alkaline phosphatase levels in alkaline farmfields and a cornfield were much higher than activities found in this study (Eivazi and Tabatabai 1977, Herbien and Neal 1990). However, much less information exits on alkaline soil phosphatase compared to acid phosphatase and comparisons are therefore limited.

Alkaline phosphatase activity was significantly higher ($P \leq 0.01$) than acid phosphatase in both juniper and interspace soil throughout the study period (fig. 2). This agrees with the conclusion of Eivazi and Tabatabai (1977) that alkaline phosphatase predominates over acid phosphatase in high pH soils. Plant roots can be a major source of acid phosphatase (Dinkelaker and Marschner 1992, Juma and Tabatabai 1988, Neal 1973, Speir and Cowling 1991), but do not produce any alkaline phosphatase (Nakas et al. 1987, Tarafdar and Claassen 1988). Alkaline phosphatase originates from soil bacteria, fungi, and fauna (Ho and Zak 1979, Nakas et al. 1987, Pang and Kolenko 1986, Tarafadar and Claassen 1988). Soil microbes appear to be the main producers of phosphatase in the studied piñon-juniper soils.

Phosphatase activities were not significantly different between juniper and interspace soils. However, with the exception of the June 1994 sampling date, alkaline phosphatase activity was consistently higher in interspace than in juniper soil (fig. 2). Soil water potential measurements at the study sites indicate that juniper soils are drier than interspace soils (S. Krämer, unpubl. data). Since soil microbial activity is positively correlated with soil water potential (Griffin 1981, Wilson and Griffin 1975), higher microbial activity and therefore higher alkaline phosphatase levels can be expected in interspace soils. This explanation agrees with Hoffmann and Elias-Azar (1965) and Tarafdar and Claassen (1988), who observed higher phosphatase activity in soils with higher microbial populations. Physical and chemical soil properties (table 1) may further influence the measured alkaline phosphatase levels in juniper and interspace soils (Skujins 1976, Speir and Ross 1978).

Phosphatase activities at site 1 were generally higher than those at site 2 (fig. 2). Values were significantly different ($P \leq 0.1$) during September, November, and December 1993, and during January and June 1994. Differences in phosphatase activities between sites are likely to be caused by dissimilar soil moisture and temperature regimes due to variations in soil texture and cinder/litter cover.

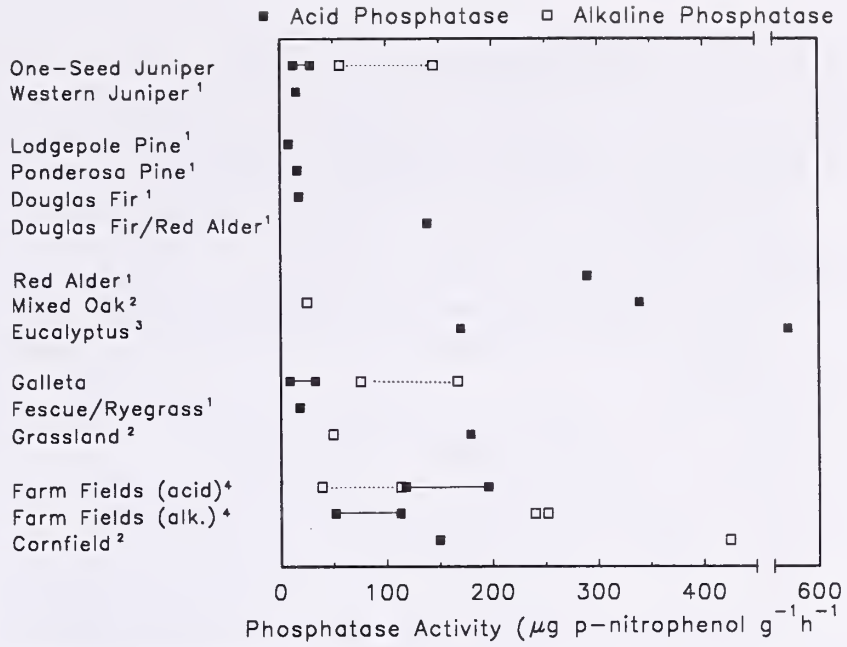

Figure 3.—Phosphatase activities (μg *p*-nitrophenol $g^{-1}h^{-1}$) in soils of various ecosystems. Sources: [1]Ho 1979, [2]Herbien and Neal 1990, [3]Adams 1992, [4]Eivazi and Tabatabai 1977. Data for one-seed juniper and galleta are from this study.

Alkaline phosphatase activities were highest during November and December 1993 (fig. 2). Significant precipitation (28.7 mm) during October 1993 and possibly favorable soil temperatures may have caused a quick proliferation of soil organisms that synthesize alkaline phosphatase. In lab incubations, a sudden increase in phosphatase activity was observed after 21 days of rewetting soils to field capacity (Pang and Kolenko 1986). The subsequent slow decrease in phosphatase activity suggests that phosphatase was being degraded and not synthesized fast enough by soil organisms to maintain the enzyme pool measured in November and December.

CONCLUSIONS

Phosphatase levels reported in this study are comparable to those of a range of soils with similar pH values. Variations in activities observed appear to be related to site specific soil and vegetation conditions. However, further studies are necessary to establish more detailed relationships between phosphatase activity and soil conditions.

Research is presently underway to examine soil moisture and temperature changes relative to organic phosphorus cycling and relate them to levels of observed phosphatase activities reported in this study. To more completely understand phosphorus dynamics in piñon-juniper soils, we must look at phosphatase as part of an environmental matrix that consists of many individual, yet interacting factors.

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Environmental Stress Influences Aboveground Pest Attack and Mycorrhizal Mutualism in Piñon-Juniper Woodlands: Implications For Management in the Event of Global Warming

Catherine Gehring and Thomas Whitham[1]

Abstract.—In this paper, we summarize our findings on the relationships between abiotic environmental stress, herbivory, mistletoe parasitism, and mycorrhizal colonization in piñon pine and one-seeded juniper. We compared trees growing in two very different environments - the nutrient and water stressed ash and cinder fields of the San Francisco volcanic field in northern Arizona, and the sandy loam soils of nearby areas. We found that levels of moth herbivory in piñons (*Pinus edulis*) were 100-fold higher, and levels of mistletoe parasitism in junipers (*Juniperus monosperma*) were three-fold higher on trees growing in the stressful cinder soils than in the sandy loam soils. Ectomycorrhizal colonization of piñon roots was two-fold higher in trees growing in the cinder soils than in the sandy loam soils, but was significantly reduced on cinder-site trees that experienced chronic insect attack. Similar mycorrhizal reductions were observed in junipers that experienced severe mistletoe infestation. Simulated moth herbivory significantly reduced mycorrhizal colonization of piñons growing in the cinder soils, but not of piñons in the sandy loam soils. These results indicate that environmental stress influences three important parameters in piñon-juniper woodlands: 1) the likelihood that a tree will experience herbivore or parasite attack, 2) the abundance of mycorrhizal mutualists on a plant, and 3) the degree of mycorrhizal reductions that result from biotic stresses such as herbivory. The importance of environmental stress in these interactions suggests that global warming could cause significant increases in pest attack and complex changes in levels of mycorrhizal mutualisms. Furthermore, because these interactions in piñons are associated with host plant genetics, piñon trees growing in stressful environments may possess unique stress-tolerant genotypes that are important to conserve.

INTRODUCTION

The degree of environmental stress (e.g. nutrient and water stress) experienced by plants can have important effects on a plant's susceptibility to herbivore attack (White 1969, 1974, 1976, 1984), and on the abundance of mycorrhizal mutualists present on a plant's root system (Meyer 1973). Herbivores and mycorrhizae are also known to interact with one another, although the role of environmental stress in this interaction is still unclear (Gehring and Whitham 1994a). Piñon pines (*Pinus edulis*) and one-seeded juniper (*Juniperus monosperma*) grow in a variety of environments in northern Arizona that vary markedly in environmental stress. In particular, these tree species are community dominants in many of the nutrient and water-stressed cinder environments that have resulted from geologically recent eruptions of the San Francisco volcanic field.

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By comparing levels of mycorrhizae and herbivory in piñons and junipers in stressful cinder environments to those growing in nearby less stressful noncinder areas consisting of sandy loam soils, we can better understand the effects of environmental stress on this widespread vegetation type. In addition, because piñons and junipers are attacked by different types of pests, and have different types of mycorrhizal mutualists (ectomycorrhizae in piñons and vesicular-arbuscular mycorrhizae in junipers), it is of particular interest to determine the effect of environmental stress on these trees and their associated taxa. This information could allow us to make better predictions about the potential impacts of human-caused stresses such as global warming on piñon-juniper communities.

In this paper, we review some of our recent research on the effects of environmental stress on piñon pine and address the following questions: 1) Do piñons and junipers growing in stressful cinder environments and less stressful sandy loam environments differ in herbivore or parasite attack?, 2) Do piñons growing in cinder and sandy loam environments differ in mycorrhizal colonization?, and 3) Do herbivores and parasites interact with mycorrhizae, and is this interaction influenced by environmental stress? Although the data we used to address these questions have largely been published separately elsewhere, we bring them together here to allow a more complete synthesis of our results regarding environmental stress, and to facilitate comparisons between piñons and junipers growing in the same environment. In spite of differences between piñons and junipers in types of mycorrhizae (ectomycorrhizae and vesicular-arbuscular mycorrhizae, respectively), and major pests (insects vs. mistletoes, respectively), we find that environmental stress results in similar impacts on these trees, mycorrhizal mutualists, and pests. We use our data on patterns associated with environmental stress to make predictions about the potential effects of global warming on pest attack rates and levels of mycorrhizal mutualism in piñon-juniper woodlands, and to argue that piñons growing in stressful environments possess unique stress-tolerant genotypes that are important to conserve.

NUTRIENT AND MOISTURE STRESS ACROSS EXTREME SOIL TYPES

The four stressful cinder environments and the four less stressful noncinder environments that we compared differed substantially in soil nutrient and moisture levels (Gehring and Whitham 1994b)(Table 1). Soil from the cinder sites averaged 63% lower levels of phosphate, 40% lower levels of soil moisture, and 70-90% lower nitrogen mineralization rates than soils from the nearby limestone-derived sandy loam sites. Two of the same sites (one cinder and one noncinder) have been shown to differ in the same nutrients (Mopper et al. 1991), as well as many others (e.g., magnesium, potassium, calcium), with the cinder sites always possessing the lower values (Cobb et al., in review). The lower levels of soil nutrients and moisture in the cinder soils have been associated with a 23% reduction in piñon shoot growth (Gehring and Whitham 1994b), a 66-90% reduction in piñon cone production (Christensen and Whitham 1991), and a 15% increase in tree water potentials (Mopper et al. 1991) relative to piñons growing in sandy loam soils.

Table 1 – Soil parameter comparisons between cinder and noncinder soils.[1]

	Cinder	Noncinder	p Value
Phosphate (ppm)	4.45	12.20	.0001
Soil moisture (% water)	5.61	9.39	.0001
Nitrate mineralization (ppm)	.60	5.86	.0001
Ammonium mineralization (ppm)	-.84	2.47	.054

[1] Values are the means of four cinder and four noncinder sites in northern Arizona. Data are from Gehring and Whitham (1994b).

HERBIVORY AND MISTLETOE PARASITISM INCREASE WITH PLANT STRESS

Our results suggest that environmental stress leads to increased susceptibility to moth herbivory in piñon pines and to increased susceptibility to mistletoe parasitism in one-seeded juniper. Piñon pines growing in cinder soils from four different sites in northern Arizona experienced an average shoot mortality due to the stem- and cone-boring moth (*Dioryctria albovittella)* of 7% while piñons at four nearby sandy loam sites experienced less than 0.05% shoot mortality (Gehring and Whitham 1994b)(fig. 1A). Considering that these insects selectively destroy a tree's terminal shoots thereby turning trees into shrubs, even relatively low levels of damage can have dramatic impacts on a tree's architecture and cone production (Whitham and Mopper 1985). A similar pattern was observed by Mopper et al. (1991) for one cinder site and one sandy loam site, and the data presented here suggest that this pattern is a general one.

Piñons at Sunset Crater vary in susceptibility to moth attack; resistant trees experience chronically low levels of moth attack while susceptible trees growing nearby experience chronically high levels of moth herbivory (Whitham and Mopper 1985). Furthermore, resistant and susceptible piñons differ genetically in both allelic frequency and heterozygosity (Mopper et al. 1991). Our data suggest that resistant and susceptible trees may also be present at cinder sites other than Sunset Crater. Although we have no genetic data for these other sites, trees at these sites varied ten-fold or more from one another in level of moth herbivory. Based upon our genetic studies of other sites, these findings suggest that some of these trees were resistant while others were susceptible (Gehring and Whitham, unpub. data).

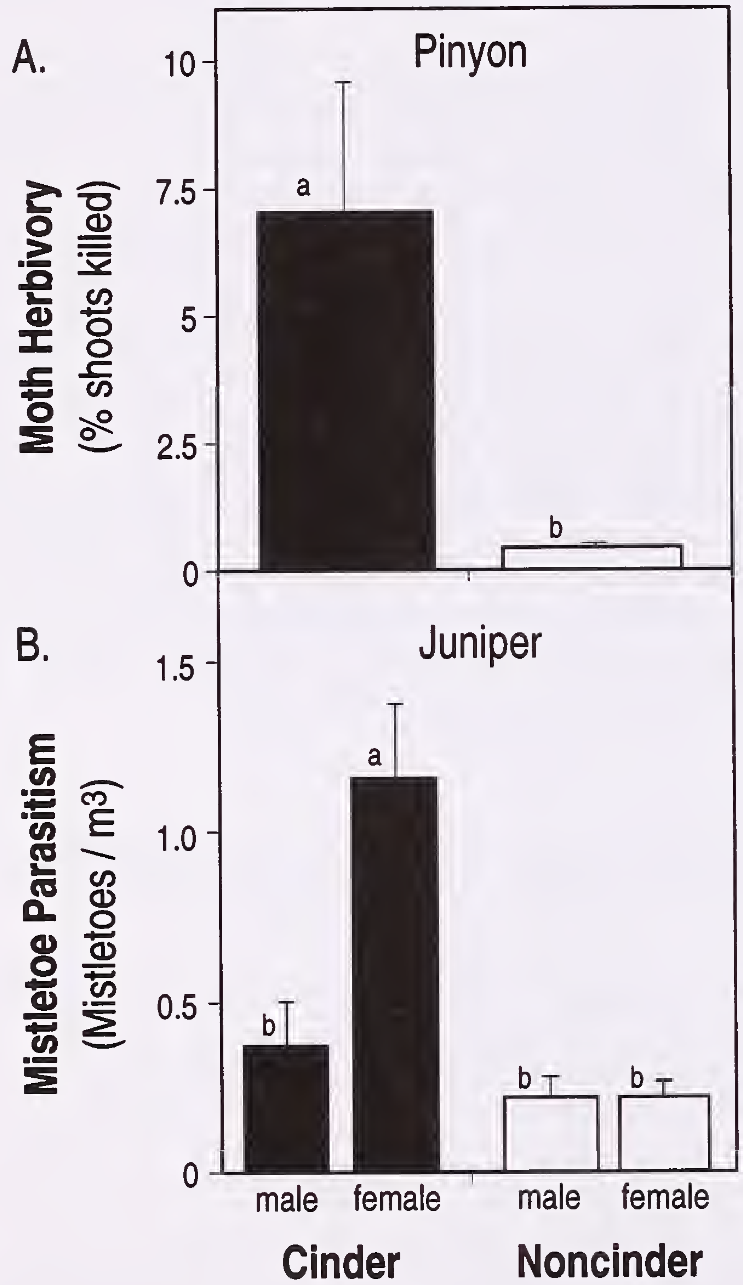

Figure 1A.—Level of stem- and cone-boring moth herbivory on piñon pines growing in cinder and sandy loam soils. Values are means ± S.E. and represent the average of four cinder and four sandy loam sites in northern Arizona. Different letters above the bars denote significant differences at $p < 0.05$ and were adapted from Gehring and Whitham (1994b).

Figure 1B.—Level of mistletoe parasitism on male and female junipers at one cinder and one noncinder site. Data are means ± 1 S.E. and were adapted from Gehring and Whitham (1992). Different letters above the bars denote significant differences at $p < 0.05$.

Juniper trees showed a similar pattern with regard to environmental stress - junipers growing in the cinders of Sunset Crater had higher levels of mistletoe parasitism than junipers growing at a nearby noncinder site (Gehring and Whitham 1992)(fig. 1B). The mistletoe, *Phoradendron juniperinum* removes water, minerals, and carbon from its host plant (Hull and Leonard 1964, Ehleringer et al. 1985, Marshall and Ehleringer 1990) causing branch die-back and increased water stress in heavily infested plants (Ferrell 1974, Knutson 1983). The difference between sites in mistletoe parasitism was largely due to higher levels of mistletoe infestation in female trees—female trees at Sunset Crater had three-fold higher levels of mistletoe parasitism than male trees at Sunset Crater or than male or female trees at the noncinder site (Gehring and Whitham 1992)(fig. 1B).

The higher levels of mistletoe parasitism on female junipers at the stressful site could be due to a preference by avian mistletoe seed dispersal agents for female trees (Gehring and Whitham 1992). Female junipers possess two potential food resources —mistletoe berries and juniper berries, and birds may thus spend more time on female trees than male trees, and deposit more mistletoe seeds there. However, our finding that male and female junipers growing in the less stressful environment did not differ in mistletoe parasitism, even though they possessed a similar avifauna and abundant berries, is not consistent with this hypothesis.

A second hypothesis to explain the difference between sexes in mistletoe parasitism is that mistletoe growth and survival is greater on female trees than male trees in the stressful cinder environment (Gehring and Whitham 1992). Female junipers may be less resistant to mistletoe attack than male junipers if they are under greater stress as are females of several other dioecious plant species (Stark 1970, Hikmat et al. 1982, Freeman and MacArthur 1982). The male-biased sex ratio (1.56 males for every female) at the stressful site is consistent both with the hypothesis that female junipers are under greater stress in that environment, and with studies of biased sex ratios in junipers and other plant species (Freeman et al. 1976).

Experimental studies demonstrate that the increased susceptibility of piñons to moth herbivory described here is, at least in part, caused by environmental stress. Moth-susceptible piñons at the Sunset Crater site that received supplemental nutrients and water to experimentally reduce environmental stress, produced significantly higher levels of defensive resins (60% increase) and suffered significantly less moth herbivory (9% reduction) relative to untreated control trees (Cobb et al., in review). These results provide observational and experimental support for the plant stress hypothesis (White 1969, 1974, 1976, 1984) which predicts that herbivore performance will be higher on stressed plants.

ECTOMYCORRHIZAL COLONIZATION IN PIÑON INCREASES WITH PLANT STRESS

Environmental stress was also significantly associated with ectomycorrhizal colonization in piñon pines. Piñons growing in four cinder environments had, on average, two-fold higher levels of ectomycorrhizal colonization than piñons growing in four sandy loam soil sites (Gehring and Whitham 1994b)(fig. 2). This result is consistent with the hypothesis that ectomycorrhizae are most important to plants growing in stressful

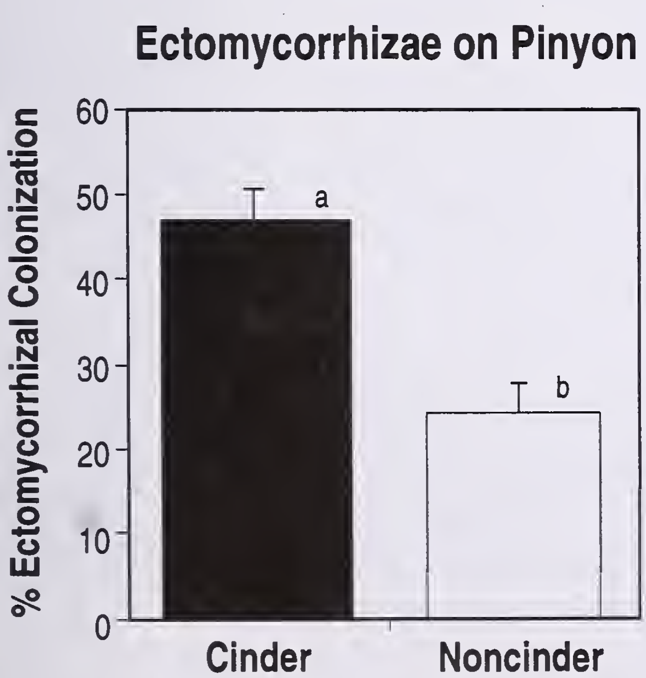

Figure 2.—Levels of ectomycorrhizal colonization of piñons growing in cinder and sandy loam soils. Values are means ± 1 S.E. and represent the average of four cinder and four sandy loam sites. Different letter above the bars denote significant differences at $p < 0.05$. Data were adapted from Gehring and Whitham (1994b).

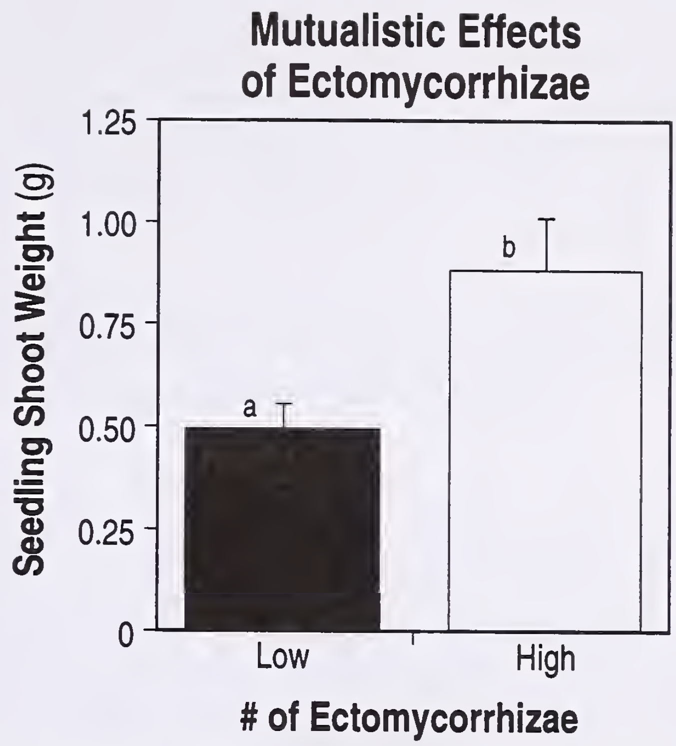

Figure 3.—Shoot weight of piñon seedlings grown in cinder soils with lower (80 or less) or higher (150 or more) numbers of ectomycorrhizal roots. Data are means ± 1 S.E. and were adapted from Gehring and Whitham (1994b). Different letters above the bars denote significant differences at $p < 0.05$.

environments where soil fertility is low and the need for enhanced nutrient and moisture uptake is greatest (Meyer 1973). Although we do not have comparable data for the vesicular-arbuscular mycorrhizae of juniper, similar relationships between soil fertility and vesicular-arbuscular mycorrhizal colonization were found by Boerner (1986) and Van Noordwijk and Hairiah (1986). However, other researchers have observed no significant correlation between ectomycorrhizal colonization and soil fertility (e.g., Lee and Lim 1989, McAfee and Fortin 1989), and the results of studies that monitored changes in ectomycorrhizal colonization following nutrient supplementation are similarly variable, suggesting that other factors are also important (e.g., Gagnon et al. 1987, Arnebrant and Soederstroem 1990, MacFall et al. 1990, Termorshuizen and Ket 1990).

Although cinder and noncinder site piñons differed in ectomycorrhizal colonization, data from seedling studies in the greenhouse demonstrate that ectomycorrhizae enhance seedling growth in both soil types. We observed a significant positive correlation between ectomycorrhizal abundance (total # of ectomycorrhizal roots) and shoot weight for seedlings grown in both cinder and noncinder soil types (Gehring and Whitham 1994b). For example, in cinder soils, the shoot weight of seedlings with high numbers of ectomycorrhizae

(150 or more) was approximately 44% higher than the shoot weight of seedlings with lower numbers of ectomycorrhizae (80 or less)(fig. 3). This positive relationship between ectomycorrhizae and shoot growth suggests that any environmental factor that reduces ectomycorrhizae could negatively affect piñon growth.

HERBIVORES AND MISTLETOE PARASITES NEGATIVELY AFFECT MYCORRHIZAE IN PIÑONS AND JUNIPERS

In both piñons and junipers, we observed a significant negative relationship between mycorrhizal colonization and pest attack. In mature piñons, ectomycorrhizal colonization of trees resistant to moth attack was approximately 30% greater than ectomycorrhizal colonization of moth-susceptible trees in the cinder soils of Sunset Crater (Gehring and Whitham 1991). Removal of moths from susceptible trees resulted in a rebound in ectomycorrhizal colonization demonstrating that the moth was responsible for the mycorrhizal reductions in susceptible trees (fig. 4A). Younger piñons that experienced severe herbivory by a needle-feeding scale insect also suffered significant reductions in ectomycorrhizal colonization that were eliminated following insect removal (Del Vecchio et al. 1993)(fig. 4B).

A similar negative relationship between pest attack and mycorrhizal colonization is found in one-seeded juniper even though junipers have a different type of mycorrhizal mutualist and are hypothesized to be better adapted to arid conditions than piñon pines. Vesicular-arbuscular mycorrhizal colonization of juniper roots was 30% lower in trees with high mistletoe densities than in trees with low mistletoe densities (Gehring and Whitham 1992)(fig. 4C). The consistent nature of these results suggests that even the mycorrhizae of more dry-adapted species will decline following pest attack.

To assess the importance of environmental stress to the interactions between mycorrhizae and aboveground pests, we simulated herbivory at a sandy loam site and compared the mycorrhizal responses of trees at this site to trees experiencing the same type of simulated herbivory at a cinder site. Our results indicate that environmental stress is an important component of the interaction—trees at the cinder site experienced declines in ectomycorrhizal colonization while those at the sandy loam site did not (Gehring and Whitham, in prep.). These findings suggest that environmental

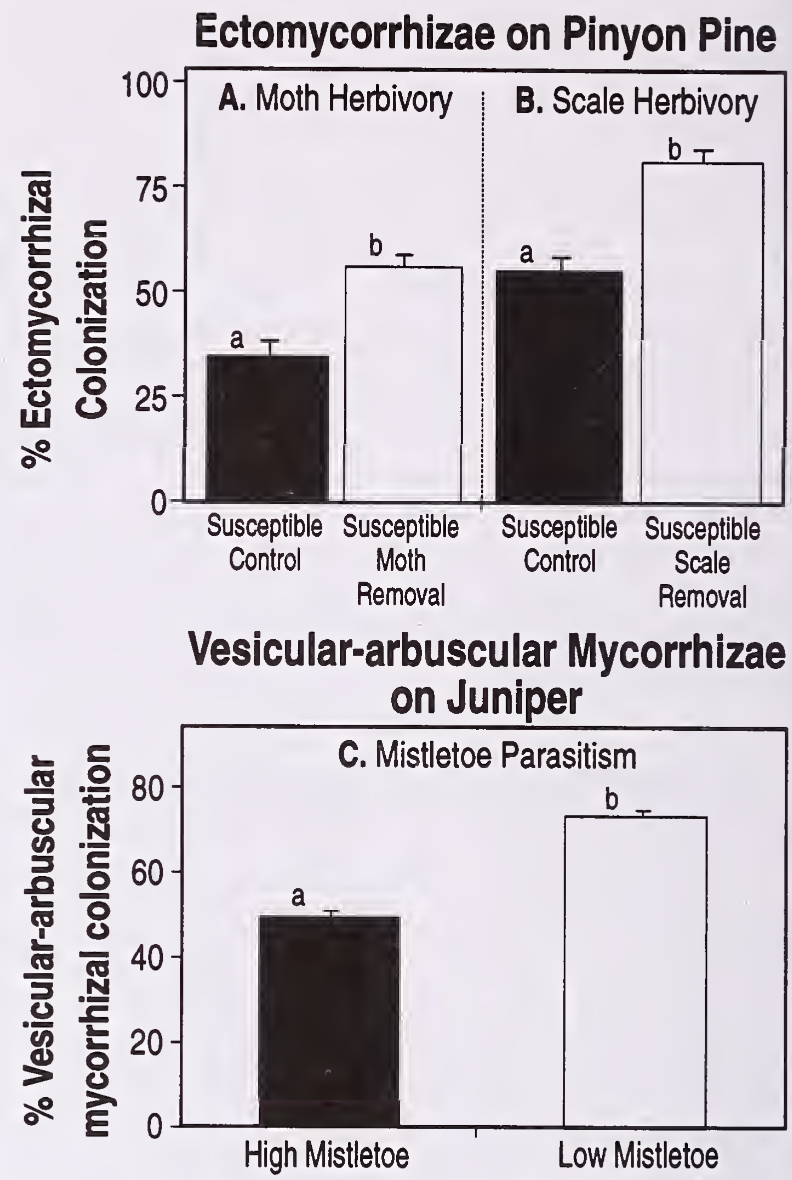

Figure 4.—The relationship between moth (A) and scale (B) herbivory and ectomycorrhizal colonization in piñon pine, and the relationship between mistletoe parasitism and vesicular-arbuscular mycorrhizal colonization in juniper (C). Graphs A and B demonstrate that ectomycorrhizal levels increased following herbivore removal in piñons, while Graph C shows that vesicular-arbuscular mycorrhizal colonization of juniper roots is lower in heavily mistletoe parasitized trees. Values are means + 1 S.E. and different letters above the bars denote significant differences at $p < 0.05$. Data were adapted from Gehring and Whitham 1991, 1992, and Del Vecchio et al., 1993).

stress not only influences the responses of mycorrhizae and herbivores individually, but also influences the interactions between the two. Trees growing in more benign environments may be able to retain their mycorrhizae following herbivory or other pest attacks while trees growing in more stressful environments cannot.

MANAGEMENT IMPLICATIONS

Our findings, summarized in Table 2, have several potential implications for the management

Table 2 – Summary of interactions among environmental stress, pest attack, and mycorrhizal colonization in pinyons and junipers.

	Higher Environmental Stress		Lower Environmental Stress	
Factor	Pinyon	Juniper	Pinyon	Juniper
pest attack	high moth herbivory	high mistletoe parasitism (♀ > ♂)	low moth herbivory	low mistletoe parasitism (♀ = ♂)
mycorrhizae	high ectomycorrhizal colonization	no data	low ectomycorrhizal colonization	no data
mycorrhizae-pest interaction	natural or simulated herbivory causes declines in ectomycorrhizae	high levels of mistletoe parasitism associated with declines in vesicular-arbuscular mycorrhizae	no effect of simulated herbivory on ectomycorrhizae	no data

of piñon-juniper woodlands. First, our results suggest that piñons and junipers are more likely to experience attack by three different pests as environmental stress increases. This finding is especially noteworthy because these pests exhibit the same patterns even though they have different lifestyles and feeding modes; a parasitic mistletoe that feeds from the xylem sap, a scale insect that feeds from the mesophyll of needles from juvenile plants, and a stem- and cone-boring moth that attacks mature trees. These results have implications for broad issues associated with global climate change. For example, if environmental threats such as global warming cause soil in more benign environments to become warmer and drier (two characteristics of the stressful environments we studied), our findings suggest that trees growing in warmer conditions would experience increased susceptibility to attack by a variety of pests and would, as a result, suffer reduced rates of growth and reproduction. Ayres' (1993) observation that the rate of increase of moth populations on mountain birch trees was 2.9-fold higher on trees growing in a greenhouse warmed by only one degree Celsius relative to controls supports this hypothesis. Ayres (1993) predicted that global warming of only 2 to 4 degrees would lead to outbreaks of many insect herbivores if insects are generally more sensitive to temperature increases than their host plants. However, we believe that plant-herbivore responses to global warming are likely to be more complex than this. For example, 75% of the 450 studies reviewed by Waring and Cobb (1992) reported significant herbivore responses to plant stress. These responses varied from positive to negative to nonlinear and depended upon the types of plants (e.g., flowering plants vs. conifers) and the resource requirements of the herbivores involved (Waring and Cobb 1992).

Second, our data suggest that the mycorrhizae of piñon-juniper woodlands are also likely to be affected by global climate change, although the response of mycorrhizae is less clear. Our finding that piñons growing in stressful cinder environments have higher ectomycorrhizal levels than piñons growing in sandy loam soils leads us to predict that mycorrhizal colonization would increase with global warming. We found that piñons growing in sandy loam soils had 33% higher levels of ectomycorrhizal colonization during a drier year than a moister year, supporting this hypothesis (Gehring and Whitham, unpub data).

However, we have shown that pests such as herbivores and mistletoes have a negative effect on mycorrhizae and have hypothesized that the densities of these pests were likely to increase with global warming. Therefore, any increases in mycorrhizae observed in response to the increased abiotic stress of warmer, drier soil could be offset by decreases in mycorrhizal colonization in response to increased pest attack. The mycorrhizae of some herbaceous species, especially grasses, have been shown to be reduced by herbivory (e.g., Bethlenfalvay et al., 1988, reviewed by Gehring and Whitham 1994a) suggesting that piñon-juniper community understory species may exhibit similar complicated relationships with environmental stress and parasite attack.

Third, the negative association we observed between aboveground pests and belowground mutualists emphasizes the importance of studying both components of the plant (shoot and root systems) in concert. Assessment of damage to aboveground tissues alone does not give us a complete understanding of the impacts of aboveground pest attack. For example, aboveground herbivory has negative effects on piñon ectomycorrhizae in cinder soils, but not in sandy loam soils, suggesting that the effects of aboveground herbivory on belowground processes can vary with environmental stress and may not be easily predicted. The same is likely to be true for other aboveground stressors such as grazing, some fires, etc.

Finally, the patterns of increasing herbivory and mycorrhizal reductions on trees growing in cinder soils have additional management implications because they are associated with host plant genetics. Mopper at al. (1991) found genetic differences both between piñons growing in cinder and noncinder soils, and between moth-resistant and moth-susceptible piñons growing in the cinders. Furthermore, Cobb and Whitham (1994) observed an association between growth and genotype in piñons growing in the cinders, and found that the slowest growing genotypes were significantly less abundant in mature trees than juvenile trees suggesting that selection had favored the fastest growing genotype. These differences suggest that the abilities of piñons at Sunset Crater to survive and to resist herbivory are likely to be genetically based. These results have two additional implications for the management of piñon-juniper woodlands.

First, these genetic data combined with data on the associations between piñon community members and piñon insect resistance, argue that there is a genetic basis to piñon community structure that links community members. We have already described linkages between mycorrhizal mutualists and insect-resistant and insect-susceptible piñons. In addition, Christensen and Whitham (1991, 1993) found that moth herbivory on insect-susceptible trees had significant impacts on the birds and mammals dependent upon piñon seeds for food. Thus, through its negative effect on the cone production of genetically susceptible trees, moth herbivory caused a shift in the balance between birds and mammals. At stressed sites with high levels of moth herbivory, the majority of the piñon crop was harvested by mammals, who act as seed predators, rather than by birds who are important seed dispersers (Christensen and Whitham 1991, 1993). Such plant genetics-based linkages between diverse taxa in piñon-juniper woodlands may make this community more susceptible to environmental perturbations than other communities where members are less tightly linked or are loose assemblages of species. Therefore, management decisions that affect one community member (e.g., piñon pine) may have repercussions on the entire community dependent upon that species.

Second, because plant genetics plays a role in piñon drought tolerance and resistance to insect herbivory, environmentally stressful areas such as Sunset Crater are important to conserve because of the unique plant genotypes they possess. For example, Sunset Crater and other cinder sites may contain some of the most drought-tolerant and insect-resistant piñon genotypes. These stress-tolerant genotypes could be commercially important for outplanting in arid areas, and could serve as adapted gene pools in the event of global warming and piñon die-back. Thus, although it is important to preserve the center of a species distribution, where its growth and reproduction is greatest, the conservation of more extreme boundary populations under greater biotic and abiotic stress may be of equal importance.

ACKNOWLEDGEMENTS

The work reviewed here was supported by USDA grants 91-37302-6224 and 92-37302-7854, DOE grant DE-FG03-94ER61849, and NSF grant BSR-9107042. The authors thank the U.S. Forest Service for access to the study sites.

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Stand Dynamics on Upper Elevation Piñon-Juniper Watersheds at Beaver Creek, Arizona

Gerald J. Gottfried[1] and Peter F. Ffolliott[2]

Abstract.—There is a lack of information about stand dynamics, especially volume growth, in the piñon-juniper woodlands of the southwestern United States. Such information is vital for managing woodlands on a sustainable basis for tree products. Harvesting in excess of growth will diminish the resource. Growth information is also needed to understand ecosystem dynamics and to ascertain stand changes that affect other resources, such as wildlife habitat. Two overstory inventories, spanning a 24-year period, were conducted on permanent points on two untreated watersheds in central Arizona. Alligator juniper (*Juniperus deppeana*) is the dominant species on the watersheds, which are representative of woodlands at the upper elevations along the Mogollon Rim. Although inventory procedures have changed the first inventory in 1964, the repeated measurements utilizing the original techniques can produce valuable information about stand changes over the intervening period. Periodic annual growth for trees present in 1964 and 1988 was 18.5 cubic feet per acre and net periodic annual growth was 20.3 cubic feet per acre. Relationships between diameter at breast height (dbh) class and equivalent diameter at root collar (edrc) and between edrc and total height or crown area were developed for alligator juniper.

INTRODUCTION

Healthy and sustainable ecosystems are goals of ecosystem management. Information on stand dynamics, particularly growth, is essential for the management of any ecosystem. Excessive harvesting or mortality, above growth levels, will diminish the resource, compromising sustainability objectives. Basic stand growth and dynamics information is also necessary in order to understand ecological processes within an ecosystem and can be used for planning and evaluating impacts of a variety of management treatments. Information on tree growth, mortality, and stand dynamics in commercial forests and in many woodlands is routinely collected by managers and researchers. Some studies have followed stand dynamics for decades. Although piñon-juniper woodlands cover large areas of the Southwest, similar data collections have only begun in recent years. One reason for the delay is that ecosystem management of piñon-juniper woodlands for a number of resources and amenities is a relatively recent development (Gottfried and Severson 1993). Following World War II, trees were eradicated from large areas in the hope of improving forage for livestock production, water yields, and wildlife habitat. The value of destroyed tree resources was not considered. Another reason for the lack of multiresource management is difficulty of obtaining data. In most temperate forests, past growth can be determined by increment core samples from trees. This procedure will work in woodlands where piñon is the main species or an important component. However, increment cores

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have less value in stands where junipers dominate, since these trees have many false and missing rings.

In the late 1950s and 1960s, a watershed evaluation program was established in central Arizona to test hypotheses concerning the relationships between vegetation manipulations and the augmentation of water yields. The program was concerned with the ponderosa pine (*Pinus ponderosa*) and piñon-juniper vegetation types. Research efforts also included evaluating the effects of a series of treatments on livestock forage, timber production, wildlife habitat, recreational values, and erosional dynamics. As part of the effort, repeated overstory inventories were conducted at permanent inventory points to ascertain changes resulting from treatments.

Some watersheds, designated as control areas, were not treated. Two piñon-juniper watersheds, dominated by alligator juniper (*Juniperus deppeana*), were not treated and, therefore, provide the opportunity to evaluate stand changes from 1964 to 1988. Woodland inventory techniques had not been refined in 1964 when the watersheds were first inventoried. The inventory crew adapted procedures commonly used in ponderosa pine forests to juniper species characterized by multi-stemmed growth forms. Although woodland inventory procedures have changed (Meeuwig and Budy 1981), repeated measurements using the original procedures provide valuable information about stand dynamics over the 24-year period. The information, although from one case study, could be applicable to similar alligator juniper stands within the Southwest.

STUDY AREA

The Beaver Creek Study Area is located south of Flagstaff along the Mogollon Rim and within the Verde River Basin of central Arizona. The area within the Coconino National Forest; the USDA Forest Service is responsible for administration of activities not related to research. Elevations in the watersheds range from 3,000 to 8,000 feet. Beaver Creek contains 18 small experimental watersheds, six of which support piñon-juniper stands. These stands are located on sloping mesas and breaks, steep canyons, and valleys; elevations range from 4,500 feet to 6,500 feet (Clary et al. 1974). Utah juniper (*J. osteosperma*) is the dominant tree species on three of the watersheds; alligator juniper, the species of interest, is dominant on the others.

Piñon-juniper woodlands are generally located at 7,500 feet in the Southwest. The alligator juniper stands at Beaver Creek are present at elevations less than 7,500 feet but are considered upper elevation stands in areas along the Mogollon Rim. Alligator juniper, a representative of the Madrean flora of Mexico, is present above 6,000 feet in Arizona and in the southern two-thirds of New Mexico (Gottfried and Severson 1993). It is also the most common juniper in northern Mexico.

Repeated inventories of the two untreated alligator juniper watersheds are the basis for the study. These areas are designated Watershed No. 4 and Watershed No. 5. The characteristics of these watersheds have been presented by Clary et al. (1974), Baker (1982), and Pollisco (1987). Average elevations of these watersheds are 6,200 to 6,400 feet, where annual precipitation averages about 20 inches and ranges from 16 to 27 inches (Clary et al. 1974). Approximately 62 percent of the precipitation falls from October through April (Baker 1982). Mean annual temperature is 50° F.

The soils on the two watersheds primarily belong to the Springerville series, with Springerville very stony clay, 0 to 10 percent slopes being most common (Williams and Anderson 1967). Springerville soils, which developed from weathered basalt and cinder materials, are classified as Typic Chromusterts. Basalts and cobblestones can cover from 30 to 50 percent of the surface.

The tree species on the two areas included alligator juniper, Utah juniper, piñon, ponderosa pine, and Gambel oak (*Quercus gambelii*). The taxonomy of the piñon is still unclear. It generally has one needle in a fascicle and has been classified as *Pinus edulis* var. *fallax*, *P. fallax* or *P. californiarum* subsp. *fallax*. The two watersheds had similar basal areas, but the distributions of the species were different (table 1.) Alligator juniper was the most common species on both watersheds, with 55 and 86 percent of the basal areas, respectively. The high number of alligator juniper trees on Watershed 5 is because of the larger number of young trees. No effort was made to separate trees of sprout or seed origin. Utah juniper and ponderosa pine appeared to be more common on Watershed 4. Ponderosa pine was present along the drainages and on the upper slopes. Alligator juniper constitutes 69 percent of the basal area on the combined stand and 75 percent of the trees (table 1). Blue grama (*Bouteloua gracilis*) is the principal understory species. The vegetation has been classified as belonging to the *Juniperus deppeana/Bouteloua gracilis* Habitat Type (USDA Forest Service 1987).

Table 1.—Stand conditions in 1964 on Beaver Creek Watershed 4, Watershed 5, and the combined watersheds. (Tree and basal area (square feet) values are on a per acre basis.)

	Watershed 4		Watershed 5		Combined Watersheds	
Area (acres)	333		64		397	
No. inventory points	63		46		109	
Species	**Trees**	**Basal Area**	**Trees**	**Basal Area**	**Trees**	**Basal Area**
Alligator juniper	95.2	22.6	471.3	37.0	253.9	28.7
Piñon	0.0	0.0	31.8	1.6	13.4	0.7
Utah juniper	48.3	7.5	56.0	1.6	51.6	5.1
Ponderosa pine	33.6	9.9	1.0	2.2	19.8	6.7
Gambel oak	1.9	0.8	0.7	0.5	1.4	0.7
Total	179.0	40.8	560.8	42.9	340.1	41.9

METHODS

Information on tree growth, mortality, and stand dynamics was based on the repeated measurements of trees surrounding permanent inventory points in 1964 and 1988. The point locations were determined according to a multiple random start design (Shiue 1960). The points were on transects established perpendicular to the main stream channel on each area and extended to the watershed boundaries. Tree information was collected at every third point along the transects. The distances between points and, thus, the number of points were different on the areas (table 1). Inventory data were combined to improve representation of conditions in piñon-juniper stands characterized by alligator juniper.

All measurements were made on trees selected by variable plot (point) sampling based on a 25 BAF angle gage. A total of 109 points were included in the analysis; several points were eliminated because of questionable data. The 1964 inventory adapted techniques commonly used in ponderosa pine forests to the woodlands. In this inventory, the gage was aimed at the breast height (bh) to determine if a tree was to be included in the sample, and the species and diameter at breast height (dbh) were determined. Trees that were forked below bh were tallied as separate trees. The measurement locations were not permanently marked on the trees. Current procedures for using point sampling in piñon-juniper woodlands call for the angle gage to be sighted at stump height or at the root collar (rc) (Meeuwig and Budy 1981). Fixed area plots are used by some woodland managers and researchers (Chojnacky 1988). In addition, woodland tree diameter measurements are commonly made at rc not bh. However, the use of dbh is easier to justify with alligator juniper, since older trees are often single-stemmed. To replicate the 1964 inventory, the crews used the same procedures in 1988. Border trees were checked with a tape to compare tree distance from the point to the critical distance based on dbh and the BAF. In 1988, measurements were also made at drc, and measurements of total height and mean crown diameter were included. Mean crown diameter is the geometric mean of the longest crown diameter and the perpendicular diameter, and represents the vertical crown projection. Only dbh and total height were measured on ponderosa pine and Gambel oak. Tree regeneration was not sampled.

The 1964 data were recorded by 2-inch diameter class; for example, the 10-inch class includes trees with diameters between 9.0 and 10.9 inches. In 1988, measurements of drc and dbh were made to the nearest 0.1 inch. Equivalent dbh (edbh) and equivalent drc (edrc) were calculated for stems over 1.5 inches on multi-stemmed trees (Chojnacky 1988). Growth was based on changes in dbh class over the period; this is appropriate because bh was not marked on sample trees. Some trees showed declines in dbh over the period. Since past growth cannot be determined from increment cores, these trees were assigned the 1988 diameter, providing a more conservative estimate of growth.

Growth was calculated using standard procedures (Husch et al. 1972, Chambers 1984) and following the example described by Gottfried (1992) for a southwestern mixed conifer stand. Changes were based on trees present in 1964 and 1988; these are classified as "survivor trees". The 1988 trees per acre values include ingrowth into the 2-inch class, while ingrowth for volume includes new trees that grew into the 2-inch class or survivor trees that grew into the 6-inch class for ponderosa pine. Ongrowth trees, other than those qualifying as ingrowth, are not included; these are trees of any size that were too small to be measured in 1964 but have grown sufficiently during the interim to be included in the subsequent inventory. In variable plot sampling, ongrowth does not represent past periodic growth but serves as a basis for future growth evaluations.

Volume for piñon and the junipers was based on the cubic foot volume equations developed by Chojnacky (1988) for Arizona woodland species. Regression relationships were developed between the 1988 dbh class and edrc (figure 1) to make the volume calculations. A similar relationship was calculated by Chojnacky (1988) using data from the San Carlos Apache Reservation in south-central Arizona (figure 1). A relationship between edrc and total height also was required (figure 2). Chojnacky (1988) only used data from single-stem trees while data from single and multi-stem trees were combined for the development of the Beaver Creek relationships. Approximately 20 percent of the junipers in the Beaver Creek sample had multiple stems. Ponderosa pine volumes were based on equations developed by Myers (1963) and oak volumes were based on tables presented by Barger and Ffolliott (1972).

Regression relationships were developed between edbh and edrc, edrc and total height, and edrc and crown area since there is a lack of information about characteristics of alligator juniper. Several linear and multiple regression models were evaluated, and the best, based on the coefficients of determination (r^2), are presented.

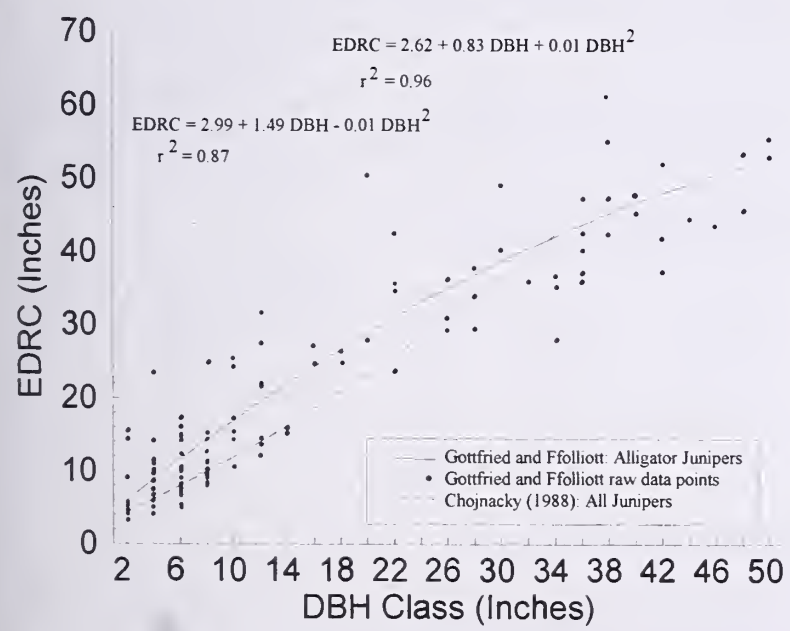

Figure 1.—Relationship between DBH class and EDRC for alligator juniper at Beaver Creek. (The Beaver Creek relationship is compared with the one developed by Chojnacky (1988) for junipers on the San Carlos Apache Reservation.)

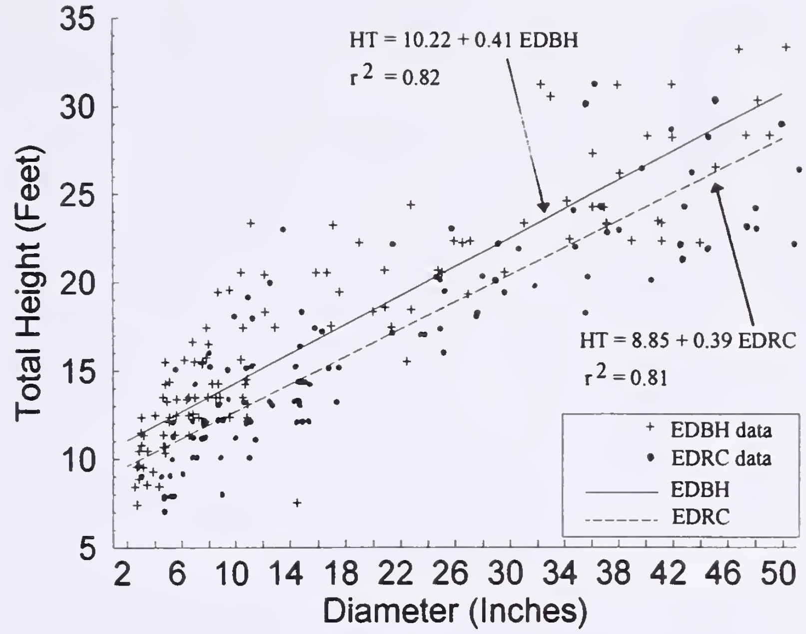

Figure 2.—Total height by diameter relationships for alligator juniper at Beaver Creek.

RESULTS

Total Stand

Trees and Basal Area

Stand changes over the 24-year period, including ingrowth and mortality, are presented in table 2 and figure 3. The data indicate increases in the most diameter classes equal to or greater than 4 inches. A majority of trees in the 2 through 8-inch dbh classes grew into the next higher class. Many larger trees also grew into larger dbh classes. A few trees grew two size classes during the period. The number of survivor trees (table 2), as with basal area, does not change in this accounting procedure. There was a gross increase of 90 trees per acre and a net increase of 68 trees per acre, or 2.9 trees per acre per year.

The survivor stand had a basal area of 37.6 square feet per acre. This value does not change because the same trees are present during both periods. In point sampling, basal area is a function of the number of trees tallied. Total ingrowth produced an increase of 1.8 square feet per acre while mortality was 4.1 square feet. Net basal area growth for the period had a decline of 2.3 square feet per acre; this is equivalent to a net periodic annual decline of 0.096 square feet.

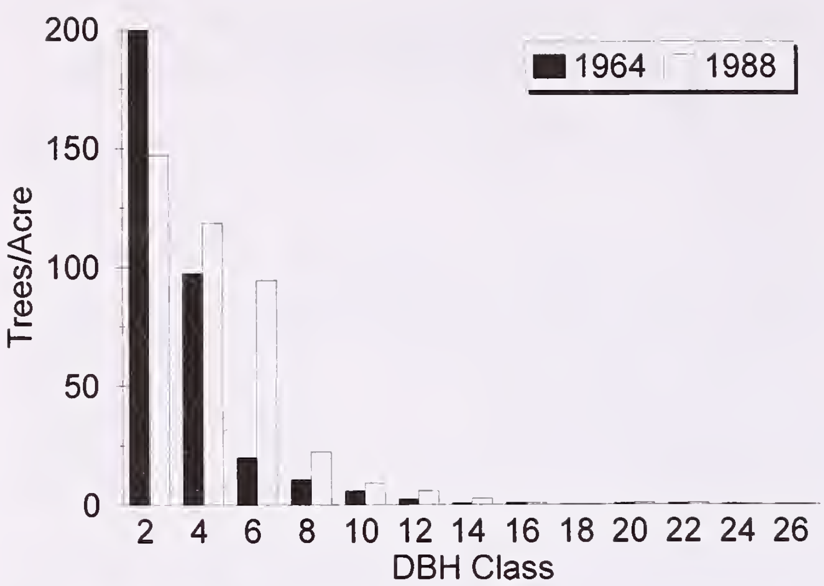

Figure 3.—Distribution of trees per acre by diameter class for the stand between 1964 and 1988.

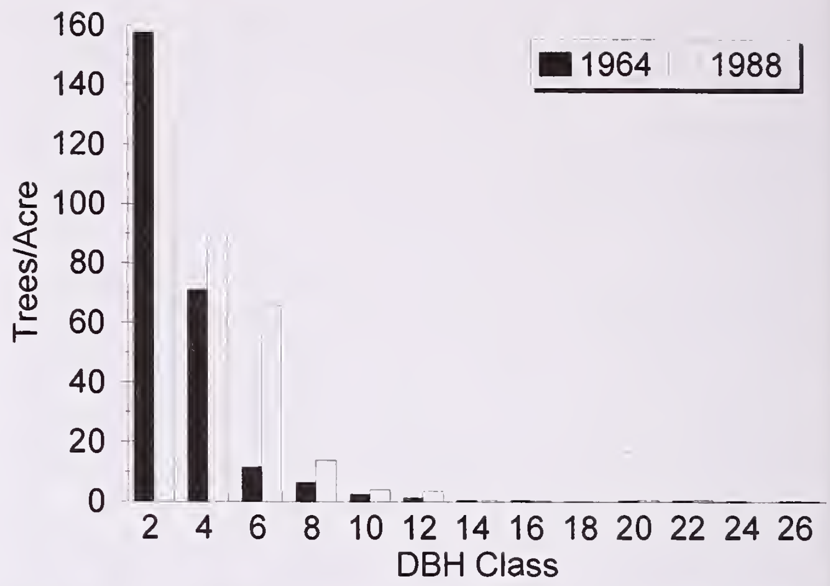

Figure 4.—Distribution of trees per acre by diameter class for alligator juniper between 1964 and 1988.

A similar shift in the distribution of trees among size classes is demonstrated for alligator juniper (figure 4). Alligator juniper had the greatest increases (table 2). Net periodic annual growth was 2.2 trees per acre. Survivor basal area was 25.9 square feet, ingrowth was 1.4 square feet, and mortality also was 2.8 square feet. The net periodic annual increment was a decline of 1.4 square feet.

Mortality (table 2) included trees that died of natural causes and those trees that were mistakenly or illegally harvested. Seventy-five percent of the alligator juniper mortality, in terms of basal area, was in trees 24 inches or larger that were harvested. It was not determined if harvested trees were dead before they were cut. One 20-inch ponderosa pine was also cut. Ponderosa pine mortality for the 24 years, in terms of basal area, was 1.2 square feet and piñon mortality was 0.2 square feet.

Volume

Cubic foot per acre volume increased during the 24-year period (table 2). The stand originally contained 1,010.0 cubic feet per acre; this is equivalent to 13.5 cords per acre, if 75 cubic feet per cord (Conner et al. 1990) is assumed. Survivor periodic growth was 445.1 cubic feet, gross growth was 567.8 cubic feet, and net periodic growth was 487.2 cubic feet. The net periodic annual increment was 20.3 cubic feet per acre per year. The stand grew by

Table 2.—Total stand and cubic foot volume changes between 1964 and 1988.[1]

	Changes in Number of Trees Per Acre							
	Periodic						Annual	
Species	V_1	M	V_{s1}	I	V_{s2}	G_s	G_g	G_n
Alligator juniper	253.9	10.9	243.0	63.1	243.0	0.0	2.6	2.2
Piñon	13.4	10.5	2.9	10.5	2.9	0.0	0.5	0.0
Utah juniper	51.6	0.0	51.6	10.5	51.6	0.0	0.5	0.5
Ponderosa pine	19.8	0.3	19.5	5.8	19.5	0.0	0.2	0.2
Gambel oak	1.4	0.0	1.4	0.0	1.4	0.0	0.0	0.0
Total	340.1	21.7	318.4	89.9	318.4	0.0	3.8	2.9
	Changes In Number of Trees Per Acre							
	Periodic						Annual	
Species	V_1	M	V_{s1}	I	V_{s2}	G_s	G_g	G_n
Alligator juniper	646.2	51.0	595.2	50.4	920.2	13.5	15.6	13.5
Piñon	3.6	0.0	3.6	0.0	7.8	0.2	0.2	0.2
Utah juniper	224.7	0.0	224.7	36.8	269.9	1.9	3.4	3.4
Ponderosa pine	123.9	29.6	94.3	35.5	157.1	2.6	4.1	2.9
Gambel oak	11.6	0.0	11.6	0.0	19.5	0.3	0.3	0.3
Total	1010.6	80.6	929.4	122.7	1374.5	18.5	23.6	20.3

[1] *V_1, number or volume of trees measured at the first inventory; M, number or initial volume of mortality trees; V_{s1}, number or initial volume of trees measured at both inventories (survivor trees); I, number or final volume of ingrowth; V_{s2} - V_{s1}; G_g, gross growth: G_s + I; G_n, net growth: G_s + I - M.*

0.27 cord per acre per year. Alligator juniper, with a net periodic annual increment of 13.5 cubic feet per acre, produced about two-thirds of the net growth.

Annual survivor growth for alligator juniper was 13.5 cubic feet per acre. Ninety-seven percent of the growth occurred in trees that were in the 2 through 8-inch dbh classes in 1964. Survivor trees in the 10 through 22-inch classes accounted for two percent and larger trees accounted for the remaining one percent of the growth.

Stocking

In 1964, 73 percent of the points were stocked with trees at 25 square feet per acre. Ingrowth only accounted for one additional point. One point, which was stocked in 1964, became non-stocked because of mortality.

ALLIGATOR JUNIPER RELATIONSHIPS

Understanding relationships between edbh and edrc (figure 5), edrc and height (figure 2), and edrc and crown area (figure 6) is helpful when managing alligator juniper stands, especially if local data are not available or if the sample size is small. Even if the actual coefficients are not applicable, the availability of functional models may be helpful and reduce analysis time. The edrc and height relationship was not compared with the dbh class and height relationship prepared by Barger and Ffolliott (1972).

One possible use of the edrc-crown area and edrc-total height relationships for developing areal volume and stand tables. Data from a number of

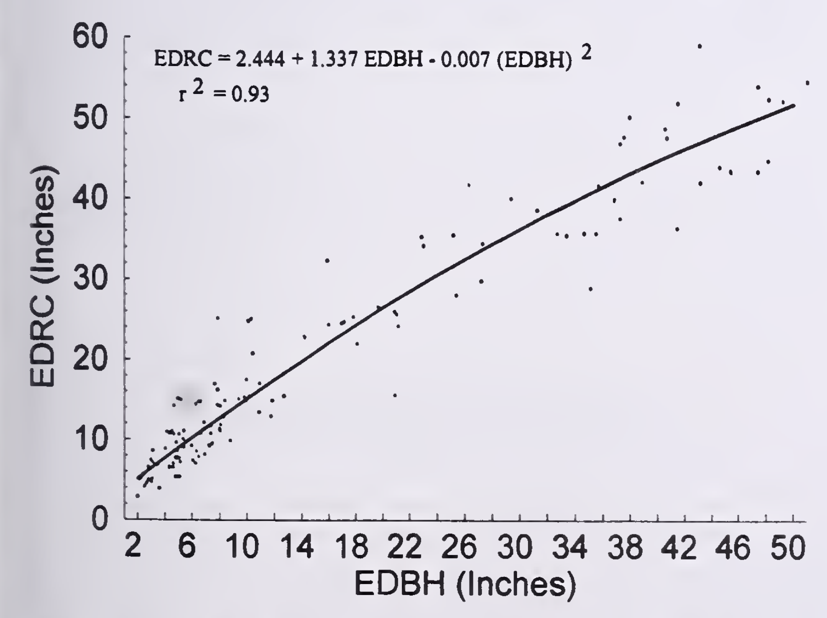

Figure 5.—Relationship between equivalent DBH (EDBH) and EDRC for alligator juniper.

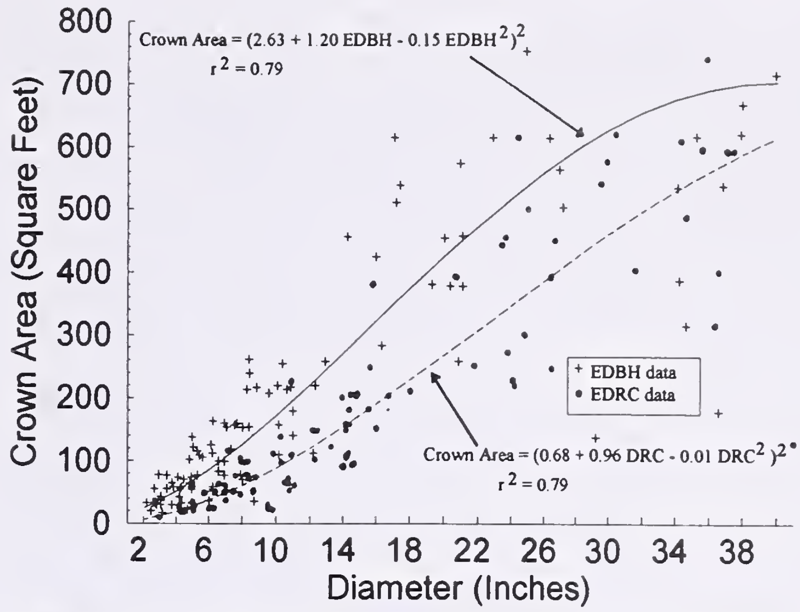

Figure 6.—Crown area by diameter relationships for alligator juniper at Beaver Creek.

stands would be needed, and evaluations of the volume tables would be necessary before being used in management activities.

DISCUSSION

Long-term growth information is not common for southwestern piñon-juniper stands. Efforts currently are being made to remedy this situation as managers begin to consider multiresource, ecosystem management for the woodlands. Growth information is needed to avoid exploiting the tree resources. This exploitation would not only impact the trees and the continuous flow of related products but also affect wildlife species that depend on the trees or on interior woodland habitats. Alligator juniper is important for a number of wildlife species, and managers often attempt to prevent harvesting of the species. Even the diversity of herbaceous species would be affected, since some cool season grasses depend on a tree cover (Clary and Morrison 1973, Gottfried and Severson 1993).

Repeated inventories on Beaver Creek provide some information about stand dynamics over time in terms of the distribution of trees by diameter class and volume growth. The analyses indicate that stand density is increasing but at a slow rate. Net growth was only 2.9 trees per acre per year. The smallest diameter classes had the greatest growth; this is consistent with the findings of Barger and Ffolliott (1972) who reported diameter growth between 0.05 and 0.07 inch per year. A direct data comparison is possible, however.

Initial stand volume of 1,010 cubic feet per acre was relatively high. Conner et al. (1990) reported that average stand volume for piñon-juniper stands in Arizona national forests was 663 cubic feet per acre including only woodland species and 879 cubic feet per acre including commercial timber species. Net periodic annual growth was 13.5 cubic feet per acre. This is higher than the average net annual growth rate of 6.1 cubic feet per year for all Arizona woodlands (Conner et al. 1990). The range was from 11.7 to 3.1 cubic feet per acre. Ingrowth for the period was 42.1 cubic feet greater than mortality. Although volume growth was above average, most of it was concentrated in the smaller size classes; growth rates were low in the dominant, and commercially preferred, larger trees. The stand is producing about 6.5 cords per acre every 24 years. If unauthorized harvesting could be prevented, most dead juniper wood and some from ponderosa pine could be salvaged, resulting in the availability of 23.6 cubic feet per year or 7.5 cords every 24 years. The stand is merchantable, especially if fuelwood demand is high and markets are close to the stand. A 50-year cutting cycle would produce 13.5 cords, without yields of dead material or ingrowth trees.

Although stand growth is above average for Arizona, most of it is occurring in the smaller size classes. There is still a concern that harvesting could be concentrated in the commercially desirable, and ecologically important, larger trees. Growth rates decrease over time, and there is little information about how long it takes for a 8-inch tree to grow into the 24-inch diameter class. The stand is uneven-aged and the possibility of harvesting according to a single-tree selection prescriptions could be explored. However, the relatively low stand densities reported here, based on basal area, would restrict the prescription depending on the desired levels of crown cover desired. Any prescription would have to protect some of the larger tree for wildlife purposes and should eventually produce a residual stand that is visually esthetic.

Stand growth and dynamics information are also necessary for areas where commercial tree resources are less important than other ecosystem considerations. Harvesting justifiably could exceed growth if managers wanted to create a more diverse landscape by cutting small dispersed openings for wildlife (Gottfried and Severson 1993). Growth information would allow managers to determine the course of tree recovery in regenerated openings and to plan for future treatments designed to ensure spatial and temporal diversity. Information could identify future excesses or deficiencies in the distribution of diameter classes needed by wildlife or future impacts of trees on the production of herbaceous vegetation, and allow for corrective actions.

Ideally, some untreated areas, such as these two Beaver Creek watersheds, should be reserved for long-term monitoring of growth, mortality, and stand dynamics, as well as dynamics of other components of the ecosystem. Monitoring should also be initiated in more of the existing reserved areas. Data from the reserved areas would provide basic ecological information and a basis for evaluating management activities.

CONCLUSION

Stand dynamics and volume growth data are essential for sound management of piñon-juniper woodlands. This information is necessary not only for commercial utilization of tree resources, but also to predict future stand conditions and treatments needed for healthy wildlife habitat or sustained production of herbaceous vegetation. Long-term growth records and studies often are not available and are difficult to obtain from stands where junipers are the main component. The alligator juniper stand on Beaver Creek appears typical of many other stands throughout Arizona and New Mexico. The stand dynamics information could be applicable to many of these stands and might be used with caution if local information is unavailable. However, managers should compare conditions in their areas to those at Beaver Creek and evaluate the suitability of the information before extrapolating the data and making any decisions. The Beaver Creek data might be used in preliminary planning, for example.

Monitoring tree and stand dynamics over time is definitely needed to adequately project conditions and treatment needs. Basic long-term stand data are also needed to better understand of ecological dynamics within an ecosystem. This is particularly important for ecosystem management within the southwestern piñon-juniper woodlands.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the conscientious assistance of H.C. Sanchez, A. Pott, J.H. Yazzie, and R. Kasch of the Rocky Mountain Station; and that of D.P. Guertin and R.R. Pollisco of the University of Arizona.

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Preliminary Results of Decomposition and Cellulose Degradation Along an Environmental Gradient in Northern Arizona

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Abstract.—Litter bags containing ponderosa pine, piñon pine, one-seeded juniper, blue grama grass, and snakeweed litter were placed along an environmental gradient, running from Great Basin Desert scrub through a piñon-juniper woodland community and up into a ponderosa pine forest. Litter types were swapped along the gradient to determine how climate affects decomposition. Litter bags were removed every other month, weighed for mass loss, and analyzed for the different carbon fractions of lignin, cellulose, and carbohydrates after each field collection. The number of cellulose degrading bacteria, organic matter, and the physical characteristics of soils from each site are reported. Thus far, litter placed at the higher elevation sites decomposes faster than at the lower sites. Additionally, snakeweed litter appears to be decomposing more rapidly than any other litter type, followed by blue grama grass, one-seeded juniper, ponderosa pine, and piñon pine. When all species between all sites are compared, initial C:N and lignin:N ratios of the litter samples do not appear to be good indicators of decomposition. When decomposition within sites is compared, initial data show that lignin content alone of the litter may be the best indicator of potential rates of decomposition at the lower elevational sites. In contrast, the lignin:N ratios correlate well with the decomposition rates at the upper sites.

INTRODUCTION

The process of decomposition is controlled by several factors including temperature, moisture, soil structure, and litter quality (Waring and Schlesinger 1985). Since temperature and moisture regulate many ecosystem functions, such as microbial activity and nutrient storage, they are the most critical driving forces in ecosystems (Swift et al. 1979). The effect of temperature and moisture on decomposition changes throughout different biomes (Bray and Gorham 1969). The resulting effect of temperature and moisture on decomposition will also vary according to the litter quality of that biome (Berg et al. 1990). Litter quality, typically referring to the carbonaceous component, and its relationship to the limiting nutrient(s) in an ecosystem, often defines the rate at which decomposition may proceed. Past studies have suggested that the ratios of C:N, lignin:N, and/or cellulose:N are the most significant indicators of the rate of decomposition (Moorhead and Reynolds 1991, Meentemeyer 1978, Schlesinger and Hasey 1981, Aber and Melillo 1980). High nutrient concentration in relation to stored energy (low carbon:nutrient ratio) will promote a higher rate of decomposition (Berg et al. 1982). Litter quality can also be expressed in terms of the relative proportion of the organic constituents. Higher concentrations of sugars and cellulose will further promote the rate

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of decomposition because they are more easily digested by the microflora and fauna (Swift et al. 1979). Small changes in temperature or moisture may have a negligible effect on the decomposition rates of litter of poor quality, whereas, a slight change in either factor could greatly alter the decomposition rate of litter of good quality (Meentemeyer 1984, Berg et al. 1993).

It is anticipated that there will be an average increase in global temperature of at least 1° C in the next 35 to 50 years, as a result of increases in atmospheric CO_2 (Schlesinger, 1991). Schneider (1989), Neilson (1989) and others have shown, using general circulation models (GCM's), that the Southwest will not only experience a rise in temperature but a change in precipitation. Neilson states that, as a result of this increase in temperature, areas (e.g., northern Arizona) will undergo a shift in precipitation from snow to rainfall events (pers. com.). As a result of the change in climate, the GCMs forecast regional spatial shifts in vegetation (Solomon and Shugart, 1993) that will have an effect on carbon dynamics across the landscape (Berg et al. 1990, Anderson 1991, Klopatek et al. 1992). In order to better understand how a climate change may affect carbon dynamics, a litter bag experiment is underway along an environmental gradient proceeding from a Great Basin Desert scrub zone, through piñon-juniper woodlands, and ending in a ponderosa pine forest. Included in this gradient are two ecotones, one between the desert scrub and piñon-juniper communities and the second between the piñon-juniper and ponderosa pine communities. The gradient has an average 2° C temperature difference. Litter samples from the dominant vegetation types have been swapped along the gradient. The placement of litter samples between sites should mimic a change in climate, and any differences in decomposition rates of a given species at different sites should be directly attributable to differences in microclimate changes. This will demonstrate whether decomposition is directly correlated to the environmental changes or, alternatively, more influenced by litter quality. Since ecotones are areas that are highly sensitive to changes (Gosz and Sharpe 1989), the process and rate of decomposition should be highly variable in the ecotones even though only small differences in environmental factors may be observed (Gosz 1992). Thus, this study provides an excellent opportunity to evaluate how climatic, chemical, and biological factors regulate decomposition; in turn, the study will provide information on how climate changes may affect ecosystem processes across the landscape. The specific objectives in this study are to: 1) determine how temperature and moisture influence the decomposition of plant litter along an elevational gradient that changes both in temperature and moisture; 2) evaluate how litter quality affects decomposition along this environmental gradient; and, 3) ascertain how biological activity and chemical properties of soil regulate decomposition.

MATERIALS AND METHODS

Site Description

The study area is located in the Coconino National Forest, due north of Flagstaff, Arizona. Within this area we have chosen five study sites that occur along a 7 km environmental gradient ranging along: (1) a Great Basin Desert scrub (DS); (2) a transition zone from desert scrub to piñon-juniper (DS-PJ); (3) a piñon pine-juniper woodland (PJ); (4) a second transition zone from piñon-juniper to ponderosa pine (PJ-PP); and (5) a ponderosa pine site (PP). Each site consists of a 1 ha plot that has been subdivided into 4 quadrants and fenced to prevent invasion of domestic livestock. The sites are all located within a 10,000 ha (25,000 A) grazing allotment.

All sites were chosen so that geological, topographic, and edaphic differences were minimized. Aspects of the sites range from 20 to 130° with slopes from 2 to 5 percent. The soils at all sites are derived from volcanic material and are classified as Typic Agriborolls at the upper elevations and grading into Aridic Argiustolls at the lower elevations. The soils are all silty clay loams and are slightly basic to slightly acidic. Site descriptions are listed in table 1.

Experimental Design

In late fall of 1993, a litter bag decomposition experiment was established using abscised needle litter collected from ponderosa pine, piñon pine, one-seeded juniper, and blue grama grass and both dead leaves and stems from snakeweed. Each litter type was separated from any foreign material and thoroughly mixed to ensure the purity and homogeneity of the samples. The following number of bags were constructed per each litter type: 180 blue grama bags (BOGR), 98 snakeweed (GUSA), 180 one-seeded juniper (JUMO), 180 piñon pine (PIED), and 98 ponderosa pine (PIPO). Ten grams

Table 1.—Site descriptions.

SITE	Elevation	Slope	Dominant Vegetation
DS	1960 m (6430 ft)	2.3%	*Bouteloua gracilis* Bouteloua gracilis (H.B.K.) Lag. ex Steud.) *Eurotia lanata* Ceratoides lanata (Pursh) J.T. Howell
DS-PJ	2018 m (6620 ft)	2.0%	*Bouteloua gracilis* *Juniperus monosperma* (Juniperus monosperma (Torr.) Little) Pinus edulis (Pinus edulis Engelm. *Gutierrezia sarothrae* (Gutierrezia sarothrae (Pursh) Britt and Rusby)
PJ	2094 m (6870 ft)	4.2%	*Bouteloua gracilis*, *Pinus edulis*, *Juniperus monosperma*
PJ-PP	2222 m (7290 ft)	4.3%	*Poa fendleriana* (mutton grass) *Juniperus monosperma* *Pinus edulis* Pinus ponderosa (Pinus ponderosa Laws)
PP	2277 m (7470 ft)	5.3%	*Muhlenbergia montanus* (mountain muhly) *Poa fendleriana* (mutton grass) *Pinus ponderosa*

of litter were added to each 8 x 8 cm bag constructed of 55 micron mesh on the bottom and 2 mm mesh on the top (the larger mesh allows access to invertebrate decomposers without losing sample out the bottom) (Harmon and Melillo 1990). The bags were sealed with stainless steel staples, labeled with aluminum tags and resulting weights recorded.

Bags of litter of BOGR, PIED, and JUMO were placed at all five sites. GUSA was placed at the lower three sites (DS, DS-PJ, and PJ) and PIPO was placed at the upper three sites (PJ, PJ-PP, and PP). Litter bags were placed in the interspaces at each site to reduce any variability of microclimate and nutrient effects between canopies and interspaces. Four bags of each litter type from each site are being collected every two months throughout the duration of the study. Upon collection, litter bags are placed separate paper bags and transported on ice in a cooler back to the laboratory. Mass loss of litter is determined by weighing litter bags and determining net loss.

Laboratory Analysis

Soil Analysis

Soils were analyzed for several chemical and physical properties. Soils were dried at 60° C for 48 hours and sieved through a 2-mm mesh sieve. The pH's were measured using a 1:1 soil slurry with distilled water (Allen, 1989). Soil organic carbon was determined using a modified method of the Walkley-Black procedure (Jackson 1958). Listed in table 2 are the pH values and organic carbon content of soils from each site.

Cellulose Degraders

Surface soils were collected from each of the lower four sites for estimation of cellulose degrading bacteria. Estimation of bacterial numbers was determined by plate count method. Serial 10-fold dilutions of up to 10^{-5} were plated and subsequently cultured in 0.5 ml aliquots on Stan 5-0.4%

Table 2.—Selected soil properties taken from interspaces (INTER) and under tree canopies at the five study sites.

	SITE									
	Desert shrubland		DS-PJ		Piñon-Juniper		PJ-PP		Ponderosa Pine	
	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC
INTER	7.17	1.37	7.45	1.13	7.23	0.63	7.18	1.10	5.57	2.26
JUMO	*	*	8.29	1.18	8.28	1.18	7.97	1.40	*	*
PIED	*	*	N/A	1.20	7.19	0.97	7.33	1.66	*	*
PIPO	*	*	*	*	*	*	6.60	1.63	5.91	1.69

*species does not occur

cellulose agar. Culture plates were incubated for up to 1 week at 25° C in the dark. The experimental design for laboratory plate counts of cellulose bacteria consisted of collecting soils from 3 vegetation types in the DS site, 4 in each of the DS-PJ and P-J sites, and 5 in the PJ-PP site. Three subsamples were taken from each vegetation type and each was tested with three replicate plates from four dilutions, yielding a total of 576 plates. Although no samples for cellulose degraders were taken at the PP site during the early collection, later samplings have included this site.

Plant Analysis

All sampled litter bags were placed in a drying oven at 65° C for a minimum of 12 hours or until thoroughly dried after collection. The litter bags were then removed from the oven and left at room temperature for 24 hours to allow them to reach equilibrium. The samples were ground through a 20 mesh sieve in a Wiley mill. Ground samples were analyzed for nitrogen, carbon, ash content and the different carbon fractions (see below). Litter carbon and nitrogen were determined using a Perkin-Elmer HCN analyzer. The ash content was determined by ashing litter samples for 4 hours at 550° C. Carbon values were confirmed by calculating 48% of the ash-free dry mass (Schlesinger 1977).

Leaf Litter Carbon Fraction Analysis

Samples were analyzed for Klason lignin, cellulose and total carbohydrates. Oven dried litter samples were milled through a 40-mesh screen and then vacuum dried at 45° C. Approximately 200 mg of the sample was hydrolyzed with 2.00 ml 72% (w/w) H_22S0_4 for 1 hr at 30° C. Samples were then diluted to 4% (w/w) H_22S0_4 with distilled water, fucose added as an internal standard, and a secondary hydrolysis performed for 1 hr at 121° C. Following secondary hydrolysis, samples were immediately filtered through tared crucibles containing glass fiber filters. The filtrate and three washes w/ 5 ml distilled H_2O were collected in 100 ml volumetric flasks. The acid-insoluble residue (Klason lignin) was washed an additional six times with 10 ml hot distilled H_2O and quantitated gravimetrically. Sugar content of the hydrolysates were determined by anion exchange high performance liquid chromatography using pulsed amperometric detection.

Statistical Analysis

This study is just underway, and therefore, at this stage data collected and reported on in this paper represent apparent trends unless otherwise stated. Further sample collections will allow us to statistically analyze the data and develop conclusions. Mass loss data were analyzed using ANOVA with a SAS (1989) statistical program, but yielded few significant differences. For bacteria, least-significant differences (P = 0.05) were calculated only when F value indicated significant difference using ANOVA. It is our intent to evaluate each of the significant parameters (i.e., climate, chemical, physical and biological) that regulate decomposition. These parameters will be used to construct a decomposition model for these predominant semiarid Southwestern ecosystems.

RESULTS AND DISCUSSION

Cellulose Degraders

The overall number of cellulose degrading bacteria (per g dry wt soil) were greater in soils from under BOGR than any other vegetation type (fig. 1). Interspaces had the second highest number of bacteria followed by JUMO and GUSA, and the two pine species. Despite the greater organic matter concentrations under tree canopies, the number of cellulose degraders present were significantly ($p \leq 0.05$) lower than vegetated and non-vegetated interspace soils. It is possible that allelopathic substances may have inhibited these bacteria. Allelopathy has been shown to reduce other soil bacteria in these areas (Klopatek et. al 1990). At the

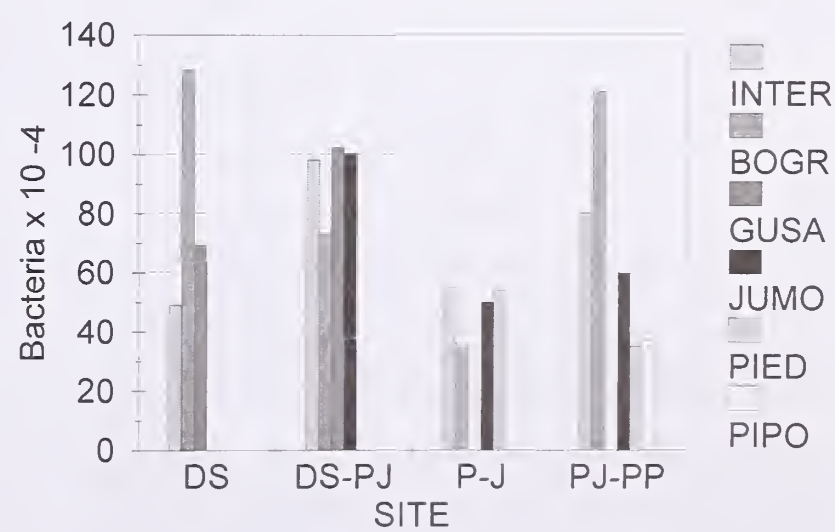

Figure 1.—Number of cellulose degraders in soils taken from interspace, INTER; Bouteloua gracilis, BOGR; Guittierrezia Sarothrae, GUSA; Juniperus monosperman, JUMO; Pinus edulis, PIED; Pinus ponderosa, PIPO.

DS and PJ-PP sites the number of bacteria were greatest under BOGR, whereas there were no differences in the number of bacteria within either the DS-PJ or the PJ sites. The PJ site had the lowest overall number of bacteria which may be related to the low organic carbon in the soils due to the relatively young age of the site since last fire (ca. 140 yrs).

Mass Loss

The effects of climatic factors (i.e., temperature and moisture) on the rate of decomposition are presented in figure 2. Overall mass loss data reveals that the rate of decomposition for BOGR, GUSA, JUMO, and PIPO increases as one moves up the gradient from the lower (DS) to the higher elevational site (PP). But at this time, the total mass loss of all species only differed significantly between the DS and PP sites, as PP site exhibited a statistically greater loss than the DS site. This is probably the result of greater soil moisture and corresponds with the level of actual evapotranspiration (Meentemeyer 1978) at the higher elevational sites. We anticipate that this result will be maintained for several months, particularly through the warmer, dry periods.

Few differences were found when comparing individual species between sites. There were no differences in mass loss for BOGR, GUSA, PIED, and PIPO along the gradient, whereas there was significantly greater decomposition of JUMO at the PJ-PP and PP sites compared to the DS site. When comparing individual species, within a site we found the following results. At the DS site, GUSA was significantly different (i.e., greater mass loss) from PIED and JUMO, whereas BOGR did not differ from any other species. At site DS-PJ, only GUSA showed a significant difference from PIED, and no other significant differences between species were found. There were no significant differences found between any of the species at the PJ, PJ-PP, and PP sites. Apparent differences in the rate of decomposition between species at selected sites are also shown in figure 2. In examining individual litter samples, GUSA appears to be decomposing more rapidly than any other litter type, followed by BOGR, JUMO, PIPO, and PIED. If this holds true, it may be attributed, in part, to the greater percent readily decomposable C sources (Swift et al. 1979) such as glucose, xylan, and cellulose of GUSA and BOGR (table 4) and high numbers of cellulose degrading bacteria (Fig. 1).

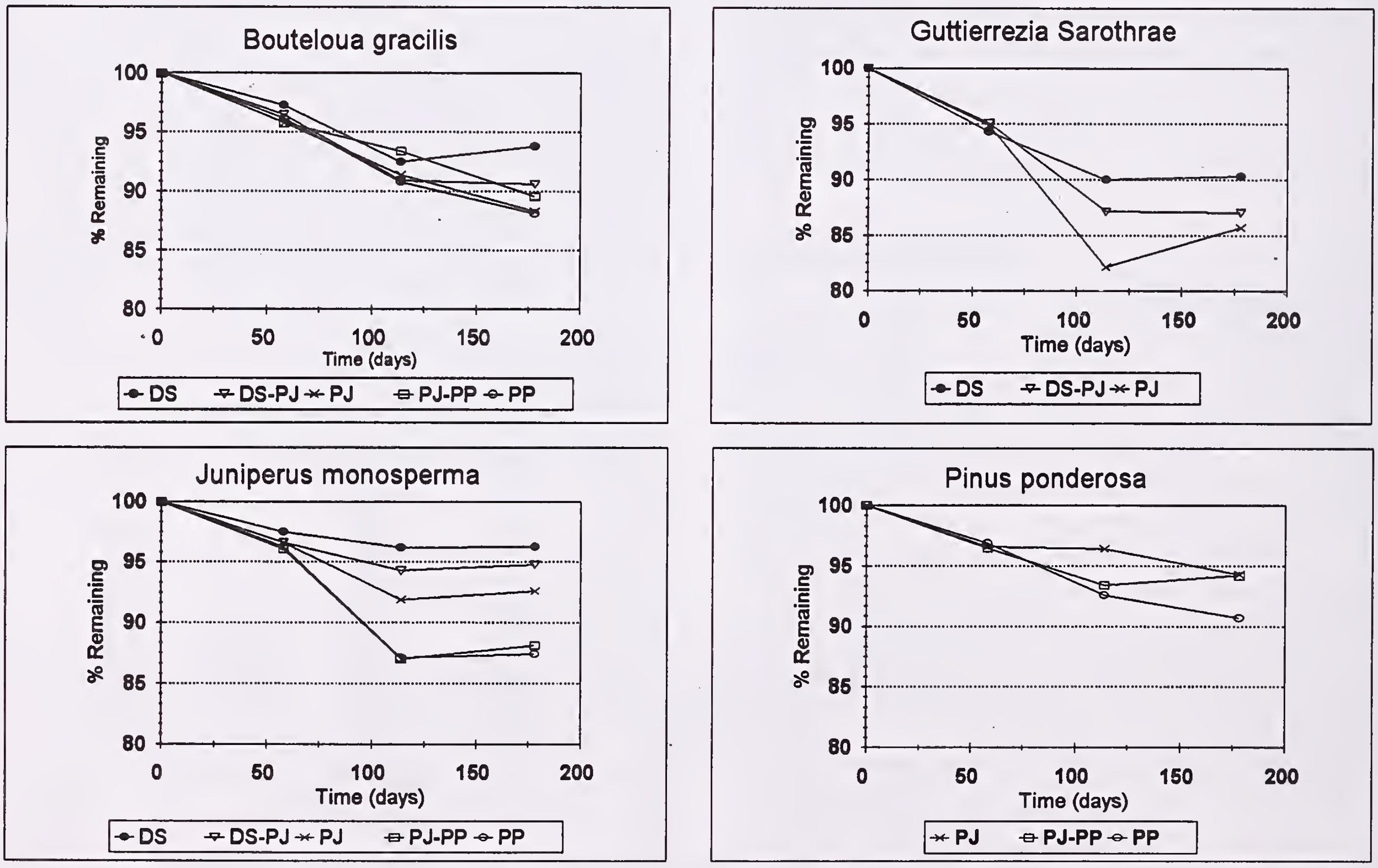

Figure 2.—Decomposition (mass loss) of selected litter types along the gradient over 9 months. Key: DS = Desert Shrub, DS-PJ = Desert Shrub-Piñon Juniper, PJ = Piñon-Juniper, PJ=PP = Piñon-Juniper-Ponderosa Pine, PP = Ponderosa Pine.

Table 3.—Carbon fractions of the five litter types prior to decomposition. Key: KL = Klason Lignin; ASL = Acid Soluble; CEL = Cellulose; Arab = Arabinan; Rham = Rhaman; Gal = Galactan; Glu = Glucan; Xyl = Xylan; Man = Mannan; TL = Total Lignin; Lignin:Carbohydrate ratios determined by Raman Spectroscopy; TS = Total Sugars; values are gm/l gm, TL:CELL = Total Lignin:Cellulose ratio.

	Chemical Analysis												
	KL	ASL	CEL	Arab	Rham	Gal	Glu	Xyl	Man	TL	TS	TL:TS	TL:CELL
	%												
BOGR	27.7	3.2	31.6	3.5	.08	1.44	31.71	18.23	.44	30.9	55.4	.56	.98
GUSA	26.3	4.2	25.47	1.8	.6	1.4	25.7	14.1	.7	30.5	44.3	.69	1.20
JUMO	37.2	4.2	16.73	5.2	.6	2.2	17.5	1.8	2.3	41.4	29.6	1.40	2.47
PIED	41.6	3.9	16.60	3.9	.5	2.3	18.3	1.4	5.1	45.5	31.5	1.44	2.74
PIPO	40.7	3.0	19.50	3.2	.5	2.4	21.2	2.8	5.1	43.7	35.2	1.24	2.24

Effects of Litter Quality

In order to determine the rate of decomposition for a specific litter type, it is important to understand what factors other than climate may be limiting decomposition. In this study nitrogen appears to be a limiting nutrient as suggested by Klopatek et al. (1990) for nearby piñon-juniper sites, while the relative concentrations of organic constituents varies between litter types (table 4). Table 3 lists the C content and litter quality of the initial litter samples. Percent N concentrations were greater in JUMO litter than any other species (table 4). In addition, JUMO had the lowest C:N and lignin:N ratios, whereas PIED and GUSA with the highest C:N ratios had the same percent N content.

Figure 3 shows the relative changes in carbon fractions as a result of decomposition of different litter types at selected sites. When comparing all species between sites, initial C:N and lignin:N ratios of the litter samples do not appear to be good indicators of decomposition (table 3 and Fig. 3). However, when comparing decomposition within sites, initial data shows that lignin content alone of the litter may have the greatest influence on the rate of decomposition (McClaugherty et al. 1985, Berg and Ekbohm 1990). At the lower three sites (DS, DS-PJ, and PJ), initial lignin concentrations from all litter samples are inversely related to the resulting decomposition rate (table 4). GUSA has the lowest lignin concentration and is subsequently decomposing more rapidly than BOGR, JUMO, and PIPO, respectively. Thus, at these lower sites, lignin may be a fair indicator of decomposition. In contrast, at the upper two sites (PJ-PP, PP), the lignin:N ratio is related to the decomposition rate. This trend may be attributable to a switching of limiting factors (between lignin, N and moisture) at the midpoint of the gradient. At the lower elevations, soil moisture limits plant growth and appears to limit decomposition, whereas at the two upper elevations, it appears that the moisture no longer limits, but N may be limiting decomposition. N content of the initial litter was equal within each litter type, but different between each type (Table 4). Since JUMO has the lowest lignin:N ratio and the greatest N content, it decomposed faster than the other litter types, but only at the two upper elevational sites.

Table 4.—Litter elements of the five litter types. Key : %N = Percent Nitrogen, C:N = Carbon to Nitrogen Ratio, Lignin:N = Lignin to Nitrogen Ratio.

	Litter Elements			
	% N	C:N	Lignin:N	% Ash
BOGR	0.540	72.11	57.22	14.92
GUSA	0.590	80.03	51.69	3.11
JUMO	0.915	54.93	45.25	6.63
PIED	0.590	84.39	77.12	4.45
PIPO	0.715	69.41	61.12	3.10

We view these preliminary findings as interesting differences in ecological processes that may be influenced by future climate changes. The initial results suggest several different scenarios for changes in carbon fluxes given a temperature and moisture change. We report indications of trends; however, the evidence on how climate, litter quality and bacterial activity affect decomposition will become more apparent as this research progresses.

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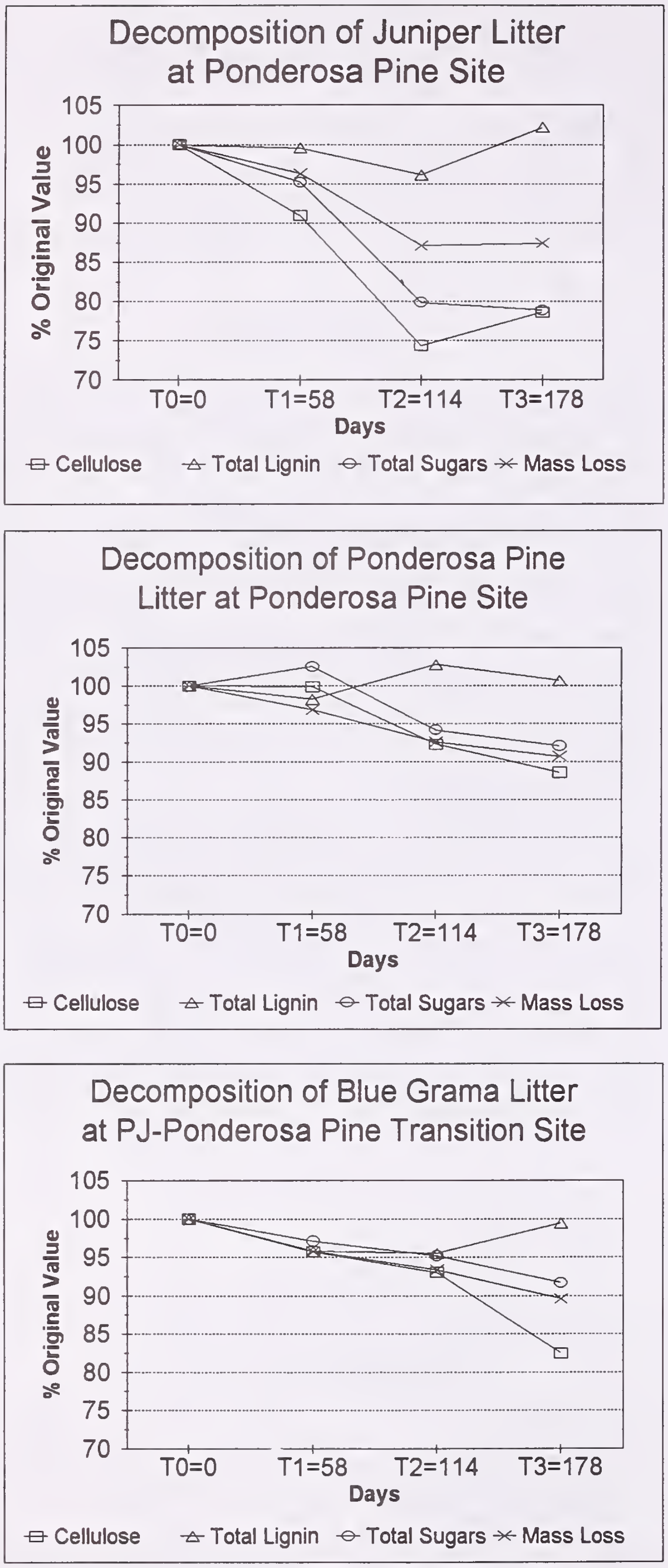

Figure 3.—Relative changes in carbon fraction as a result of decomposition of different litter types at selected sites.

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Deer, Small Mammal, and Songbird Use of Thinned Piñon-Juniper Plots: Preliminary Results

Steven K. Albert[1], Nelson Luna[2], and Albert L. Chopito[2]

Abstract.—In 1992, three 1-hectare plots were thinned to basal area densities of 7, 13, and 19 m^2/ha. Response of mid-story and understory vegetation and use of the plots by deer, small mammals, and songbirds was also measured. Vegetation increased dramatically on the heaviest thinned plot at years post treatment. Number of species present increased significantly ($p < 0.10$) on the treatment plots. Composition of the plant species also changed. Deer use increased in correlation with the amount of trees removed (Rsq = 0.948). Overall small mammal abundance increased on all treated plots. However, piñon mouse density decreased on treated plots. No overall pattern of songbird use of treated or untreated plots emerged from the data. Plot size may have been too small to accurately reflect bird habitat preference. Small thinnings in piñon-juniper woodlands have less drastic effects on wildlife than chainings and are a viable management tool for multiple resource managers.

INTRODUCTION

Several studies have shown the importance of piñon-juniper woodlands to game and non-game wildlife (Swenson 1977; Zarn 1977; Balda and Masters 1980; Balda 1987; Gubanich and Panik 1987; Miller and Albert 1993) and a few studies have explored the effects of chaining or burning of piñon-juniper woodlands on wildlife (McCulloch 1969; Sedgewick and Ryder 1987; Howard et al. 1987; Stevens 1987; Stager and Klebenow 1987; Rosenstock et al. 1989;) However, the days of cabling and chaining piñon-juniper woodlands have long since passed. Range and forestry practices have recognized the value of piñon-juniper woodlands, and have evolved toward uneven-aged and uneven-density management of stands and a multiple use approach to woodland resources. This often includes thinning and selective cutting of piñon and juniper for fuel wood or other uses. Yet little research has been published on the effects of thinned piñon-juniper woodlands on wildlife.

The Zuni Indians and their ancestors have utilized the piñon-juniper woodlands of the Colorado plateau and the piñon-juniper woodlands of the Zuni Valley have provided material and cultural sustenance for the Zuni people for 4,00-7,000 years (Miller and Albert 1993). Central to the Zuni's reliance on the woodlands as a resource is the wildlife which this ecosystem supports. Deer, the most revered animal in Zuni culture, spend the majority of their time on the Reservation's piñon-juniper covered mesa-tops which provide escape and thermal cover and abundant forage such as bitterbrush (*Purshia tridentata*) mountain mahogany (*Cercocarpus montanus*), cliffrose (*Cowania stansburiana*), and gambel oak (*Quercus gambelii*). These areas also remain relatively free of snow during winter, allowing deer easier travel and access to food.

Like many Pueblo tribes in New Mexico, the Zunis also make abundant use of bird feathers for prayer sticks and ceremonial dress (Ladd 1963, Tyler 1979). Ladd (1963) mentioned 72 species of birds important to Zuni ceremonialism. Some of the most important species, (scrub jays (*Aphelocoma coerules-*

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cens), flickers (*Colaptes auratus*), and western bluebirds (*Sialia mexicana*) among others) are frequently found in piñon-juniper woodlands.

Rodents and other small mammals, though not held in the high cultural esteem of deer or songbirds, are important food sources for culturally important animals such as foxes and raptors and their abundance may indirectly affect populations of these predators. For these reasons the Zuni Fish and Wildlife Department initiated a study to assess the response of wildlife to piñon-juniper thinning. The data presented in this paper are the preliminary results of an on-going study.

The authors wish to thank Ronald Miller and Roger Jensen of the BIA Zuni Agency Branch of Forestry for cooperation in setting up the study. Vernon Quam, Cynthia Skinner, Larry Livingston, and Wilbur Haskie assisted in data collection. Thomas Skinner assisted in data analysis.

STUDY AREA

The Zuni Indian Reservation encompasses nearly 203,000 hectares (500,000 acres) in central western New Mexico and eastern Arizona (Fig. 1). Elevations on the Reservation range from approximately 2400 meters (7,800 ft) on the western slope of the Continental Divide to approximately 1,800 meters (6,000 ft) where the Zuni River leaves the Reservation. This range in elevation gives rise to a wide variety of habitat types: douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) forests at the higher elevations grade into piñon-juniper woodlands and eventually sagebrush (*Artemesia tridentata*) or juniper (*Juniperus monosperma*) dominated shrub and woodlands. The Rio Nutria and Rio Pescado join on the Reservation to form the Zuni River. Nine major and several smaller impoundments from these

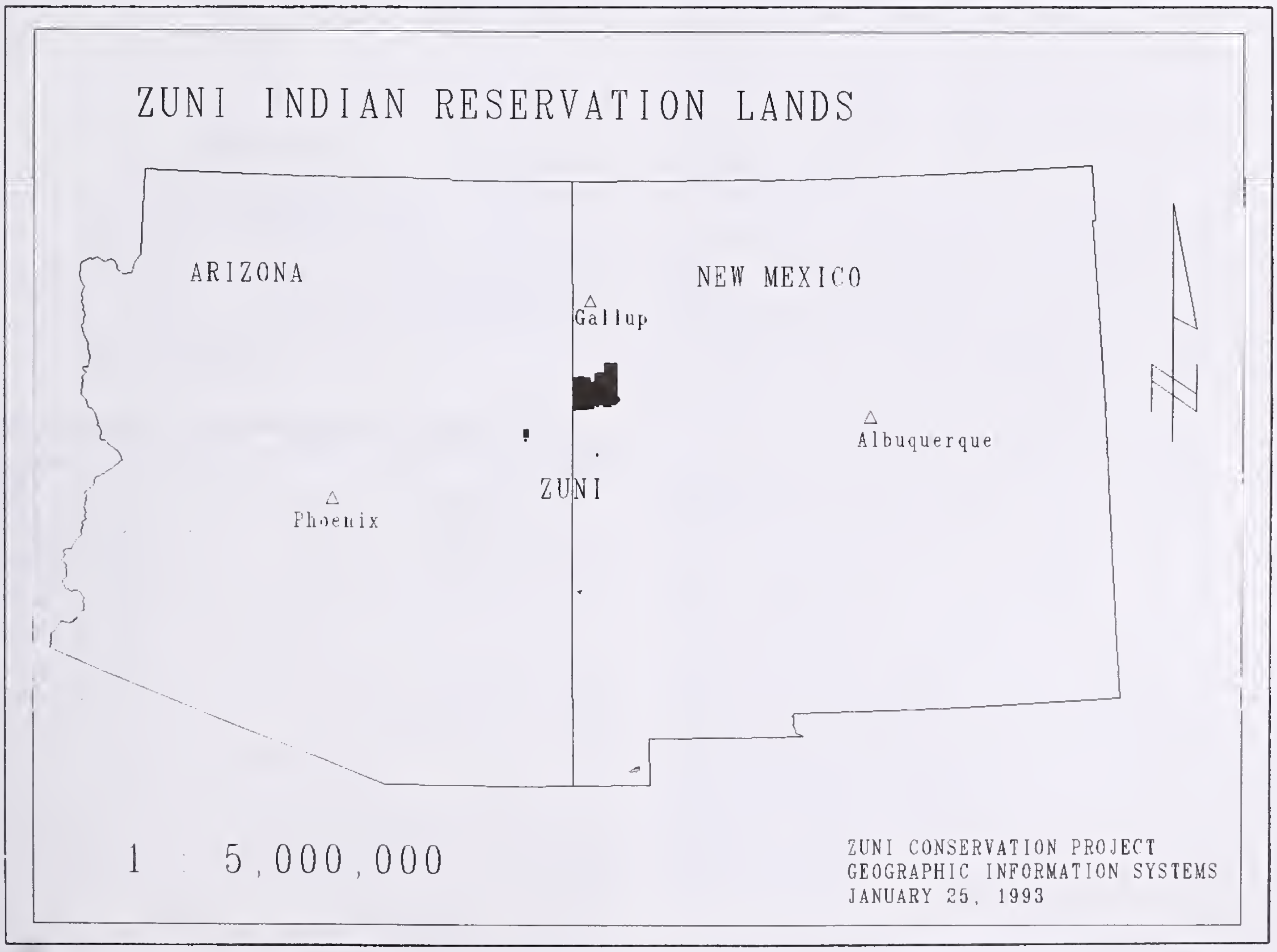

Figure 1.—Zuni Reservation lands, Arizona and New Mexico. Map produced by the Zuni Conservation Project Geographic Information Systems.

rivers and other streams offer a variety of wetlands and lakes. The piñon-juniper habitat type is by far the most abundant in Zuni, encompassing nearly 78,781 hectares (194,618 acres), or 46% of the 169,622 hectare (419,026 acre) main Reservation.

In 1992 the Bureau of Indian Affairs (BIA) began an uneven-aged density stocking study on top of Television (TV) Mesa, east of the village of Zuni. The top of the mesa is relatively flat at an elevation of 2159 meters (7084 ft). The habitat on top of the mesa is a fairly even mix of piñon and one-seed juniper trees with a sparse sagebrush understory. The piñon-juniper habitat on TV Mesa and in many parts of the Zuni Reservation is fairly unbroken and contains few openings.

METHODS

In June 1992, three 1 ha. (2.4 acre) plots were thinned to basal area densities (BA) of 7, 13, 19, and 30 m^2/ha. (31, 55, 83, and 130 ft^2/acre). Each plot was subdivided into 6 equal-sized sub-plots to ensure an equal distribution of the stocking density throughout the plot. Slash was left scattered through the plots unpiled. In conjunction with the BIA study the Zuni Fish and Wildlife Department and the Zuni Conservation Project began to assess the response of vegetation and the use of these plots by various species of wildlife, including deer, small mammals, and songbirds.

General Parameters

The slash and canopy layers for the treated and control plots were measured after cutting. Slash was estimated using the Handbook For Inventorying Surface Fuels and Biomass in the Interior West (Brown et al. 1982). Only slash < 8 cm diameter was used to estimate total down woody fuels. Twenty random points were used within each plot. Canopy cover was estimated for each plot by determining if each of 26 previously established transect points on the big game pellet transects fell underneath canopy or open sky. The total of points that fell under a tree canopy was divided by 26 to give an estimate of canopy cover.

Vegetation

Browse, grass, and forb cover were sampled using a double-sampling technique: the comparative yield method (Haydock and Shaw 1975) and the dry weight rank method ('t Mannetje and Haydock 1963). These methods, which were further refined by researchers at the University of Arizona (Smith and Despain 1992; Despain and Smith 1992) allow a breakdown of the dry weight biomass and relative abundance of all plant species in an area and can be used to estimate carrying capacity for both livestock and wildlife (Albert and Krausman 1992). Two 91 meter (300 ft) transects were established in each stocking plot. Each transect consisted of fifty 0.16 m^2 quadrats, spaced 1.8 meters (6 ft) apart. In the comparative yield method, 5 vegetation "standards" were established which represented a gradation from the lowest to the highest vegetation biomass likely to be encountered on a particular plot. These standards were visual estimates made after surveying the vegetation in the area. When the quadrat was placed on the ground, the vegetation in the quadrat was given a subjective "rank" of 1-5, corresponding to how well it represented one of the standards. The average rank of all the quadrats was calculated and the standards were clipped, oven dried, and weighed to derive their corresponding dry weight. For the dry weight rank method, the three most abundant plant species in the quadrat were ranked according to their estimated dry weight. All species were summed over the plot and multiplied by an algorithm which estimated their relative abundance. Piñon and juniper seedlings of stem < 1 cm were included in the vegetation estimates.

Deer

Deer use was estimated by establishing 26-0.004 ha. (0.01 acre) permanent circular sub-plots per stocking plot. One meter (3.2 ft) re-bar stakes were driven into the ground in the center of each plot and all the deer pellets were cleared from a 3.7 meters (12.1 ft) radius from the center of the sub-plot. Sub-plots were subsequently re-checked and the number of deer pellet groups tallied and removed from the plot to derive a relative use index.

Small Mammals

Small mammals were live-trapped in aluminum Sherman live traps baited with a mixture of peanut butter and rolled oats. One transect of 20 traps, spaced approximately 3 meters (10 ft) apart was placed lengthwise down the center of each stocking plot. A small wad of cotton was placed in each trap to allow the animals a bed and prevent hypo- or hyperthermia. During the first two trapping seasons, data recorded included species, sex, weight, and reproductive status of each animal trapped. Each animal was marked with a small dab of nail polish behind the ear and released where it was caught. However, after the outbreak of the Hantavirus in the spring of 1993, we tried to minimize our contact with rodents, and recorded only species numbers. All data have been standardized to reflect only relative abundance and animals caught/100 trap night. Traps found sprung that contained no animals were not counted as a trap night.

Songbirds

Songbird use was recorded from 3, 15 meter (50 ft) radius fixed stations in each stocking plot. Fixed radius plots were used reduce bias from visibility differences in the different density stocking plots. The fixed-point count has been shown to be an efficient and accurate method of surveying relative abundance of songbirds (Bibby et al. 1992). All birds which landed within a sub-plot in a 10-minute time span were recorded. Nest searches were also conducted in the spring of 1993.

RESULTS

General Parameters

As expected, slash was inversely proportional to stocking density and canopy cover was directly proportional to stocking density (Table 1).

Table 1.—Slash and canopy measurements of study plots.

	BA 7	BA 13	BA 19	BA 30
Slash (kgs/ha) (< 8 cm dia.)	2986	1924	1563	703
Canopy Cover (%)	23	31	38	58

Vegetation

Vegetation biomass increased steadily in the BA 7 plot, with an especially large increase at 2 years post-treatment (Fig. 2). By 2 years post-treatment (PT), the dry weight of vegetation had nearly tripled. The BA 13 showed a very slight decrease in vegetation biomass in successive years, and vegetation in the BA 19 and BA 30 (control) decreased at 1 year PT followed by a slight increase the next year.

Frequency (number of plants encountered) of selected species varied by plot. Blue grama (*Bouteloua gracilis*) increased on all plots at 1-year PT and decreased on the BA 7, BA 19, and Control plots at 2 years PT. Buckwheat (*Erigonum* spp.) increased at 1 year PT and decreased at 2 years PT on all plots (Fig. 3). Big sagebrush (*Artemesia tridentata*)

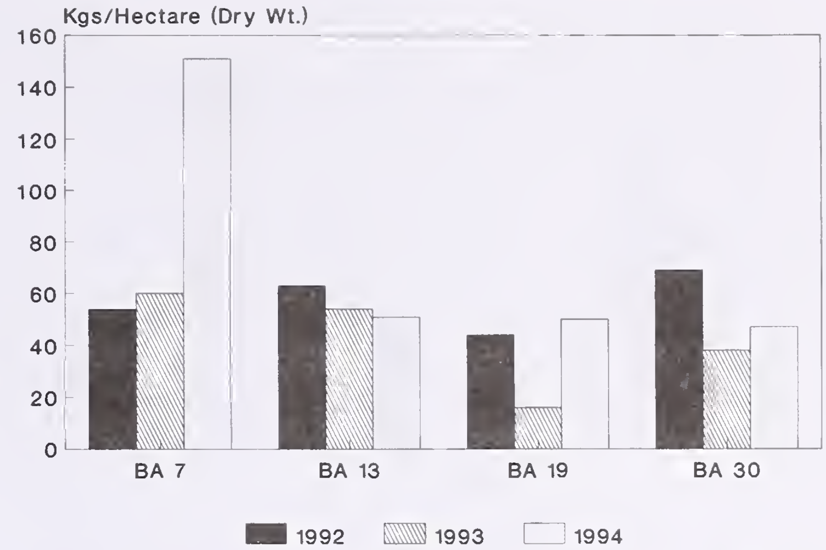

Figure 2.—Vegetation biomass response on study plots, 1992-1994.

was present in small amounts on all four plots and decreased slightly or held steady on all plots. In 12 of the 15 cases (80%) where any of the 5 most prominent species was found in all three years on a plot, the number of plants increased at 1 year PT. In 12 of the 15 cases (80%) the number of plants decreased from 1 to 2 years PT.

Percent composition of plant species changed from year to year (Fig. 4). Juniper and piñon seedlings began to show up 1 year PT, and forbs such as aster (*Aster* spp.), deer vetch (*Lotus wrightii*) and lupine (*Lupinus* spp.) and grasses such as dropseed (*Sporobolus* spp.) and blue grama (*Bouteloua gracilis)* became more common (Table 2). There was a significant increase in the number of species/plot in all the treated plots from 1992 to 1994 ($p < 0.10$ paired t-test).

Deer

A qualitative assessment of initial deer use of all plots showed that deer use was small. This was probably due to the fact that the study area was unfenced and fairly frequently visited by automobiles. However, after the areas was fenced (including the addition of a heavy locked gate 1 km. from the study area) approximately 1 year after the study began, deer use increased dramatically. Additionally, the vegetation response of the treated plots was much more dramatic 2 years PT. The pellet plots were re-visited in May 1994. The number of pellet groups counted were 29, 6, 4, and 1 in the BA 7, 13, 19, and Control plots, respectively. There was a strong negative correlation between stocking density and the log of the number of pellet groups found ($y = -0.06x + 1.74$; $Rsq = 0.948$; $p = 0.027$) (Fig. 5).

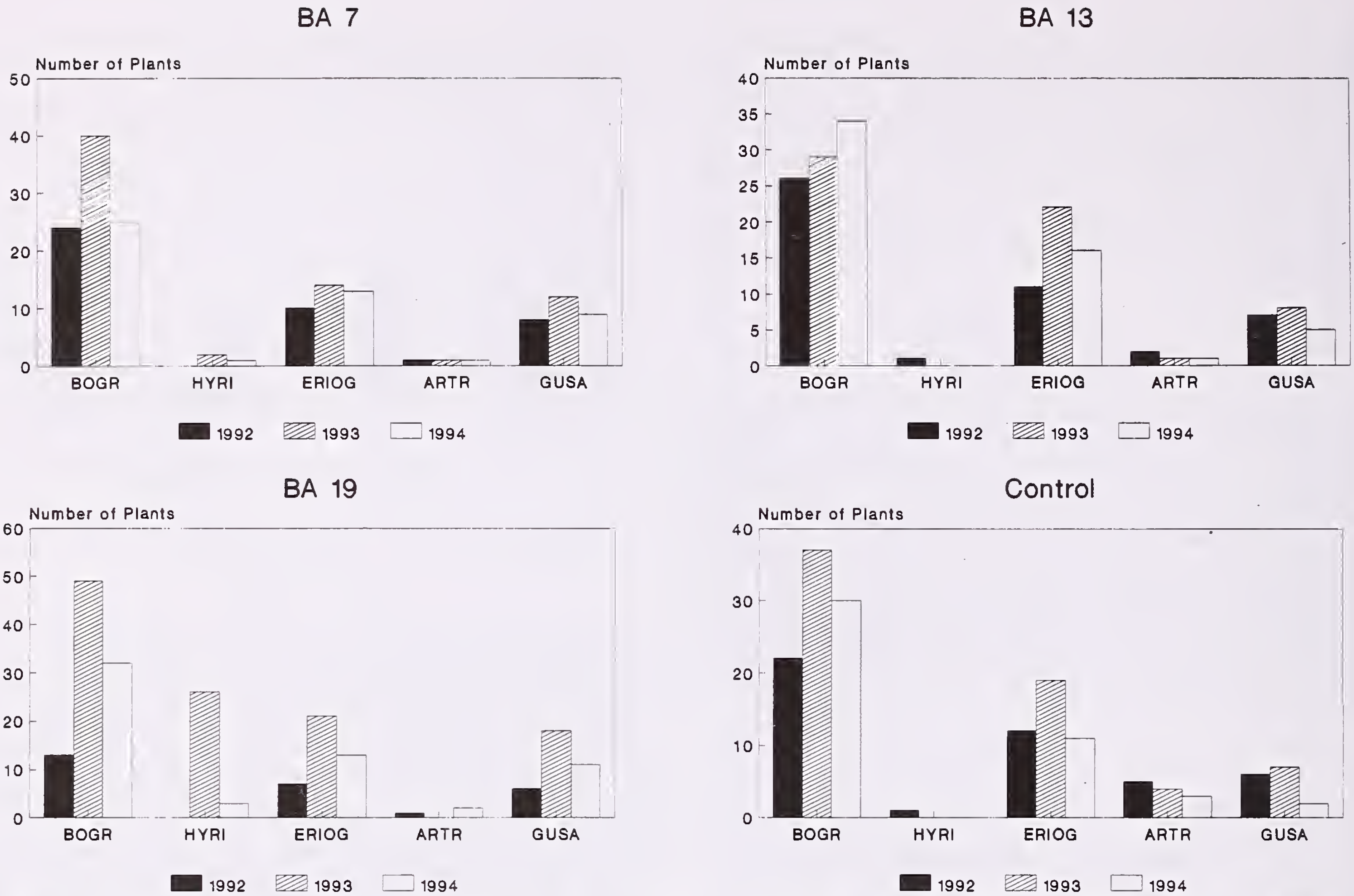

Figure 3.—Frequency of select plant species on study plots, 1992-1994. Abbreviations: BOGR=*Bouteloua gracilis*; HYRI=*Hymenoxys richardsonii*; ERIOG=*Erigonum* spp.; ARTR=*Artemesia tridentata*; GUSA=*Gutierrezia sarothrae*.

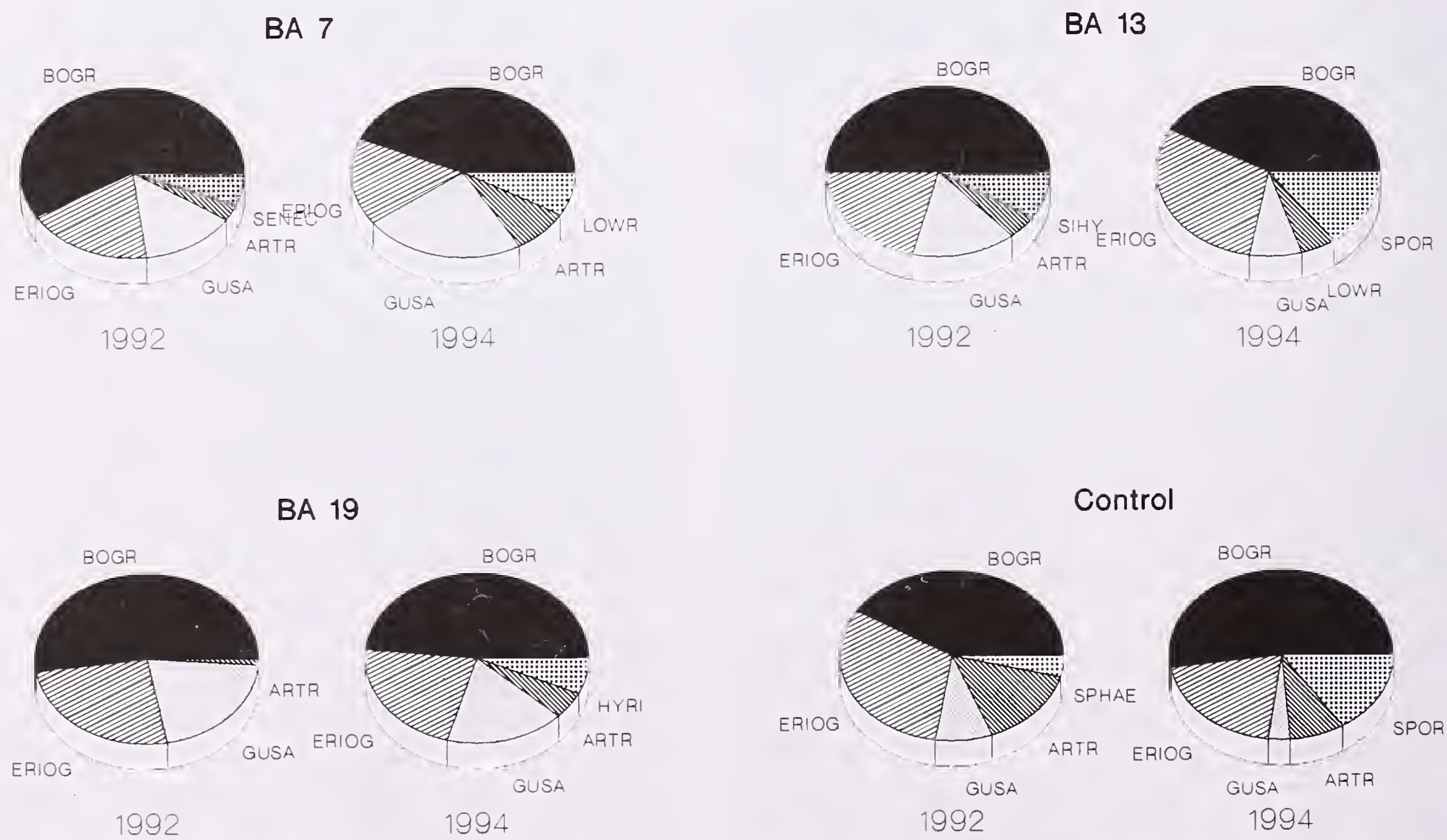

Figure 4.—Percent composition of the five most abundant plant species on each study plot, 1992 and 1994.

Table 2.—Percent composition of plants found in study plots, 1992-1994.

	1992				1993				1994			
Plot	07	13	19	30	07	13	19	30	07	13	19	30
Species												
BOGR	38	33	45	30	28	32	44	36	26	33	28	33
SPOR	--	--	--	--	14	5	--	4	7	12	2	10
ERIOG	12	14	22	23	14	27	25	17	10	24	12	13
BRASS	--	2	--	--	--	8	--	--	<1	--	1	--
GUSA	--	10	18	6	12	--	14	8	14	6	10	2
PIED	--	<1	--	--	8	5	5	21	7	7	9	19
JUMO	--	--	--	--	--	2	4	4	--	1	3	6
ARTR	2	3	1	11	1	1	--	5	2	2	3	5
ASTER	--	--	--	--	1	<1	--	3	1	1	<1	1
SIHY	--	6	--	3	--	3	--	<1	<1	--	--	--
ARIST	--	--	--	--	--	--	--	--	1	--	--	--
HYRI	--	<1	--	2	2	--	5	--	1	--	4	--
LOWR	1	6	--	--	11	9	2	--	9	4	--	--
OPUNT	2	1	--	1	1	2	--	--	<1	1	--	--
ERIGE	--	--	--	--	--	--	--	--	2	--	--	--
SPHAE	--	--	--	3	--	--	--	--	--	--	--	--
SENEC	6	--	--	--	--	--	--	--	--	--	--	--
PUTR	2	--	<1	--	--	--	--	--	--	--	--	--
MELIL	--	--	--	--	--	1	--	1	--	--	--	--
LUPIN	--	--	--	--	2	--	--	--	--	--	--	--
OEPA	--	--	--	--	--	<1	--	--	--	--	--	--
UNKFOR	31	24	14	21	6	4	1	3	20	9	29	11
Tot. # Species	8	11	6	9	12	14	8	11	15	11	11	9

Abbreviations: BOGR=*Bouteloua gracilis*; SPOR=*Sporobolus* spp.; ERIOG=*Erigonum* spp.; BRASS=*Brassicaceae* spp.; GUSA=*Gutierrezia sarothrae*; PIED=*Pinus edulis*; JUMO=*Juniperus monosperma*; ARTR=*Artemesia tridentata*; ASTER=*Aster* spp.; SIHY=*Sitanion hystrix*; ARIST=*Aristida* spp.; HYRI=*Hymenoxys richardsonii*; LOWR=*Lotus wrightii*; OPUNT=*Opuntia* spp.; ERIGE=*Erigeron* spp.; SPHAE=*Sphaeralcea* spp.; SENEC=*Senecio* spp.; PUTR=*Purshia tridentata*; MELIL=*Melilotus* spp.; LUPIN=*Lupinus* spp.; OEPA=*Oneothera pallida*; UNKFOR=Unknown Forb.

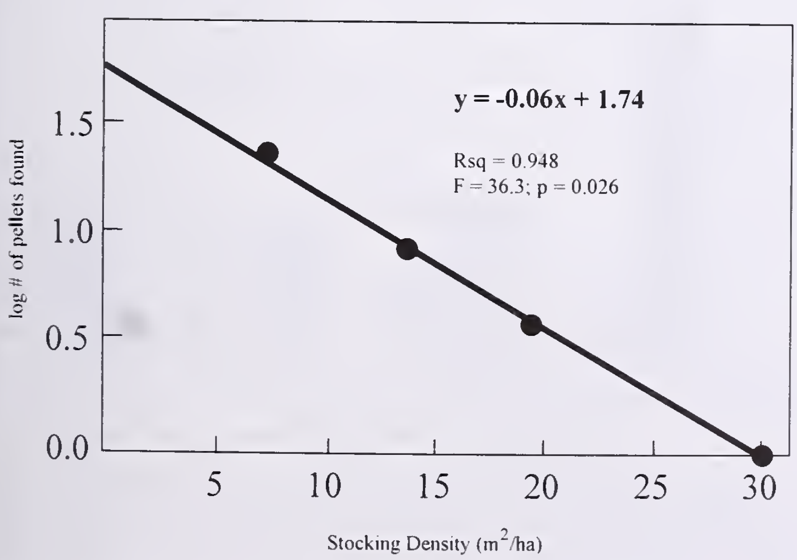

Figure 5. —Regression of the log of pellets found in study plots on stocking density (basal area).

Small Mammals

Species trapped included deer mouse (*Peromyscus maniculatus*), piñon mouse (*Peromyscus truei*), white-throated woodrat (*Neotoma albigula*), and cliff chipmunk (*Eutamias dorsalis*) (Table 3). Overall, small mammal density was lower on all plots which had been thinned than on the control plot when trapping was first conducted (approximately 3 months post-treatment) (Fig. 6). By the following spring, however, small mammals had recolonized the treated plots and overall small mammal numbers increased by 1019%, 749%, and 85% on the BA 7, BA 13, and BA 19 plots respectively, compared to a 27% increase on the control plot (Table 2). Most of this increase was due to the explosion in the numbers of deer mice. There was a negative association between stocking density and numbers of deer mice. Conversely, there was a positive association between plot density and numbers of piñon mice (Fig. 7). Total numbers of all small mammals increased from the first to the second trapping period on all plots, and decreased slightly in the third trapping period on all plots except the BA 19. As mentioned above, the winter and spring of 1993 were very wet. Coupled with a bumper crop of piñon nuts in the fall of 1992, the large increase in small mammals was not surprising. White-throated woodrats were most abundant on the BA 7 plot, though the numbers may be misleading. The 5 animals/100 trap nights in October 1993 probably represented only 2 individuals (animals were not marked). All other woodrat numbers probably represented only 1 woodrat/plot/trapping period. One cliff chipmunk was trapped on the BA 55 plot in October 1993.

Table 3.—Small mammals (Animals/100 trap nights) trapped in study plots, 1992-1993.

	DM	PM	WW	CC	n	Total	%
BA 31							
10/92	3	3	0	0	77	5	
3/93	49	7	2	0	153	58	+ 1019
10/93	37	1	5	0	76	43	- 25
BA 55							
10/92	3	1	0	0	76	4	
3/93	22	11	1	0	157	33	+ 749
10/93	9	17	0	1	79	27	- 1 9
BA 83							
10/92	5	13	1	0	79	19	
3/93	18	16	1	0	159	35	+ 85
10/93	27	12	0	0	78	39	+ 9
Control							
10/92	9	28	0	0	78	37	
3/93	20	27	1	0	156	47	+ 27
10/93	16	22	0	0	73	38	- 19

Abbreviations: DM=Deer Mouse; PM=Piñon Mouse; WW=White-throated Woodrat; CC=Cliff Chipmunk; n=Trap nights; %=percent increase/decrease since previous trapping period.

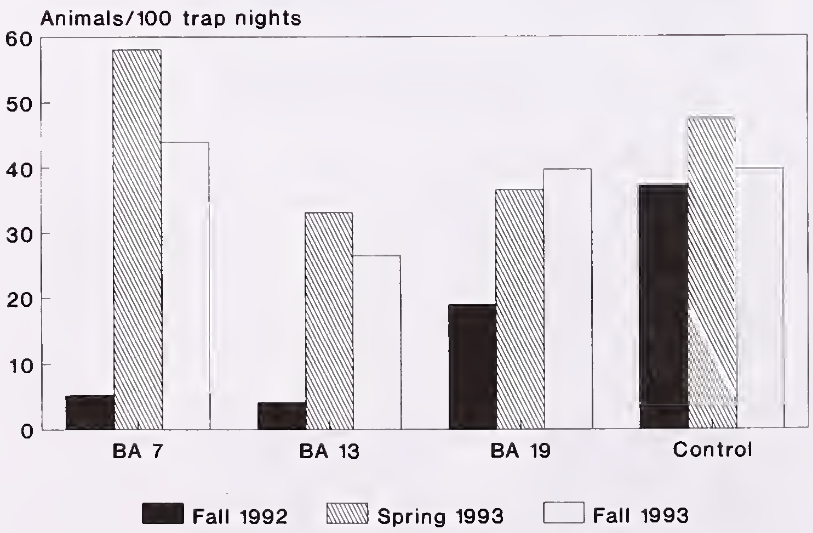

Figure 6.—Small mammal densities on study plots, 1992-1994.

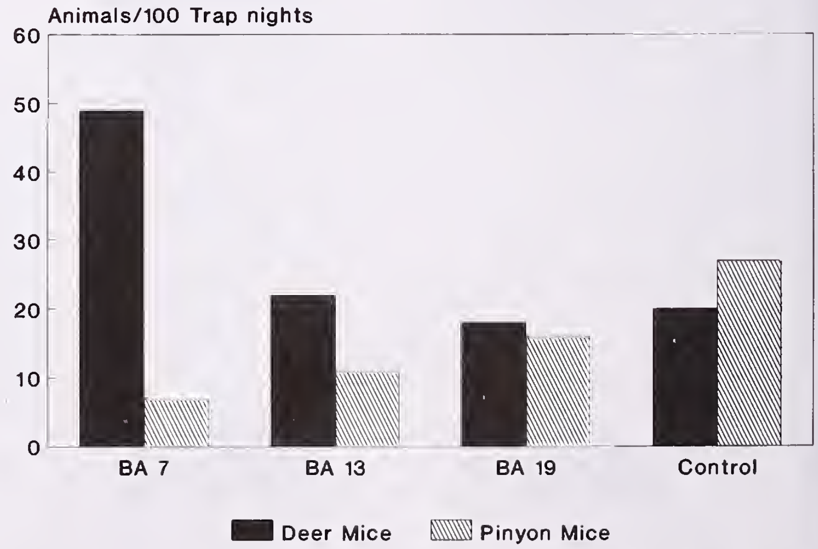

Figure 7.—Deer mouse and piñon mouse densities on study plots, March 1993.

Songbirds

Because the small plot sizes led to generally small daily and seasonal sample sizes, results were summed over seasons. Thirty two species were detected on the treatment and control plots. The BA 7 plot had the highest number of total birds (212) (in our sampling procedure, it was possible that individuals were counted more than once) and the Control plot had the highest number of species (23) (Table 4). Nine species (northern flicker, gray flycatcher, ash-throated flycatcher, mountain chickadee, plain titmouse, brown creeper, black-throated gray warbler, chipping sparrow, and dark-eyed junco) were detected in all of the plots. Six species (mourning dove, dusky flycatcher, common raven, cedar waxwing, American goldfinch, and lesser goldfinch) were detected in only one or both of the two sparser plots, and four species (scrub jay, bushtit, red-breasted nuthatch, and a wren spp.) were found in only one or both of the two denser plots.

Table 4.—Bird species and number of occurrences in study plots, 1992-1994.

Species		BA 7	BA 13	BA 19	Control
Mourning Dove	*Zenaida macroura*	0	1	0	0
Bl-Chinned Hummingbird	*Archilochus alexandri*	0	1	0	0
Hairy Woodpecker	*Picoides villosus*	1	2	2	0
Downy Woodpecker	*Picoides pubescens*	1	3	0	2
Northern Flicker	*Colaptes auratus*	2	2	4	1
Dusky Flycatcher	*Empidonax oberholseri*	1	0	0	0
Gray Flycatcher	*Empidonax wrightii*	3	3	8	2
Ash-Throated Flycatcher	*Myiarchus tyrannulus*	2	1	2	1
Unknown Flycatcher	*Tyrannidae spp.*	0	0	0	1
Piñon Jay	*Gymnorhinus cyanocephalus*	4	1	0	19
Scrub Jay	*Aphelocoma coerulescens*	0	0	0	1
Common Raven	*Corvus corax*	0	1	0	0
Mountain Chickadee	*Parus gambeli*	45	35	15	34
Plain Titmouse	*Parus inornatus*	38	36	37	32
Bushtit	*Psaltriparus minimus*	0	0	0	9
White Breasted Nuthatch	*Sitta carolinensis*	10	12	12	0
Red-Breasted Nuthatch	*Sitta canadensis*	0	0	0	2
Brown Creeper	*Certhia americana*	3	1	1	1
Unknown Wren	*Troglodytes spp.*	0	0	0	1
Ruby-Crowned Kinglet	*Regulus calendula*	4	0	3	3
Blue-Gray Gnatcatcher	*Polioptila caerulea*	4	0	1	0
Western Bluebird	*Sialia mexicana*	4	4	0	8
Townsend's Solitaire	*Myadestes townsendi*	0	3	0	7
American Robin	*Turdus migratorius*	2	0	0	1
Cedar Waxwing	*Bombycilla cedrorum*	1	0	0	0
Unknown Vireo	*Vireo spp.*	5	3	5	6
Bl Throated Gray Warbler	*Dendroica nigrescens*	2	2	2	2
Chipping Sparrow	*Spizella passerina*	19	11	11	11
Dark-Eyed Junco	*Junco hyemalis*	40	42	45	56
American Goldfinch	*Carduelis tristis*	2	0	0	0
Lesser Goldfinch	*Carduelis psaltria*	17	10	0	0
Red Crossbill	*Loxia curvirostra*	0	7	0	5
Unknown		2	0	12	2
Total Birds		**212**	**181**	**160**	**207**
Total Species		**22**	**21**	**15**	**23**

DISCUSSION

Vegetation

Our results concur with most other studies that showed an increase in grass and forbs with removal of the overstory canopy. Arnold et al. (1964) concluded that the increase in grasses slows after 5-8 years. The increase in the number of species was also significant. Continued monitoring of the plots will more clearly document the shift in vegetative communities and species.

Deer

The literature on deer use of converted piñon-juniper range is conflicting. Some studies have shown increased deer use on cleared plots (McCulloch 1973; Springfield 1976; Short et al. 1977; Howard et al. 1987) while other studies have not shown deer use to increase (Terrel 1973; Terrel and Spillett 1975; Swenson 1977). The concurrent rise in grass and forb species with timber removal would be expected to provide forage for deer. Barney and Frischknecht (1974) estimated that these changes would last for up to 20 years. In at least one study (Terrel 1973) the probable reason that deer did not use the cleared plots more was that the conversion process had removed the shrub cover in addition to the trees. Although the shrub cover was sparse in our plots, care was taken to remove only the trees. In a study by McCulloch (1969) deer use increased on burned plots immediately following a fire, but it was noted that the burned areas were barren of important browse plants such as cliffrose (*Cowania mexicana*) and gambel oak (*Quercus gambelii*). Published literature is nearly unanimous in recommendations for piñon juniper control projects for big game: 1) Openings must be small and close to escape cover, usually 0.1-0.2 miles (0.16 to 0.32 km) maximum. The plot sizes in our study were too small to amplify; 2) projects must be located near areas of historic big game usage; 3) browse plants must be left intact or re-established following treatment; 4) plots must be protected from severe weather.

Small Mammals

Other studies (Baker and Frischnecht 1973; O'Meara et al. 1981; Severson 1986; Sedgewick and Ryder 1987) have found increased populations of small mammals on modified piñon-juniper woodlands. Our results show that some small mammals (especially deer mice) have the potential to reach very high populations on cleared plots if slash is left intact. However, Severson found that piñon mice increased on treated plots if the overstory canopy was left relatively intact and sufficient slash was present. Our results concur with Sedgewick and Ryder (1987), which indicate that even with sufficient slash, piñon mice will decrease in treated plots. Insufficient numbers of white-throated woodrats and cliff chipmunks were trapped to make any statistical inferences. Severson (1986) reported that woodrats increased on treated plots, while O'Meara et al. (1981) reported that woodrat numbers decreased.

Songbirds

The small plot sizes and large "edge" area in our study became especially problematic in analyzing the bird data and may have obscured some habitat relationships. For example, the black-throated gray warbler, a species known to prefer denser stands, appeared equally in all treatments and the control. While other studies (Sedgewick and Ryder 1987) showed a clear reduction of bird abundance and species richness in treated plots, no clear pattern of bird usage emerged from the data, aside from a few species which are generally known to prefer open areas (mourning dove, lesser and American goldfinch, common raven) and a few which are generally known to prefer closed canopies (scrub jay, bushtit, wren). The vast majority of birds showed no clear preference on our small plots. When sample sizes permit, a breakdown of seasonal variations in bird use may reveal additional patterns. Additionally, the small sample plots did not give us the opportunity to examine a very important aspect of habitat preference: nesting. Future plans for this study, however, include the examination of territories in the different plots.

SUMMARY

Our results indicate that small openings in the relatively unbroken piñon-juniper woodlands on portions of the Zuni Reservation would benefit a wide variety of species: deer, small mammals (except piñon mice), and some species of songbirds. These results generally agree with other studies that show openings can increase vegetation biomass, and increase deer use and small mammal populations. However, the results clearly differ from previous studies which have shown reduced songbird use of chained plots. Obviously, the only birds which are capable of using chained plots are those which do not depend on trees. However, our thinned plots maintained significant tree and canopy cover. Though sparse, the BA 7 plot still had a canopy cover of 23%, and may bark gleaners and canopy dependent species (e.g. black-throated gray warblers, white breasted nuthatches, brown creepers) continued to use the BA 7 plot). Care must be taken when creating forest openings that negative effects such as increased edge does not result in negative effects such as brown headed cowbird (*Molothrus ater*) parasitism or predation (Wilcove 1985). A mosaic of successional stages would most likely benefit a wider variety of wildlife species.

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Relationships Among Plant Species Composition and Mule Deer Winter Range Use on Eastern Nevada Piñon-Juniper Chainings

Robin J Tausch[1] and Paul T. Tueller[2]

Abstract.—Five sites in eastern Nevada were evaluated for the effectiveness of tree removal by chaining for improving winter range habitat for mule deer. Cluster analysis based on a correlation matrix from plant species cover and deer-days use per acre was used to determine plant species associations preferred by the deer. Areas of the chainings that were closed stands with older trees consistently had the highest success of seeded exotic grasses and the lowest post-treatment deer use. Seeded native species also did poorly on these sites. Areas of the chainings with young scattered trees generally had adequate understory to rapidly respond following treatment. Seeded exotic grasses did the poorest when native species were abundant. Mule deer use was significantly related to the area of each chaining with the preferred mix of native shrub, grass and forb species following treatment. On four of the five chainings one grass, squirreltail, identified the preferred plant species mix.

INTRODUCTION

A major limiting factor for mule deer (*Odocoileus heminous*)in the southwest is a shortage of winter range. Piñon-juniper (*Pinus monophylla, Juniperus osteosperma*) woodlands represent large areas of winter range over much of the southwest (Suminski 1993). Although there are many reasons for the loss of winter range in piñon-juniper woodlands, successional processes have been a major contributor (Tausch and Tueller 1977, Suminski 1985). Increasing tree dominance has been dramatically reducing the levels of understory cover, species composition, and production (Tausch et al. 1981, West 1984, West et al 1978).

One important justification for past efforts of tree control in piñon-juniper woodlands has been to restore the understory community for deer habitat and forage on these winter ranges. In the past, one of the more widely used procedures for tree control has been chaining, the process of dragging an anchor chain between two tractors to remove the trees. While chaining is now rare, an understanding of the success, or lack of success, of the procedure for wildlife habitat improvement may be useful for other types of management efforts. The outcome of chaining depended on many factors, including an understanding of the community ecology of these woodlands (Suminski 1993) and the preferences by deer for use of the treated areas (Short and McCulloch 1977, Tausch 1973). Other factors affecting the outcome were the time of the year the site was treated, the state of overstory dominance at treatment, if the area was seeded, and the seed mix of understory species used.

This study evaluated how mule deer use patterns on five winter range locations in eastern Nevada were affected by 1) the chaining procedure used, 2) the level of tree dominance prior to treatment, 3) area to area differences in species composition of the understory at treatment, and 4) the seeding of various exotic and native plant species.

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STUDY SITE DESCRIPTIONS

The five study areas located along the eastern edge of Nevada were investigated in 1971. Treatment of the sites was accomplished using an anchor chain pulled by two crawler tractors. The debris of downed trees from the process was left in place. No windrowing or burning was used. All sites but one were seeded with various seed mixtures that included both introduced and native shrub, grass and forb species (Tausch 1973). The success of the treatments in removing trees and the successional patterns of overstory to understory changes that followed treatment are described by Tausch and Tueller (1977). The chainings ranged in age from 2 to 13 years post-treatment when sampled. Climatic conditions for the year of sampling are described in Tausch (1973).

Blythe Springs Chaining

This chaining is located on the west side of the Delamar Mountains in south-central Lincoln County, Nevada. Treatment had occurred 13 years prior to sampling in 1971. Approximately 500 ha (1200 acres) over an elevation range of 1770 m (5800 ft) to 1980 m (6500 ft) were treated in mid-summer by chaining one way with a 28.3 kg/m (19 lb/ft) smooth chain. The area was aerial seeded with crested wheatgrass (*Agropyron desertorum*) in August of the same year at a rate of about 3.6 kg/ha (3.2 lb/ac). The dominant understory browse species included big sagebrush (*Artemisia tridentata*) and a hybrid between antelope bitterbrush (Purshia tridentata) and cliffrose (Cowania mexicana). These hybrids had both three and five lobed leaves on the same plant. Deer use of the area was primarily in winter (Berg 1966, Cole 1968, Tausch 1973).

Spruce Mountain Chaining

The treated area is located on the south side of Spruce Mountain in south-central Elko County, Nevada approximately 15 miles north of Currie, Nevada. Treatment occurred nine years prior to sampling in 1971. Approximately 1100 ha (2688 ac) over an elevation range of 1950 m (6400 ft) to 2130 m (7000 ft) were treated by chaining one way with a 83 kg/m (56 lb/ft) smooth chain. No seeding occurred on this site. The important understory browse species prior to treatment were the dominant black sagebrush (Artemisia nova), locally abundant Green rabbitbrush (*Chrysothamnus vicidiflorus*), and antelope bitterbrush which was scattered throughout the area. Deer use of the area was from early December to mid-February (Cole 1968, Humphreys 1966).

North Kern East Chaining

This chaining is long and narrow and located on the north side of the Kern Mountains at the head of Pleasant Valley in northeastern White Pine County, Nevada. It was sampled two years after treatment. Approximately 160 ha (400 ac) centered around 2160 m (7100 ft) in elevation were double chained using the Ely Chain 143 kg/m (96 lb/ft) plus 18 kg (40 lb) of railroad track per link. The site was seeded with a mixture of native and introduced species (Tausch 1973, Tausch and Tueller 1977). Dominant browse species on the site prior to treatment include big sagebrush, antelope bitterbrush, and green rabbitbrush. The Kern Mountains are a key deer use area with a resident herd that is on or near these mountains on a year-round basis. Use in the areas of the Kern Mountains that were chained occurs primarily in the spring and fall.

South Kern Chaining

Located on the south side of the Kern Mountains, this chaining covers approximately 200 ha (500 ac) between 2160 and 2200 m (7100 and 7200 ft) in elevation. The Ely chain was also used and sampling occurred three years after treatment. The majority of this chaining occurred in old, closed canopy woodlands where little understory was present prior to treatment. These were the areas where the exotic seeded grasses were the most successful (Tausch 1973). Prior to treatment big sagebrush dominated the north end of the chaining and black sagebrush the south end with antelope bitterbrush scattered throughout in areas with higher brush dominance. Patterns of deer use are similar to the North Kern East Chaining although the overall level of use was lower (Table 1).

North Kern Sagebrush Chaining

This chaining is located roughly between the other two Kern Mountains chainings, but still on the north side of the Kern Mountains. It is approximately 170 ha (400 ac) in size and covers from 2200 m (7200 ft) to 2260 m (7400 ft) in elevation. Treatment for this site used the same procedures and seeding mix as the other Kern Mountain chainings but occurred in an area without piñon or juniper. The pre-treatment shrub-dominated community is similar to the less tree-dominated parts of the area used for the North Kern East Chaining and for the northern area of the South Kern Chaining. This chaining was included to evaluate the response of the shrub community to the treatment in the absence of the trees. Patterns of deer use were similar to the other two Kern Mountains Chainings but the level of use was greater (Table 1).

METHODS AND PROCEDURES

Field Data Collection

Macroplots were established on each chaining from late spring to mid- summer 1971 to cover the range of major vegetation types present as determined by reconnaissance of the sites. Transects for counting deer pellet groups are generally established to cover as much of the habitat variation as possible (Neff 1968). Macroplots were located within a representative area of each respective vegetation type and on the same slope and aspect. Macroplot layout for sampling was identical for all chainings except for a baseline length of 152 m (500 ft) at Blythe Springs and Spruce Mountain and 76 m (250 ft) for the Kern Mountains chainings. Greater topographic complexity on the Kern Mountains chainings made the shorter baseline necessary. Ten transects were located along and on either side of the baseline on a stratified random basis with the restrictions that no transect could overlap and five must be in each half of the macroplot.

Four 0.001 ha (0.0025 ac) circles were contiguously placed along each transect for determining pellet group density which represents approximately 10 percent of the macroplot area (Tausch 1973). To be counted, a group had to have five or more pellets and had to be half or more within the boundary of the circular plot. The total number of pellet groups counted per acre were divided by 13 for an index of deer-days use per acre (Neff 1968).

Plant species cover estimates were made on four randomly selected transects out of the ten, two on each half of the baseline. Cover for shrubs was estimated in ten, 1.2 by 1.5 m (4 by 5 ft) plots per transect using an estimation guide representing two percent of the plot (Tausch 1973). Grass and forb cover was estimated in two, 3 by 6 dm (1 by 2 ft) microplots located within each shrub cover plot. Bunch grass cover estimated was basal cover. Tree cover was determined in two 20 m by 40 m (66 ft by 132 ft) plots, one randomly located on each half of the baseline. Each tree rooted in each tree plot was measured for two crown diameters, the longest and the diameter perpendicular to the longest. The crown area was calculated for each tree using the formula for an ellipse and summed by species to determine percent cover.

Analysis Methods

Cover data for the more abundant shrub and grass species were used individually. Less common shrubs and grasses were combined into groups for other shrubs and other grasses. Forbs were com-

Table 1.—Summary of the average percent vegetation cover for the species and species groups used for analysis on the chainings studied.

Species	Percent Cover				
	Blythe	Spruce	S. Kern	N. Kern E.	N. Kern
P-J	10.67	7.66	5.47	5.83	0.0
Artemisia nova (Arno) *tridentata* (Artr)	7.82	7.32	0.20	1.03	4.58
Chrysothamnus vicidiflorus (Chvi)	0.0	0.0	0.0	0.0	2.78
Purshia tridentata (Putr) (*Cowania) (Pu-Co)	1.73	0.04	0.04	0.05	0.01
Other Shrub	1.45	0.13	0.01	0.30	0.0
Agropyron desertorum (Agde)	0.04	0.0	1.63	1.59	0.47
Bromus inermis (Brin)	0.0	0.0	0.93	0.0	0.54
Bromus tectorum (Brte)	0.01	0.44	0.0	0.0	0.10
Elymus junceus (Elju)	0.0	0.0	0.39	0.03	0.0
Elytrigia intermedium (Elin)	0.0	0.0	1.61	0.73	1.02
Achnatherum hymenoides (Achy)	0.01	0.08	0.11	0.15	0.17
Achnatherum thurburiana (Acth)	0.0	0.0	0.0	0.0	1.78
Boutaloua gracilis (Bogr)	0.0	0.0	0.	0.0	0.48
Elymus elymoides (Elel)	0.33	0.39	0.03	0.14	0.062
Hesperos comata (Heco)	0.0	0.0	0.0	0.04	1.22
Pleuraphis jamesii (Plja)	0.01	0.0	0.0	0.0	0.0
Poa fendelariana (Pofe)	0.0	0.0	0.026	0.05	0.0
Poa secunda (Pose)	0.0	0.06	0.024	0.15	0.77
Pseudoroegneria spicatum (Pssp)	0.0	0.82	0.0	0.17	1.30
Forbs	0.69	1.22	1.75	1.48	4.69
Deer Days use/Ac (DDA)	3.6	23.0	3.7	10.9	25.1

bined into a single group because of a sporadic occurrence of individual species (Table 1). Correlation analysis was used to determine the relationships among the various plant species and species groups, and between those species and species groups and deer-days use per acre over the sampled macroplots. These correlations provide an index of the positive or negative association among the plant species and deer use over the sampled macroplots on each chaining (Sokal and Sneath 1963).

Because of the overlapping species distributions and other disturbances caused by chaining and seeding, the plant species associations important for deer cannot always be readily seen from field observation or from just the correlation analysis results. The matrix of all possible correlation coefficients for each chaining was used in the multivariate technique of cluster analysis. This provided a summary of the levels of positive and negative association between plant abundance and deer use. Cluster analysis utilized the weighted pair-group method using Spearman's sums of variables method (Ludwig and Reynolds 1990, Sokal and Sneath 1963):

$$r_{(x+y)z} = \frac{r_{xz} + r_{yz}}{(2 + 2(r_{xy}))^{1/2}}$$

where $r(x+y)z$ = the correlation coefficient of the species of group (z) with the new group of species or species group (x) and (y), the numerator equals the sum of the correlations of (z) with the individuals (x) and (y) of the new group, and the denominator is the square root of the number of individuals in the new group (always two in a weighted pair group method) plus two times the correlation between the individuals of the new group. This method operates on an estimation of the product moment similar to the correlation coefficient (Sokal and Sneath 1963).

Cluster analysis results were used to construct dendrograms for each chaining to determine the species group, or groups, most important, and least important for deer use. The cutoff level for group differentiation was determined by noting the presence and number of significant positive correlations between members of the same group and significant negative correlations between members of different groups. Overall average within and between group correlations were determined for each dendrogram by first converting all correlation values to z-values. All the possible within group and between group z-values were averaged and the results then converted back to correlation values (Sokal and Sneath 1963).

RESULTS AND DISCUSSION

Blythe Springs Chaining

A total of seven macroplots were sampled on this site. The bitterbrush and cliffrose hybrids were used as a single group for analysis. This, and other combinations of species, reduced the number of zero entries in the data matrix used for correlation analysis. The two shrub groups used for the correlation and cluster analysis were Artemisia and a combination of the other shrubs. Individual grasses used for analysis were squirreltail (*Sitanion hystrix*) and crested wheatgrass. The remaining grasses, even when combined into a single group had too few entries for correlation analysis. Regrowth of the surviving trees had reduced their abundance (Tausch and Tueller 1977). Forbs were infrequent and combined into a single group for analysis. The genera *Euphorbia*, *Eriogonum*, *Penstemon*, and *Astragalus* were the most common and are listed in order of decreasing abundance. Piñon and juniper were combined for total tree cover for the analysis because no difference in their affect on the understory could be detected.

Cluster analysis resulted in four groups of plant species associations (Fig. 1). These were squirreltail and deer use, shrubs other than the cliffrose/bitterbrush hybrids, the cliffrose/bitterbrush hybrids, and the trees and forbs. The highest level of forb cover occurred in areas with the highest tree cover at sampling. Most were young rapidly growing trees. The cliffrose/bitterbrush hybrids generally dominated locations where they were found, resulting in low cover of other native species and in their negative correlation with the other shrubs. Cattle use of the chaining resulted in small plants of the seeded crested wheatgrass occurring primarily under the protection of shrubs and this was reflected in its correlation and grouping with the majority of the shrub cover.

Overall, this chaining only averaged 3.6 deer-days use per acre, about a tenth of the level of use that had occurred six years earlier (Tausch 1973). This is probably the result of the rapid regrowth of the surviving trees on the site that has already reduced shrub growth and grass occurrence to nearly prechaining levels (Tausch and Tueller 1977). Deer use that was occurring was most strongly correlated with the areas of highest cover of native grasses, particularly squirreltail. Macroplots with the highest average cover of squirreltail had the lowest cover of forbs and the highest level of deer use. Macroplots with the lowest cover of squirreltail had the highest forb cover, were generally high in tree cover, and the lowest in deer use. This does not mean that deer are using squirreltail but that sites with a higher abundance of this species contained more of the factors which determine the preferred habitat for deer. Those parts of vegetation on this chaining represented by group one make up 7.8 percent of the total plant cover.

Spruce Mountain Chaining

A total of nine macroplots were sampled on this site. Species and species groups for analysis included black sagebrush, other shrubs, squirreltail, sandberg bluegrass (*Poa secunda*), cheatgrass (*Bromus tectorum*), other grasses, and forbs. Cluster analysis resulted in three groups (Fig. 2). One group included the existing black sagebrush and the native grasses. Sites with higher sagebrush and grass cover had fewer trees prior to treatment. The second group was the trees, other shrubs, and cheatgrass. Green rabbitbrush (*Chrysothamnus vicidiflorus*) made up most of the other shrub category. The last cluster group was the forbs. The most abundant forbs were russian thistle (*Salsola australis*) and tumble mustard (*Sisymbrium altisimum*) which dominated areas of the chaining that had been old, closed canopy woodlands prior to treatment. These sites had almost no understory and little seed source for spontaneous recruitment of native species after treatment. They also had the highest success in tree removal. Areas with many young trees had the highest tree survival (group two) and also had the highest cover of cheatgrass and other shrubs, the most common of which was green rabbitbrush.

Overall this chaining averaged 23.0 deer-days use per acre, second highest of the chainings studied. Deer use was most closely correlated with group one, and within that group again with squirreltail. This group represented the common sagebrush-grass community found throughout the Spruce Mountain area and was 42.8 percent of the vegetation cover on the sampled areas. It occurred on areas of the chaining with lower tree dominance and sufficient understory prior to chaining to provide the plants and seed source necessary for these species to rapidly re-dominate following chaining. Most of the sagebrush plants on these sites were post-chaining in age (Tausch and Tueller 1977). Macroplots with the highest cover of the species in group one also contained bitterbrush.

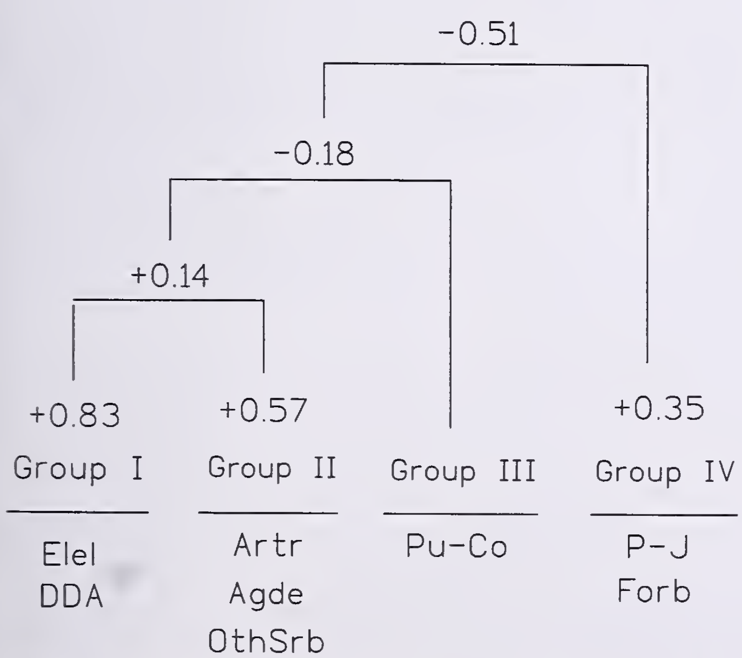

Figure 1.—Dendrogram summarized from cluster analysis of correlation coefficients showing four plant speciesp groups for the Blythe Springs chaining. Average within and between group correlation coefficients computed from Z-scores are shown on the dendrogram. Abbreviations are in table 1.

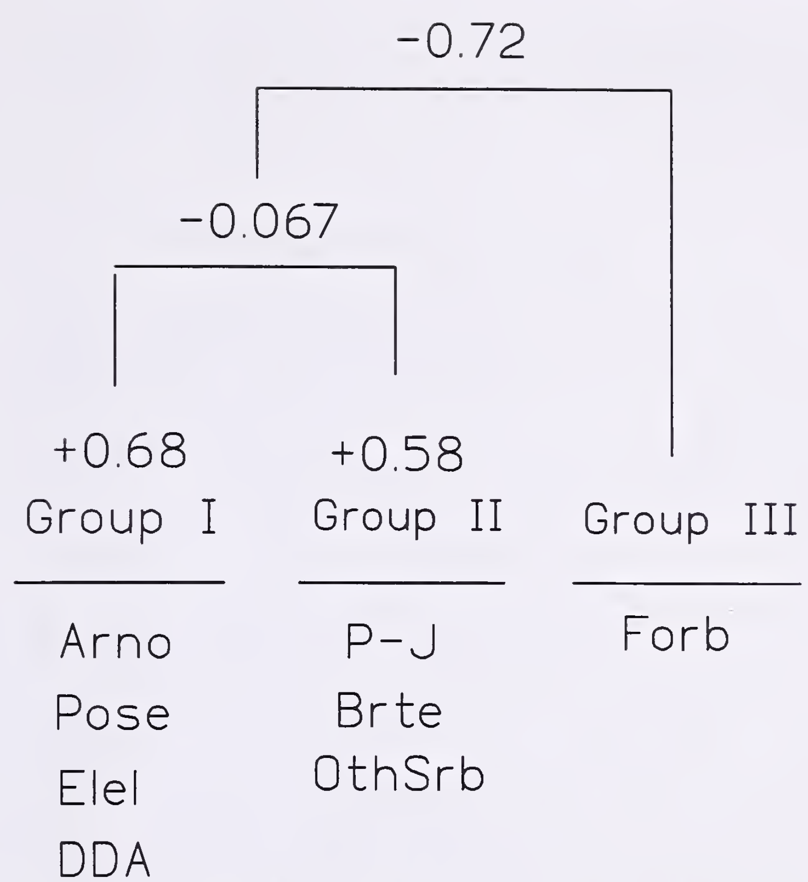

Figure 2.—Dendrogram summarized from cluster analysis of correlation coefficients showing three plant species groups for the Spruce Mountain chaining. Average within and between group correlation coefficients computed from Z-scores are shown on the dendrogram. Abbreviations are in table 1.

Macroplots dominated by exotic forbs such as russian thistle had the lowest level of deer use and little of the reestablishment of sagebrush observed elsewhere.

South Kern Chaining

The seven macroplots sampled on this site were confined to the north and east portions where the big sagebrush-dominated understory vegetation was similar to the understory communities on the other Kern Mountain chainings. Deer use was also observed to be the highest in this part of the chaining. Because of the dominance of the trees, the shrubs other than sagebrush and bitterbrush were infrequent. Even when present they occurred in only trace amounts, and were not included in the cluster analysis. The trees and the forbs were also combined into individual groups for analysis. Because of the high dominance of old trees over most of the site prior to chaining, the larger native bunchgrasses were largely absent. The age of the trees also affected the level of tree control by the chaining procedure. Most of the trees were removed except in the limited areas with younger trees (Tausch 1973).

Cluster analysis resulted in three groups that closely relate to tree maturity and dominance prior to treatment (fig. 3). Group two represents areas with the highest tree dominance and lowest pretreatment understory. Here most of the seeded exotic grasses dominated the site and deer use was the lowest. Group one areas had some sagebrush and bluegrass left in the understory before treatment and crested wheatgrass was the most successful seeded exotic species. Sites represented by group three had the greatest deer use and the highest pre-chaining cover of native species. It also had the highest tree cover because the younger average tree age found on those sites resulted in higher tree survival (Tausch and Tueller 1977).

Overall, the South Kern site averaged 3.7 deer-days use per acre, the second lowest of the sites studied. Squirreltail is again a major indicator of areas on the chaining that had the highest post-treatment preference by deer. The preferred vegetation represented 16.7 percent of the total.

North Kern East Chaining

Eleven macroplots were sampled on the North Kern East Chaining. Shrubs other than sagebrush and bitterbrush were combined into another shrub group. Forbs and both tree species were also combined into species groups. Grasses included three individual native species and the individual seeded exotic grass species (Table 1). Most of this site was occupied by young to mature vigorous trees that had recently reached a closed canopy and had little understory left. In these areas tree survival was relatively high and the seeded exotic grasses established locally where trees had been removed. In areas where a diversity of understory species were present prior to treatment, establishment of the seeded species was limited, resulting in a low relative cover.

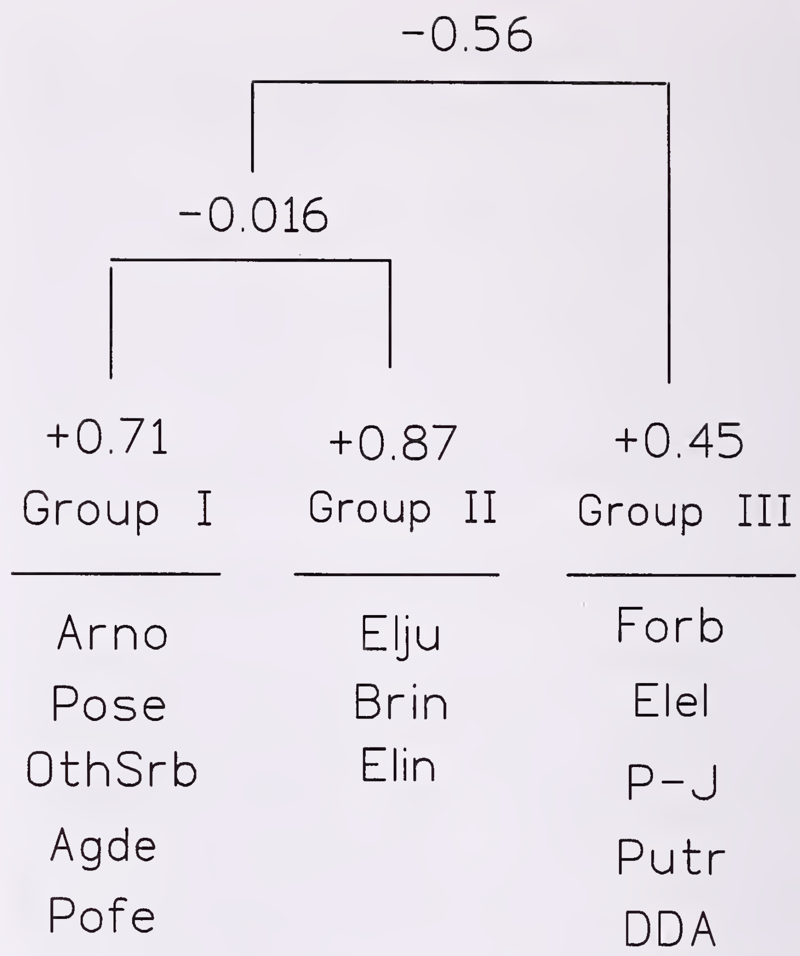

Figure 3.—Dendrogram summarized from cluster analysis of correlation coefficients showing three plant species groups for the South Kern chaining. Average within and between group correlation coefficients computed from Z- scores are shown on the dendrogram. Abbreviations are in table 1.

The three groups from cluster analysis generally related to the level of tree dominance prior to treatment (Fig. 4). Group one represents the least tree-dominated areas of the site and had the highest cover of the sagebrush- bunchgrass community present prior to treatment and the highest total shrub cover. Group two represents a more intermediate stage of tree dominance (Tausch 1973). The cover of bitterbrush is almost entirely from plants seeded during treatment. The clustering of this species in group two seems to indicate that the successional stage represented has the best conditions for germination and establishment of bitterbrush seedlings. Group three represents areas with high tree density and dominance and little to no understory prior to treatment. These again are the sites where seeded exotic grasses were the most successful.

Deer-days use per acre averaged 10.9 on this site (Table 1) with the vegetation in group one being preferred, but with group two a close second. Here also squirreltail has the highest correlation with deer use of any plant species in the preferred vegetation complex. Former tree dominated sites with the highest establishment of seeded grasses are again the least preferred by deer. Preferred vegetation represents about 29 percent of the total vegetational cover on this site.

North Kern Sagebrush Chaining

A total of sixteen species and species groups collected on five macroplots were used for analysis on this site (table 1). Because of the absence of trees, the dominance and diversity of understory species was higher than on the other sites. Success of the seeded species was low, and seemed dependent on the level of ground disturbance caused

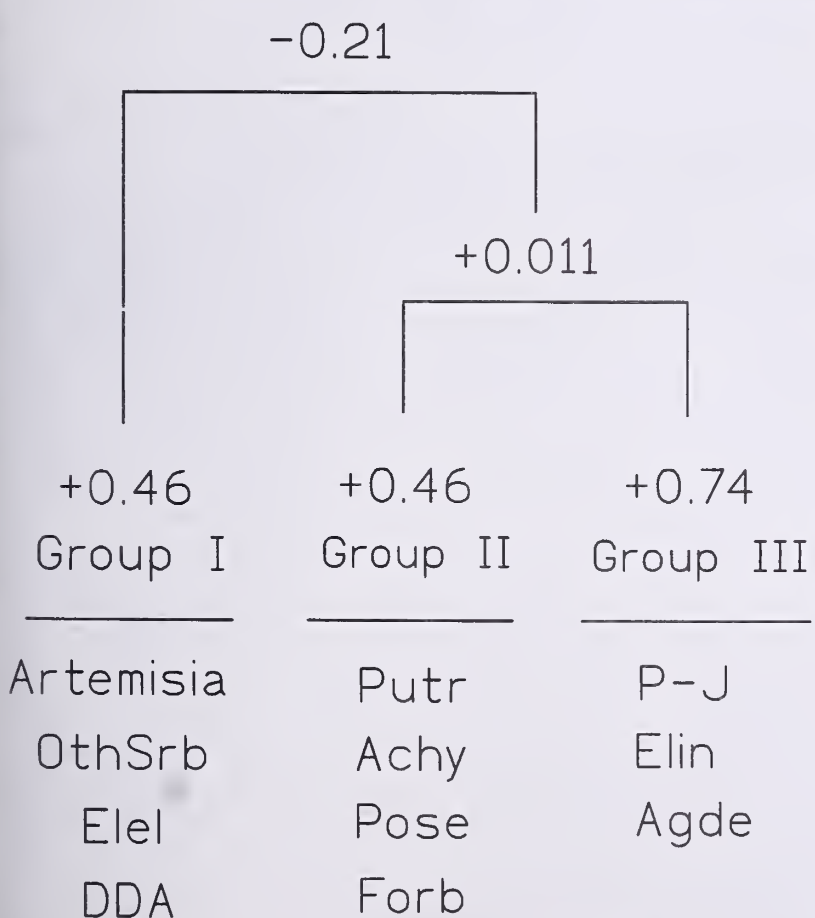

Figure 4.—Dendrogram summarized from cluster analysis of correlation coefficients showing three plant species groups for the North Kern East chaining. Average within and between group correlation coefficients computed from Z-scores are shown on the dendrogram. Abbreviations are in table 1.

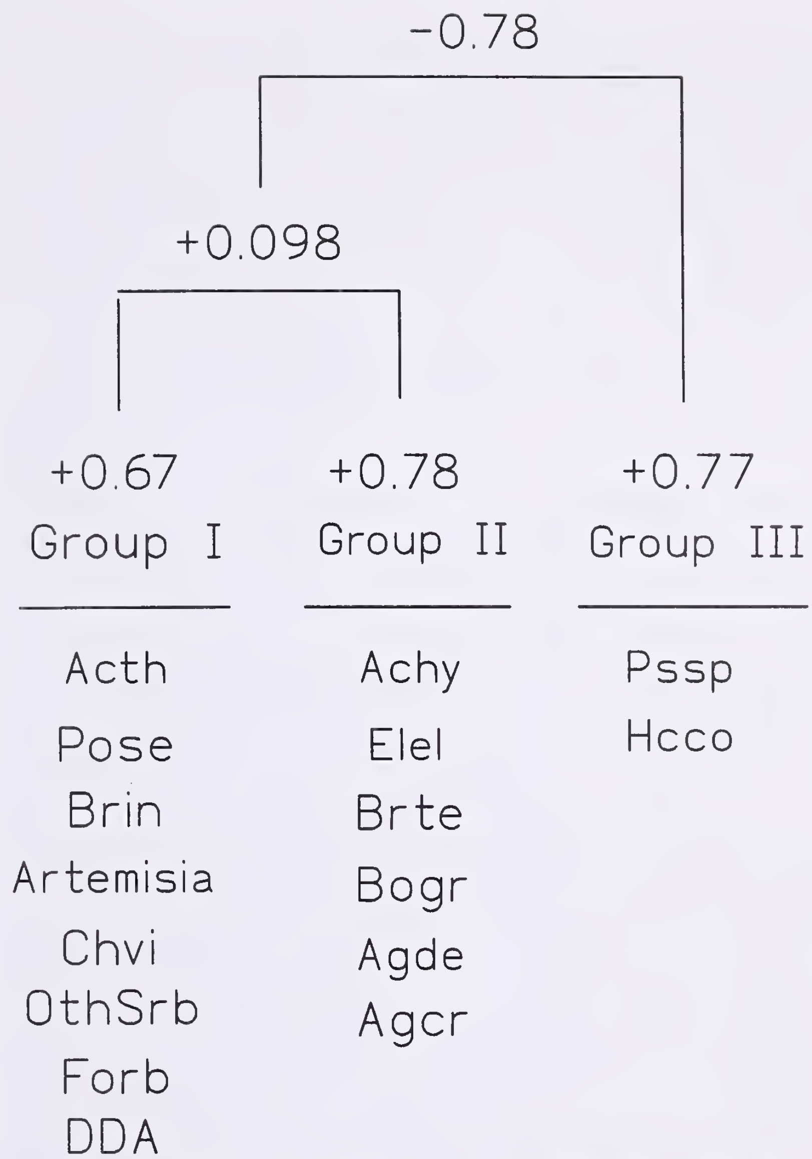

Figure 5.—Dendrogram summarized from cluster analysis of correlation coefficients showing three plant species groups for the North Kern sagebrush chaining. Average within and between group correlation coefficients computed from Z-scores are shown on the dendrogram. Abbreviations are in table 1.

by the treatment.

Cluster analysis resulted in three groups (Fig. 5). Group one represents higher shrub dominance, and group three represents areas with dominance by large native bunchgrasses prior to treatment. Group two represents areas of the site (about 10 percent of the total) that were either the most disturbed by the treatment procedure, or had a lower shrub cover prior to treatment. The large bunchgrasses of group three were absent on all the other chainings, possibly due to the combination of competition with the trees and patterns of livestock use of the sites.

This site had the highest overall level of deer use, with an average of 25.1 deer-days use per acre, of any of the sites studied. It also appeared to be the most mesic of the sites studied. Deer use was most closely associated with group one, or the vegetation complex with the best mix of native shrub, grass, and forb species. These results are consistent with those for the other chainings. This is, however, the only site where squirreltail is not in the most preferred group. Alteration of vegetation composition by the presence of tree competition, such as the reduction of larger bunchgrasses, may be responsible for this difference. Overall, the absence of trees on this site has not affected the general vegetation preferences of mule deer.

Deer Utilization Summary

All the sites studied were located in known deer use areas and were undertaken in an attempt to improve deer habitat in those areas. In the cluster analysis results deer use was closely associated with the same general vegetation complex over all the chainings. This indicated a possible relationship between the abundance of the preferred plant species on a site and the level of deer use that occurred following chaining. The average percent cover of the plant species in the preferred group identified by cluster analysis was determined for each site. This was compared with the index of average deer-days use per acre on each site using regression analysis (Fig. 6). For the five chainings studied, cover of the preferred native plant species after treatment was significantly related to the level of deer use that was present. Piñon-juniper treatments for deer habitat improvement should focus on sites that have a good representation of the preferred understory community prior to treatment. These areas are usually associated with younger stands of more scattered trees.

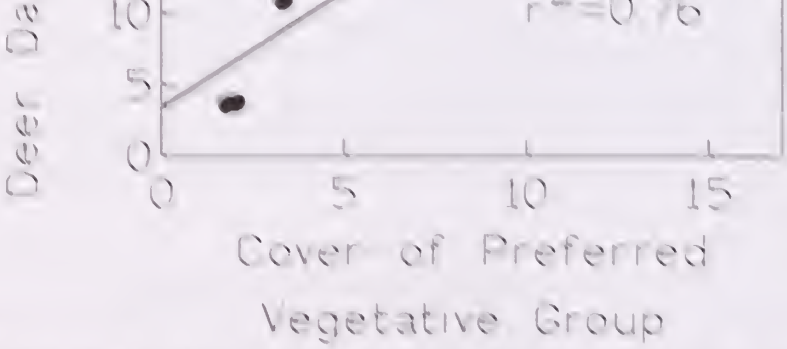

Figure 6.—Regression analysis of the percent cover of the plant species in the preferred groups in figures 1 - 5 and the deer days use per acre (DDA) on five chainings.

CONCLUSIONS

General patterns were evident in the results. Areas of closed stand woodlands with older trees consistently had the lowest deer use after treatment. This occurred even when the chained area was seeded. The seeded exotic grasses were the most successful on these locations but apparently not preferred by mule deer. Native species that were seeded as part of the treatment did poorly on the formerly tree dominated sites (Tausch 1973, Tausch and Tueller 1977). Mycorrhizal associations in the soil are a potentially important factor in the plant establishment patterns observed following treatment. Piñon has different associations than juniper and the native understory species. The introduced annuals such as russian thistle and tumble mustard, and the exotic bunch grasses seeded on the site do not require mycorrhizal associations (Klopatek et al. 1988). Ultimately, these differences in mycorrhizal associations affect vegetation patterns which in turn affect deer use. Better ways for returning native understory species to tree-dominated sites following treatment need to be developed.

When sufficient understory was present prior to chaining it responded vigorously to the treatment. Not all such understory communities, however, were the most favored by mule deer. Selectivity was also occurring among these communities. Those most preferred were generally sites with a good mix of shrubs, grasses, and forbs.

In another part of this study published elsewhere (Tausch and Tueller 1977) successional patterns indicated that the benefits of the chaining procedure for deer were short lived. Accelerated growth of surviving and reestablished trees on the chainings studied was rapidly reducing the increased understory production. All of them were projected to return to pre-chaining levels of production and deer use in less than 20 years.

While trees provide horizontal and vertical thermal cover (Suminski 1993), continuous stands have been observed throughout the southwest to result in a reduced forage base in the understory (Gottfried and Severson 1993). However, total removal of the trees, resulting in large areas of only the former understory communities, is also not effective (Severson and Medina 1983, Tausch 1973). Periodic treatment of the preferred areas with sufficient understory present, but while leaving areas of trees close by, should be a way to maintain useful productivity for deer winter range (Short et al. 1977). A number of alternative methods of tree control, such as burning, may represent better ways to accomplish this for many areas. However, all methods can have other associated negative ecosystem effects.

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Characteristics of Piñon-Juniper Habitats Selected for Feeding by Wintering Merriam's Turkey

Brian F. Wakeling and Timothy D. Rogers[1]

Abstract.—We studied winter habitat selection by Merriam's turkeys (*Meleagris gallopavo merriami*) to determine characteristics of piñon (*Pinus edulis*)-juniper (*Juniperus* spp.) habitats that may be critical to their overwinter survival. Seventy radio-instrumented turkeys were monitored during 4 years on the Chevelon Study Area in northcentral Arizona. Habitat characteristics were measured at 22 feeding sites and 17 random plots within the piñon-juniper cover type and the ponderosa pine (*Pinus ponderosa*)-piñon-juniper ecotone. Gambel oak (*Quercus gambelii*) was more prevalent at feeding sites than at random plots. Feeding sites were located in the proximity of smaller canopy openings more frequently than random plots. Forb cover was greater at feeding sites than random plots. Management strategies that 1) protect and encourage mature mast producing species, especially Gambel oak, and 2) preserve small (<0.06 ac) openings <1 mi from suitable roosting habitat will favor turkey populations.

INTRODUCTION

Merriam's turkey seasonally inhabit piñon-juniper forest cover type (Shaw and Mollohan 1992). Although this cover type comprises only a small portion of their annual use areas (Wakeling 1991), turkeys rely on piñon-juniper mast during severe winters (Ligon 1946). Winter food sources, such as piñon seeds and juniper berries (Ligon 1946, Reeves 1953, Schorger 1966), are more abundant in this cover type. Because of these characteristics, piñon-juniper habitats have been described as ideal emergency winter range (Reeves 1954).

Land management practices in the piñon-juniper woodland alter characteristics of the habitat used by turkeys. Turkey habitat use is influenced by grazing, fuel wood harvest, timber treatments, and recreational activities (Ligon 1946, Schorger 1966, Scott and Boeker 1977, Shaw 1986, Hoffman et al. 1993). Our research was designed to identify characteristics of piñon-juniper forest cover types selected by Merriam's turkey because little quantitative information was available to assist in land management decisions. We tested null hypotheses that turkeys used characteristics of feeding habitat proportionate to their measured availability.

Funding for this project was provided through Federal Aid in Wildlife Restoration Act W-78-R. The U. S. Forest Service Chevelon Ranger District of the Apache-Sitgreaves National Forests provided logistical assistance. J. S. Elliott, C. H. Lewis, J. Sacco, K. Sergent, and C. A. Staab provided field assistance. S. G. Woods assisted with GIS expertise. We would like to thank S. S. Rosenstock and R. A. Ockenfels for reviewing earlier drafts of this manuscript.

STUDY AREA

The 335 mi^2 Chevelon Study Area (CSA) was located on the Mogollon Rim, approximately 40 mi south of Winslow, Arizona, on the extreme western edge of the Apache-Sitgreaves National Forests (Fig. 1). Elevations ranged from 5500 ft in the northern portion to 7900 ft in the southern portion.

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Annual precipitation averaged 18.6 in, with 2 concentrations. The first concentration occurred during winter storms in January through March, and the second during summer monsoon storms in July through early September (Natl. Oceanic and Atmos. Admin. 1991).

Five cover types were identified on the CSA based upon U. S. Forest Service Terrestrial Ecosystem Surveys (Laing et al. 1989): 1) piñon-juniper, 2) ponderosa pine-Gambel oak, 3) mixed conifer, 4) aspen (*Populus tremuloides*), and 5) forest meadow cover types (Fig. 2). Mixed conifer cover types were dominant above 7600 ft, and extended along east facing slopes and drainages. This habitat included Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), limber pine (*Pinus flexilis*), and Rocky Mountain maple (*Acer glabrum*). Ponderosa pine dominated west facing slopes between 7600 and 6000 ft. Below 6000 ft, the piñon-juniper cover type was dominant, with ponderosa pine stringers along drainages. At elevations below 7000 ft, piñon pine and alligator juniper (*Juniperus deppeana*) were increasingly abundant. Gambel oak occurred in all wooded cover types, in pockets in the mixed conifer and piñon-juniper associations, and as a widespread codominant with ponderosa pine.

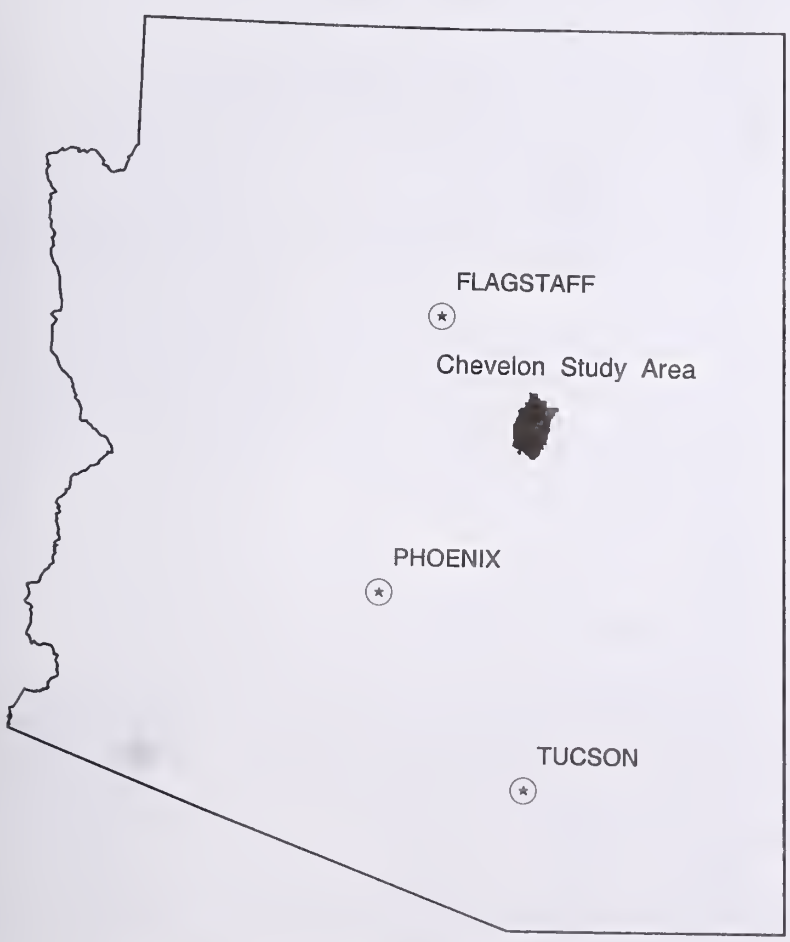

Figure 1.—Location of the Chevelon Study Area in northcentral Arizona.

Logging and grazing were the major commercial land uses on the CSA. Cutting of fuel wood, particularly in the piñon-juniper cover type, has increased over the past 2 decades. Logging began in the late 1930's and most ponderosa pine stands on level terrain have been logged at least once. However, little logging has occurred on steeper slopes in larger canyons. Until the 1960's, sheep were the primary livestock on the CSA. The predominant livestock on the CSA since the 1960's has been summering cattle.

METHODS

Merriam's turkey were captured between 1 January and 31 March during the winters of 1988-92. Turkeys were captured with box traps, drop nets, and rocket nets (Glazener et al. 1964, Bailey et al. 1980, Phillips 1982, Wakeling 1991). Each turkey was fitted with a backpack mounted radio telemetry unit (Telonics, Mesa, AZ) (Wakeling 1991). These birds were observed to determine habitat selection between 15 November and 15 April during the winters of 1990-91 through 1993-94.

We visually located radio-instrumented turkeys or feeding sign (e. g. scratching and droppings) from instrumented or non-instrumented turkeys to determine the activity center. We used this point as plot center in the mensuration of habitat characteristics. Locations were obtained approximately 2 times daily. Habitat mensuration was conducted within 2 days of when the birds abandoned the feeding site. Individual turkeys were not located >1 time per day to reduce autocorrelation of data.

We classified vegetative cover types at the sites according to Larson and Moir (1986). We considered the following Larson and Moir (1986) classifications to represent piñon-juniper habitats for our analysis: piñon pine-blue grama (*Bouteloua gracilis*), piñon pine-sparse, piñon pine-cliffrose (*Cowania mexicana*), and the piñon pine phase of ponderosa pine-Gambel oak. A 0.1-ac circular plot was used to estimate density by counting conifer and Gambel oak seedling (<1 in diameter at breast height [DBH]) and trees (≥1 in DBH).

We measured the DBH of all ponderosa pine and Gambel oak trees on the 0.1-ac plot with a diameter tape. The diameter at root crown (DRC) was measured with a diameter tape on all juniper and piñon trees. Mean DBH, DRC, and density data were used to calculate basal area (BA) on each plot according to the formula $\Sigma((DBH/2)^2 \times 3.14) \times 10$.

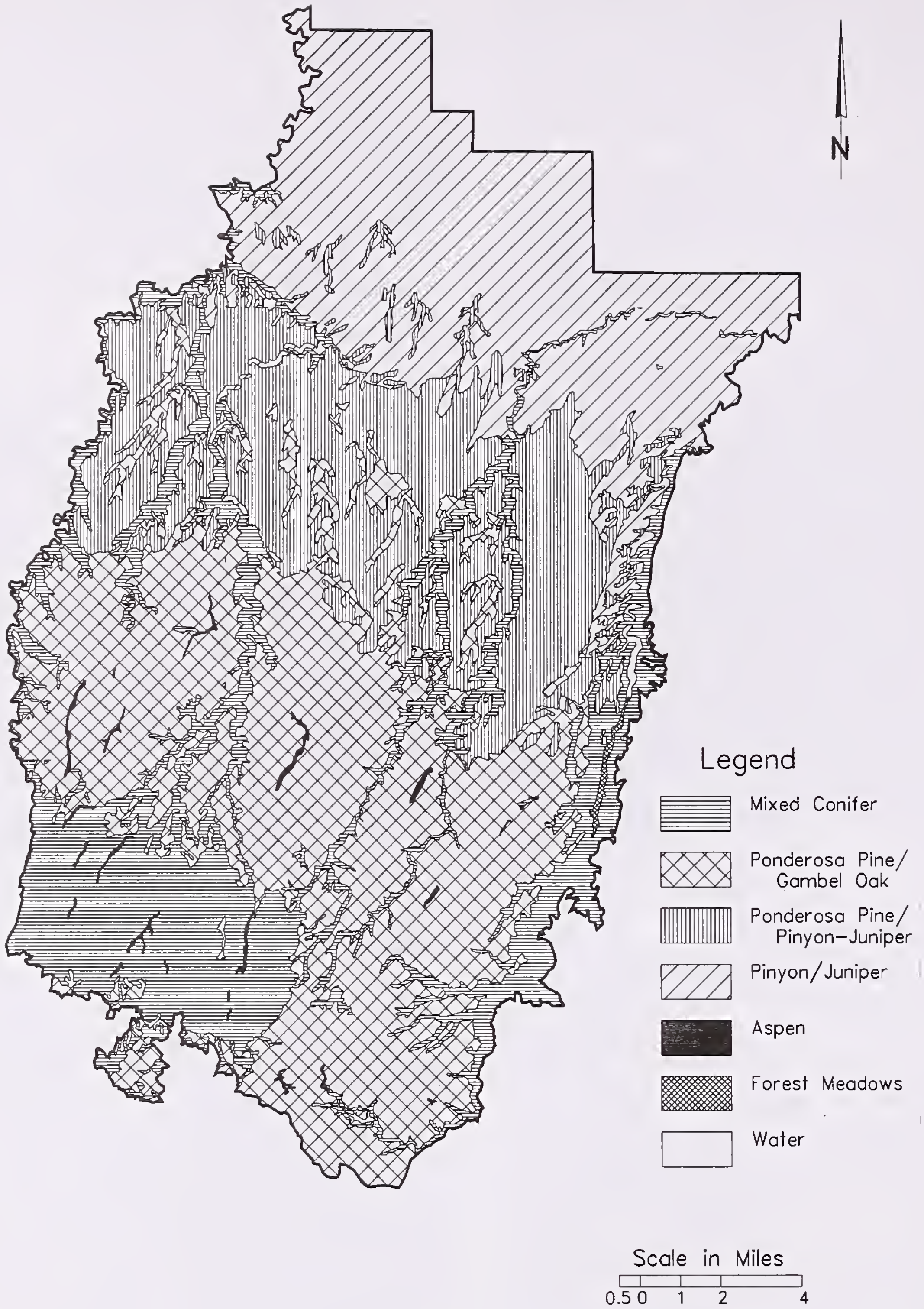

Figure 2.—Vegetative cover types on the Chevelon Study Area, based upon Terrestrial Ecosystem Surveys (Laing et al. 1989).

Canopy coverage of forbs, grasses, shrubs, deciduous trees, conifer trees, and rocks was estimated along 4 25-ft line intercept transects (Canfield 1941). The first transect was oriented randomly, radiating from site center. The 3 remaining transects were each oriented 90° from the preceding transect. We estimated canopy coverage in 3 height categories: 1) 0-17.9, 2) 18-35.9, and 3) 36-72 in. We estimated overhead canopy density with a spherical densiometer (Strickler 1959) at 4 points, 37.2 ft from the feeding site center, along the same bearing as the line intercept transects. We averaged the 4 values to calculate a mean canopy density for each site.

We ocularly estimated the distance to the nearest canopy opening from each site center. We defined canopy opening as any horizontal gap in the overstory canopy that was greater than 100 ft^2. We also ocularly estimated the dimensions and calculated the area of the canopy opening.

We recorded measurements on the same habitat parameters at 103 random plots to compare with feeding sites. Computer generated Universal Transverse Mercator coordinates were plotted on 7.5′ U. S. Geological Survey maps. We located each of these points on the ground, and then paced a random distance (<300 ft) on a random bearing to facilitate random plot center placement. This procedure was used to avoid any biases associated with initial random point location. Random plots were measured during the same season as feeding sites.

Use of piñon-juniper cover type was analyzed using Chi-square contingency table analysis, Bonferroni confidence intervals (Neu et al. 1974, Byers et al. 1984), and Jacobs' D selection index (Jacobs 1974). Because most data violated normality assumptions, we used the Mann-Whitney U statistic (Zar 1984) to test for differences between feeding sites and random plots. Differences were considered significant if $P < 0.10$. Further, differences were not considered significant if both group medians were 0, even though $P < 0.10$.

RESULTS

Seventy Merriam's turkey were captured and radio-instrumented for winter habitat study (Table 1). Twenty-two feeding sites and 17 random plots were located within piñon-juniper cover type. These comprised 9% of the turkey winter feeding sites and 16.5% of the random plots located on the CSA. Thus, turkeys used the piñon-juniper cover type less than its availability within the CSA ($X^2 = 4.017$, 1 df, $P = 0.044$, Jacobs' $D = -0.285$).

Table 1.—Age and sex of Merriam's turkey monitored for winter habitat selection on the CSA by year of capture.

	Male		Female		
Year	Juvenile	Adult	Juvenile	Adult	Total
1988	2	0	4	3	9
1989	0	0	0	1	1
1990	0	1	4	18	23
1991	1	9	3	14	27
1992	6	2	0	2	10
Total	9	12	11	38	70

Table 2.—Median values for feeding sites and random plots in piñon-juniper habitats on the CSA and Mann-Whitney *U P* values.

Habitat Component[a]	Feeding Site	Random Plot	*P*
Gambel Oak Tree Density	35.0	0.0	0.056
Gambel Oak Seedling Density	170.0	30.0	0.074
Canopy Density	28.4	40.0	0.043
Distance to Opening	8.0	0.0	<0.001
Opening Size	1375.0	3300.0	0.020
Forb Canopy Cover	0.0	0.1	0.051

[a]*Tree densities are reported on a per acre basis, canopy density and cover as a percent, distance in ft, and size in ft^2.*

Feeding sites had greater densities of Gambel oak seedlings and trees ($P = 0.074$ and 0.056, respectively) than at random plots (Table 2). Canopy density was less ($P = 0.043$) at feeding sites than at random plots (Table 2). Feeding sites were further ($P < 0.001$) from canopy openings as well (Table 2). The size of the canopy openings adjacent to feeding sites was also smaller ($P = 0.020$) than those found at random plots (Table 2).

Canopy cover of forbs was lower ($P = 0.051$) at feeding sites than at random plots (Table 2). No other difference was found between sites based upon canopy cover (Table 3). Mean DBH or DRC did not differ for any tree species between sites, nor did BA or any other tree density (Table 3).

Table 3.—Median[a] values for piñon-juniper habitats on the CSA and Mann-Whitney *U P* values.

Habitat Component[b]	Median	*P*
Grass Canopy Cover	2.6	0.209
0-17.9 in Deciduous Canopy Cover	0.0	0.013
18-35.9 in Deciduous Canopy Cover	0.0	0.041
36-72 in Deciduous Canopy Cover	0.0	0.017
0-17.9 in Conifer Canopy Cover	2.6	0.260
18-35.9 in Conifer Canopy Cover	3.6	0.812
36-72 in Conifer Canopy Cover	9.2	0.874
0-17.9 in Shrub Canopy Cover	0.3	0.561
18-35.9 in Shrub Canopy Cover	0.1	0.893
36-72 in Shrub Canopy Cover	0.0	0.199
Downed Wood Canopy Cover	2.1	0.657
Rock Canopy Cover	0.4	0.379
Mean *Pinus ponderosa* DBH	8.5	0.225
Mean *Juniperus* DRC	10.6	0.821
Mean *Pinus edulis* DRC	6.4	0.124
Mean *Quercus gambelii* DBH	3.4	0.539
BA	84.4	0.610
Pinus ponderosa Tree Density	20.0	0.291
Pinus ponderosa Seedling Density	10.0	0.917
Juniperus Tree Density	70.0	0.910
Juniperus Seedling Density	160.0	0.788
Pinus edulis Tree Density	75.0	0.394
Pinus edulis Seedling Density	180.0	0.125

[a]*Medians are presented across groups because no differences between groups were detected.*
[b]*Tree densities are reported on a per acre bases, canopy cover as a percent, DBH and DRC in inches, and BA as ft^2/ac.*

DISCUSSION

Although, the piñon-juniper cover type did not comprise a large proportion of turkey winter range, we believe that this cover type may be essential to turkeys during severe winter conditions that include deep (>1 ft) snow or poor food availability. Our study suggests that the piñon-juniper cover type may be used less than available during some winters. We speculate that this occurred during our study because winter weather conditions were mild and winter food availability adequate. Certainly, not all winters are mild nor mast crops plentiful. In fact, Shaw (1986) implicated severe winters as a potential cause for a statewide decline in Arizona's turkey populations following the winter of 1978-79. During such winters, the suitability of the piñon-juniper cover type is of paramount importance because turkeys rely on it for winter survival (Ligon 1946, Hoffman et al. 1993). This cover type is apparently used for emergency winter feeding during periods of low food availability or deep snow accumulations in adjacent habitats (Reeves 1954, Hoffman et al. 1993). Consequently, the piñon-juniper cover type can be critical to overwinter survival of Merriam's turkey during severe winters, even though it may receive limited use during mild winters.

Habitats <1 mi from roost sites receive the greatest proportion of winter use by turkeys (Wakeling and Rogers In press). Consequently, those areas <1 mi from potential roost sites, such as the ponderosa pine cover type, a pine stringer habitat, or other suitable cover type (e.g. cottonwood [*Populus fremontii*] riparian corridors), are probably the most critical portions of the piñon-juniper cover type to turkeys during severe winters. If maintaining or increasing Merriam's turkey population size is a management goal, these portions of the piñon-juniper cover type should be managed to provide suitable feeding habitat and emergency winter range during all years. Using this strategy, adequate reserves will be available during years with adverse weather or poor food supplies.

In our study, higher densities of Gambel oak trees were found in feeding habitat selected by turkeys within the piñon-juniper cover type. Because winter diets tend to be comprised mostly of mast (Reeves and Swank 1955, Laudenslager and Flake 1987, Rumble 1990), mast producing species may be used to identify potential feeding habitat.

Selection of feeding habitat characteristics may be explained either by plant phenological development or turkey behavior. Habitats that contained increased densities of deciduous trees would, by their nature, have decreased canopy density during winter before spring budding and leaf development. Because feeding sites were selected in higher densities of Gamble oak, they had lower canopy densities than random plots. Feeding sites were selected under trees, where mast crops frequently collect. Because feeding sites were selected under trees, feeding turkeys would not be located in openings while feeding. This behavior would explain the greater distance that feeding sites were selected from openings than that distance between random plots and openings. Turkeys generally select smaller openings for feeding activities in southwestern habitats during most seasons (Mollohan and Patton 1991, Hoffman et al. 1993). Smaller openings may be selected because turkeys can reach cover faster if they detect a perceived predator.

Our research has identified 2 management strategies that may favor Merriam's turkey using piñon-juniper habitats. First, because winter food supplies are important to turkeys (Wakeling and Rogers In press), protecting and increasing mature mast producing species, such as Gambel oak, juniper, and piñon trees, at ≥90 BA (all trees within stand) <1 mi from known or potential roost trees would be beneficial. Mature oaks, with regeneration in the understory, appear to be favored by turkeys. Additionally, mature alligator junipers were frequently found within the feeding site. Both Gambel oak and alligator juniper mast play an important role in turkey winter diets in the area (Wakeling and Rogers In press). Second, fuel wood harvests and prescribed burns that protect and enhance openings <0.06 ac would favor turkey populations by retaining more suitable winter feeding habitat. We speculate that the density of these small openings should not exceed 2/ac, thus maintaining about 10% of the area in openings as recommended by Hoffman et al. (1993).

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Wildlife Associations in Rocky Mountain Juniper in the Northern Great Plains, South Dakota

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ABSTRACT.—Rocky Mountain juniper is an important habitat component in the northern Great Plains. These woodlands provide vertical and horizontal vegetative structure that enhances wildlife use. Ecological approaches to managing habitats require understanding relationships between wildlife species and succession in plant communities. We determined bird, small mammals and large mammals habitat use in seral stages of Rocky Mountain juniper woodlands along the Missouri River in South Dakota. Fifty-three bird species occurred in these woodlands. Bird species diversity averaged 2.7 across 24 study sites and we tallied an average of 4.6 bird species during a 3-day sample session at each site. Black-billed Magpies and Blue Jays were the only tree-nesting species whose abundance differed statistically among seral stages of juniper. Trends in the data suggested tree and shrub nesting guilds, total bird abundance, bird species diversity, and birds species richness increased in early and late seral stages. Snags and cavity-nesting species were rare in all seral stages. Northern Flickers were more abundant in late seral juniper; House Wrens were more abundant in intermediate seral juniper. Ground-nesting species declined from low seral to high seral stages. White-footed mice, deer mice, prairie voles, total small mammal abundance, and small mammal species richness were higher in the intermediate seral stage of juniper. Eastern cottontail abundance was greatest in late seral juniper. Trends in deer use suggested higher use of early and late seral stages of juniper woodlands. Patch size, juxtaposition of other woodlands, and animal home range size likely influenced wildlife abundance in seral stages of Rocky Mountain juniper.

INTRODUCTION

Rocky Mountain juniper (*Juniperus scopulorum*) woodlands exist in scattered stands in the Missouri River basin. This species is near the eastern limit of its range (Noble 1990). Juniper woodlands occur in highly eroded and rugged terrain. There is evidence of past harvest of larger trees for fence posts (Hansen et al. 1984). Larger trees occur in areas protected from fire or inaccessible to firewood cutting. Rocky Mountain juniper does not sprout following fire or cutting (Noble 1990) and the areal extent of juniper woodlands in the northern Great Plains has increased with suppression of fires (Wright et al. 1979).

Grasses and forbs of the mixed-grass prairie are common in juniper woodlands. Little-seed rice-grass (*Oryzopsis micrantha*) is largely restricted to juniper woodlands in this region and it is often dominant in the understory (Hansen et al. 1984, Girard et al. 1989). Vegetative descriptions of "climax" stands of Rocky Mountain juniper in the northern Great Plains occur in Hansen et al. (1984) and Girard et al. (1989).

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Juniper woodlands are important habitat for wildlife because adjacent grassland habitats lack vegetation structure (Sieg 1991a). Greater vertical structure increases species richness and density of passerine birds (Willson 1974, Roth 1976, Rotenberry and Weins 1980). Juniper woodlands provide habitat necessary for existence of many bird species on the northern Great Plains (Sieg 1991a,b).

Juniper woodlands are also important for mammals. Some species of small mammals occur in greater abundance in juniper woodlands in the northern Great Plains (MacCracken et al. 1985a,b; Sieg 1988). Juniper woodlands are important habitats for mule deer (Severson and Carter 1978).

The relationships between wildlife and succession in Rocky Mountain juniper have not been examined for this region. The objective of our research was to use a coarse filter approach and examine wildlife abundance in relation to seral stages of Rocky Mountain juniper along the Missouri River in South Dakota.

STUDY AREA AND METHODS

We sampled 24 sites in 3 seral stages of Rocky Mountain juniper (N = 13, 5, and 6 in early, intermediate, and late seral stages, respectively) along the Missouri River from 1990 to 1992. A quantitative seral stage classification (Uresk 1990) was applied to Rocky Mountain Juniper woodlands to estimate seral stages (unpubl. data, Rocky Mountain Experiment Station, Rapid City, SD). The areal extent of juniper stands surrounding sample sites varied. The minimum size was large enough to encompass a 40 X 50 m plot for vegetation samples.

Of the sites we sampled, early seral juniper woodlands averaged 326 juniper seedling-saplings/ha (≤2.5 cm dbh) and 393 trees/ha (>2.5 cm dbh). Juniper seedling-saplings increased to 2087/ha with >1235 trees/ha in the intermediate seral stage. Seedling-sapling density declined to 526/ha in the late seral stage and tree density averaged 1418/ha. Tree density was similar between intermediate and late juniper, but average dbh increased from 7.5 cm to 12.7 cm and tree basal area nearly doubled in late seral juniper. Overstory canopy cover averaged 20% in early seral juniper, 50% in intermediate, and 54% in late seral juniper. Grass cover averaged 42%, 18%, and 34% in early, intermediate, and late seral stages, respectively. Little-seed ricegrass averaged 19% cover in late seral juniper. Shrubs averaged 13%, 30%, and 4% cover in early to late seral juniper, respectively.

Birds

We estimated bird abundance at each site using the variable circular-plot technique (Reynolds et al. 1980). Bird counts were conducted between sunrise and 1100 hours for three consecutive days during each sample session. In 1990, we completed one sample session in late June. During 1991-92, we completed three sample sessions between May 15 and July 4. During a 5-minute sampling interval, we recorded the identity of all birds seen or heard, sex, estimated distance from the sample point, and presence in or out of the woodland. The sampling order of sites was changed daily to ensure that bird counts occurred throughout the morning. We did not count birds when wind speeds exceeded 10 km/hr or during rainy weather.

Mammals

We estimated small mammal abundance by trapping small mammals in Sherman live-traps. Two lines of 10 traps spaced at 5-m intervals were established 10 m apart. Traps were baited with commercial bird seed mix and a mixture of peanut butter and rolled oats. We trapped small mammals four consecutive nights during the last week of July or first three weeks of August each year. Trapping periods of 3-5 days are adequate for estimating relative abundance of rodents (Johnston and Keller 1983). Each animal captured was toe-clipped for identification.

We estimated medium and large mammals use of juniper woodlands using scent pit surveys (Linart and Knowlton 1975, Conner et al. 1983, Drew et al. 1988). Vegetation and litter were cleared from four 1-m^2 plots and the plot was covered with a fine layer of sifted soil. Two plots were located 25 m above and below the center of the sample site and two, 10 m on either side. A plaster disc soaked in fatty-acid scent (USDA, Animal Pesticide Health Inspection Service, Pocatello, ID) was placed in the center of each plot. We prepared plots during the day and identified tracks (Murie 1974) of animals in the sifted soil the next morning. Each plot was prepared again and tracks were recorded on the second day. Scent pellets were removed after each sample session. Three, two-day sample sessions were completed in June, September, and November 1990; four sample sessions (April, June, September, and November) were completed in 1991 and 1992.

Analyses

Detection and density estimates of most birds decline beyond 30 m (Emlen 1971, Verner and Ritter 1988). Only birds within 30 m of the count point and within the juniper woodland were included in our analyses. Although data are reported as density estimates within 30 m of the census point, they should not be construed as absolute estimates of density. It is impossible to assure that all birds within 30 m of the census point were counted (Verner 1985).

We summarized data to estimate abundance of birds and guilds (DeGraaf et al. 1991) as averages per site in a hierarchical manner. Data were aggregated to calculate averages across days within sample session, sample sessions within years, and years within sites. Some bird species occurred on fewer than five sites; these data were not presented. However, we included data from all birds within 30 m in calculations of guild abundance, species richness, and species diversity. Bird species diversity was calculated using the Shannon-Wiener formula from average abundance per site. Bird species richness is the number of species at each site per sample session.

Small mammal abundance is estimated as the average number of unique individuals per night at each site. Small mammal species richness is the number of species captured at each site. Medium and large mammals are the average number of visits each night for each site.

Our data did not meet homogeneity of variance and normality assumptions of parametric statistics. We used a multi-response permutation procedure (MRPP) (Mielke 1984) to test hypotheses of no differences of bird abundance, guild abundance, species diversity, and species richness among seral stages. MRPP was also used to make comparisons of small and large mammal abundance among seral stages.

We used a $\alpha \leq 0.20$ for tests of differences among seral stages. Our objectives were to provide managers with information regarding wildlife relationships to seral stages in juniper woodlands. Sample sites were selected along 320 km of the Missouri River without regard to size of woodlands or landscapes. Woodland area and juxtaposition of other vegetation types add variability to wildlife associations with seral stages. We did not select more stringent levels of statistical significance because Type II errors were as important as Type I errors.

RESULTS

Common and scientific names of birds and mammals and their occurrence are in Tables 1 and 2. We observed 53 bird species in juniper woodlands. Many species were rare or occurred on fewer than 5 sites. Bird species diversity averaged 2.7 for juniper woodlands regardless of seral stage; bird species richness averaged 4.6 per 3-day sample session regardless of seral stage. Seven small mammal species were trapped and 11 other mammal species visited scent pits. Small mammal species richness averaged 2.2 per site.

Bird Responses To Seral Stages

Black-billed Magpies were more abundant ($P = 0.13$) in intermediate than early seral juniper (fig. 1). Despite a higher average, abundance of magpies in late seral juniper did not differ from other seral stages. Blue Jays were more ($P = 0.03$) abundant in late seral juniper than the early or intermediate seral stages. Tree-nesting species tended to be more common in early and late seral stages than the intermediate seral stage. Northern Flickers were more ($P \leq 0.08$) abundant in late seral juniper (fig. 2) and intermediate seral juniper had more ($P = 0.01$) House Wrens than late or early seral stages of juniper. Abundance of cavity-nesting species showed trends toward increasing from early to late seral stages in juniper. No differences were apparent among birds in the shrub nesting guild (fig. 3). Common Yellowthroats and Rufous-sided Towhees showed trends toward higher abundance in later seral stages (fig. 4). Vesper Sparrows were more ($P = 0.03$) abundant in early seral juniper, while Field Sparrows, and lark sparrows showed trends toward greater abundance in early seral juniper.

Brown-headed Cowbirds were marginally more abundant ($P = 0.21$) in early seral juniper and declined in intermediate and late seral stages (fig. 5). Trends suggested total bird abundance and bird species richness reflected abundance of the tree nesting guild, but not significantly. Bird species diversity did not differ among seral stages ($P = 0.90$).

Table 1.—Common name, genus, species, and nesting guild of birds observed in juniper woodlands along the Missouri River, South Dakota, 1990-1992.

Common name	Genus/species	Guild[1]	Seral Stage[2] Early	Intermediate	Late
Killdeer	*Charadrius vociferus*	G	X		X
Turkey Vulture	*Cathartes aura*	T	X	X	
Prairie Falcon	*Falco mexicanus*	L	X		
Ring-necked Pheasant	*Phasianus colchicus*	G	X	X	X
Wild Turkey	*Meleagris gallopavo*	G	X		
Mourning Dove	*Zenaida macroura*	T	X	X	X
Yellow-billed Cuckoo	*Coccyzus americanus*	S	X		
Black-billed Cuckoo	*Coccyzus erythropthalmus*	S	X		
Short-eared Owl	*Asio flammeus*	G	X		X
Common Nighthawk	*Chordeiles minor*	G	X	X	X
Northern Flicker	*Colaptes auratus*	C	X		X
Eastern Kingbird	*Tyrannus tyrannus*	T	X	X	X
Western Kingbird	*Tyrannus verticalis*	T	X		X
Great Crested Flycatcher	*Myiarchus crinitus*	C	X		X
Empidonax Flycatchers	*Empidonax* species	T	X		
Tree Swallow	*Tachycineta bicolor*	C	X		X
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	L	X	X	
Cliff Swallow	*Hirundo pyrrhonota*	L	X	X	X
Blue Jay	*Cyanocitta cristata*	T	X	X	X
Black-billed Magpie	*Pica pica*	T	X	X	X
Black-Capped Chickadee	*Parus atricapillus*	C	X	X	X
White-breasted Nuthatch	*Sitta carolinensis*	C	X		
House Wren	*Troglodytes aedon*	C	X	X	X
Wood Thrush	*Hylocichla mustelina*	S	X		X
American Robin	*Turdus migratorius*	T		X	
Loggerhead Shrike	*Lanius ludovicianus*	S	X	X	X
Gray Catbird	*Dumetella carolinensis*	S		X	
Brown Thrasher	*Toxostoma rufum*	S	X	X	X
Cedar Waxwing	*Bombycilla cedrorum*	T	X	X	X
Red-eyed Vireo	*Vireo olivaceus*	T	X		
Warbling Vireo	*Vireo gilvus*	T	X		
Yellow Warbler	*Dendroica petechia*	S	X		X
Common Yellowthroat	*Geothlypis trichas*	G	X	X	X
American Redstart	*Setophaga ruticilla*	T			X
Black-headed Grosbeak	*Pheucticus melanocephalus*	T	X		X
Blue Grosbeak	*Guiraca caerulea*	T	X		X
Indigo Bunting	*Passerina cyanea*	S	X		
Rufous-sided Towhee	*Pipilo erythrophthalmus*	G	X	X	X
Grasshopper Sparrow	*Ammodramus savannarum*	G	X		
Vesper Sparrow	*Pooecetes gramineus*	G	X	X	X
Savannah Sparrow	*Passerculus sandwichensis*	G	X		X
Song Sparrow	*Melospiza melodia*	G	X		
Lark Sparrow	*Chondestes grammacus*	S	X	X	X
Field Sparrow	*Spizella pusilla*	G	X	X	X
Chipping Sparrow	*Spizella passerina*	G	X	X	X
Lark Bunting	*Calamospiza melancorys*	G	X		
Western Meadowlark	*Sturnella neglecta*	G	X	X	X
Red-winged Blackbird	*Agelaius phoeniceus*	S	X	X	X
Brown-headed Cowbird	*Molothrus ater*	P	X	X	X
Common Grackle	*Quiscalus quiscula*	T	X	X	X
Northern Oriole	*Icterus galbula*	T	X		
House sparrow	*Passer domesticus*	C		X	
American Goldfinch	*Carduelis tristis*	T	X	X	X

[1] *Guild symbols—T = tree nesting; C = cavity nesting; S = shrub nesting; G = ground nesting; L = ledges, cliffs, and crevices; and P = nest parasite.*
[2] *X indicates present in seral stage.*

Table 2.—Common and scientific names and occurrence by seral stage of small and large mammal species captured or visiting scent pits in juniper woodlands along the Missouri River, South Dakota, 1990-1992.

Common name	Genus/species	Seral Stage[1] Early	Intermediate	Late
Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*	X		
Prairie vole	*Microtus ochrogaster*	X	X	X
Meadow vole	*Microtus pennsylvanicus*	X	X	X
House mouse	*Mus musculatus*	X	X	X
Hispid pocket mouse	*Perognathys hispidus*	X		
White-footed mouse	*Peromyscus leucopus*	X	X	X
Deer mouse	*Peromyscus maniculatus*	X	X	X
Coyote	*Canis latrans*	X	X	X
Porcupine	*Erethizon dorsatum*	X		
Bobcat	*Lynx rufus*	X		
White-tailed jackrabbit	*Lepus townsendii*	X		
Striped skunk	*Mephitis mephitis*	X	X	X
Deer	*Odocoileus spp.*	X	X	X
Raccoon	*Procyon lotor*	X	X	X
Eastern cottontail	*Sylvilagus floridanus*	X	X	X
Badger	*Taxidea taxus*	X		X
Red fox	*Vulpes vulpes*	X		

[1] *X indicates present in seral stage.*

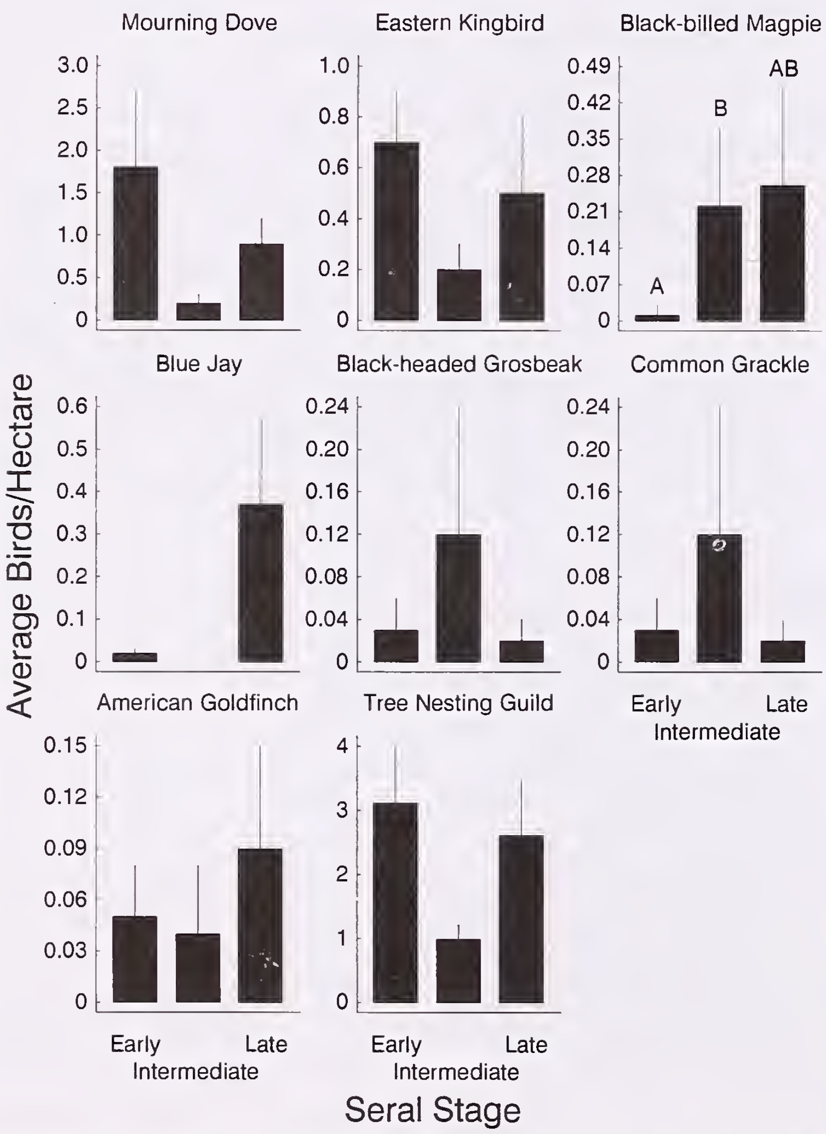

Figure 1.—Average abundance (birds/ha) of tree-nesting species among seral stages of Rocky Mountain juniper along the Missouri River, South Dakota 1990-92. Standard errors are indicated by vertical lines. Letters above abundance bars indicate significant differences among seral stages $\alpha \leq 0.20$, MRPP test.

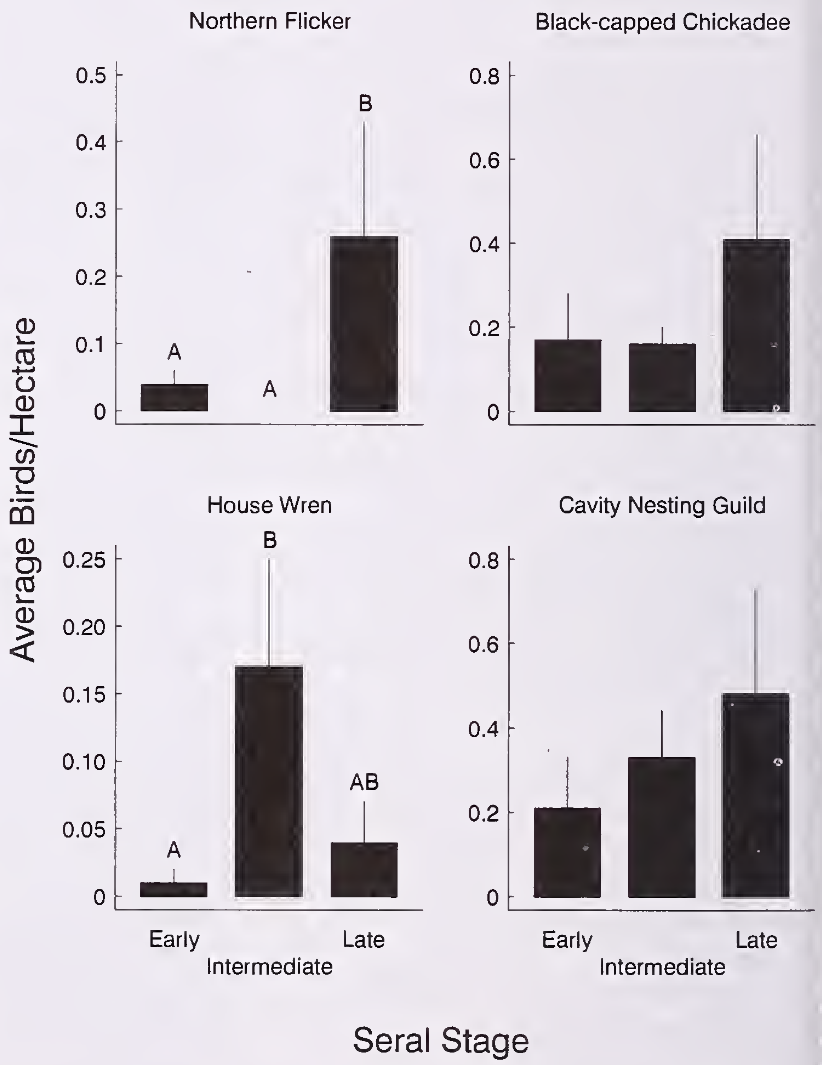

Figure 2.—Average abundance (birds/ha) of cavity-nesting species among seral stages of Rocky Mountain juniper along the Missouri River, South Dakota 1990-92. Standard errors are indicated by vertical lines. Letters above abundance bars indicate significant differences among seral stages $\alpha \leq 0.20$, MRPP test.

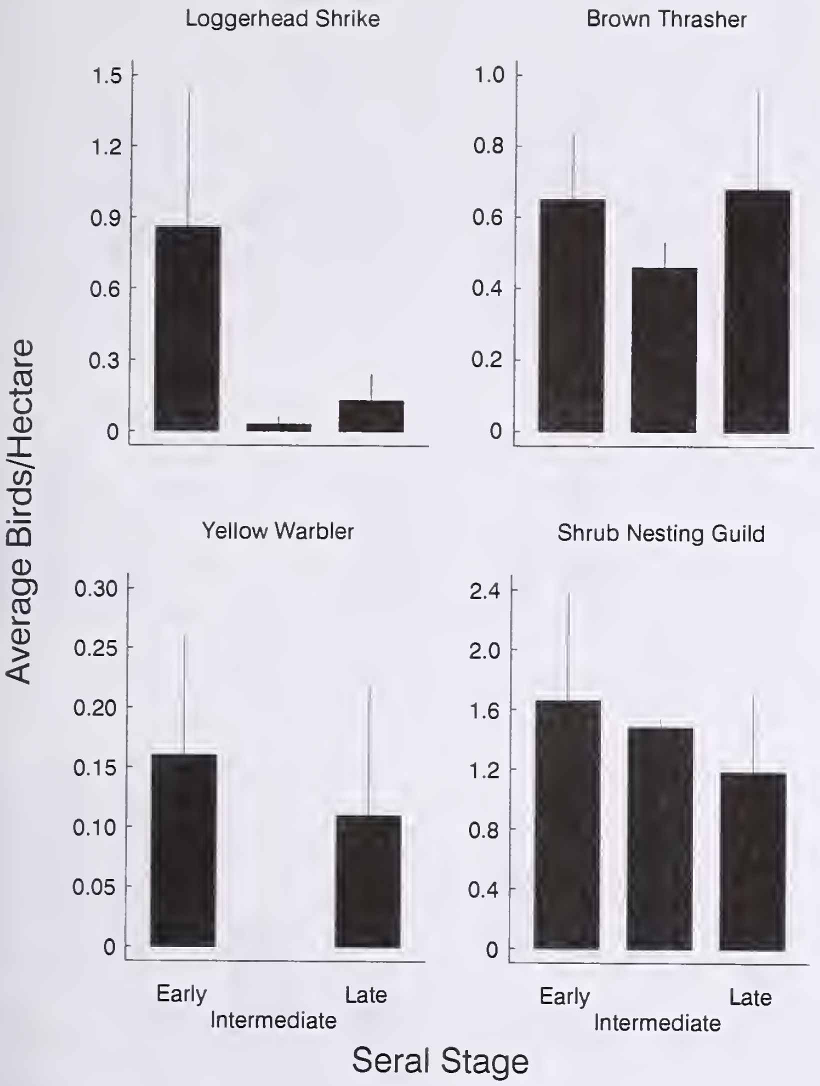

Figure 3.—Average abundance (birds/ha) of shrub-nesting species among seral stages of Rocky Mountain juniper along the Missouri River, South Dakota 1990-92. Standard errors are indicated by vertical lines. Letters above abundance bars indicate significant differences among seral stages α ≤ 0.20, MRPP test.

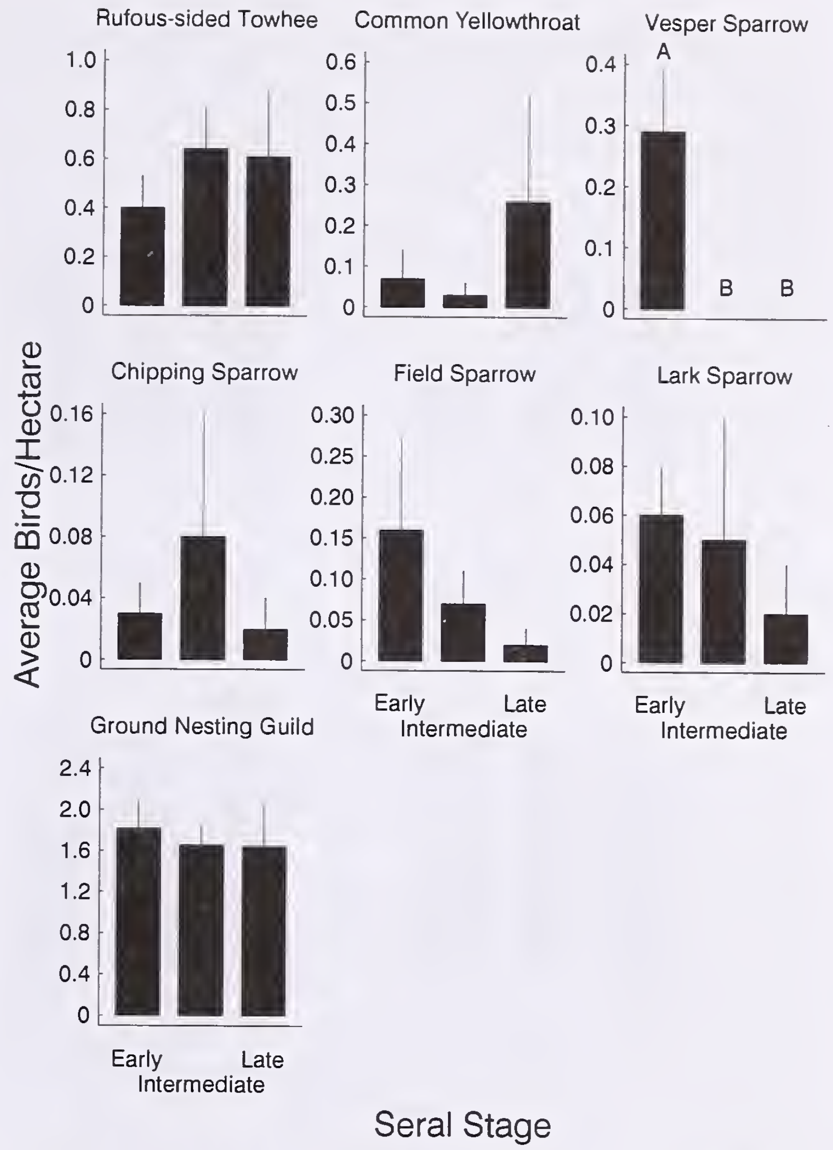

Figure 4.—Average abundance (birds/ha) of ground-nesting species among seral stages of Rocky Mountain juniper along the Missouri River, South Dakota 1990-92. Standard errors are indicated by vertical lines. Letters above abundance bars indicate significant differences among seral stages α ≤ 0.20, MRPP test.

Mammal Responses To Seral Stages

White-footed mice were more ($P < 0.12$) abundant in intermediate and late seral stages of juniper than the early seral stage (fig 6). Deer mice were the most common small mammal and abundance in intermediate seral juniper was greater ($P < 0.09$) than early or late seral juniper. Meadow voles were more ($P < 0.06$) abundant in early than intermediate or late seral stages. Prairie voles were more ($P = 0.01$) abundant in intermediate than early seral juniper; abundance in late seral juniper did not differ from the previous. Intermediate seral juniper woodlands had more ($P < 0.03$) small mammals and greater ($P < 0.11$) species richness than early or late seral stages. Hispid pocket mice occurred in low abundance in early seral juniper sites, but no differences were apparent among seral stages.

Visitations by coyote, raccoon, striped skunk, and badger did not differ among seral stages (fig. 7). Trends suggest the latter three may have used late seral juniper woodlands more than other seral stages. No trends were evident in deer use among seral stages of juniper. Cottontail abundance increased ($P = 0.04$) as succession progressed from early to late seral stages.

DISCUSSION

We expect juniper woodlands to expand in distribution with a trend toward late seral stages because of fire suppression. Grazing has little

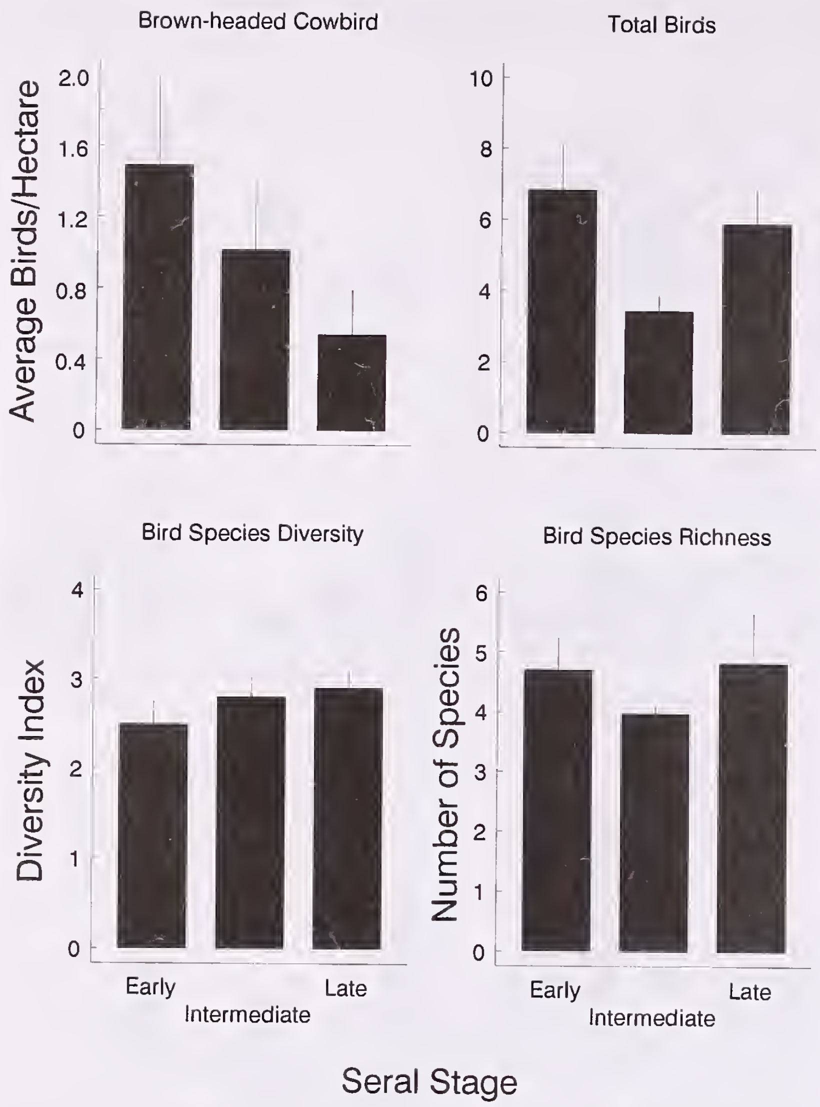

Figure 5.—Average abundance (birds/ha) of Brown-headed Cowbirds, total birds, bird species diversity, and bird species richness among seral stages of Rocky Mountain juniper along the Missouri River, South Dakota 1990-92. Standard errors are indicated by vertical lines. Letters above abundance bars indicate significant differences among seral stages $\alpha \leq 0.20$, MRPP test.

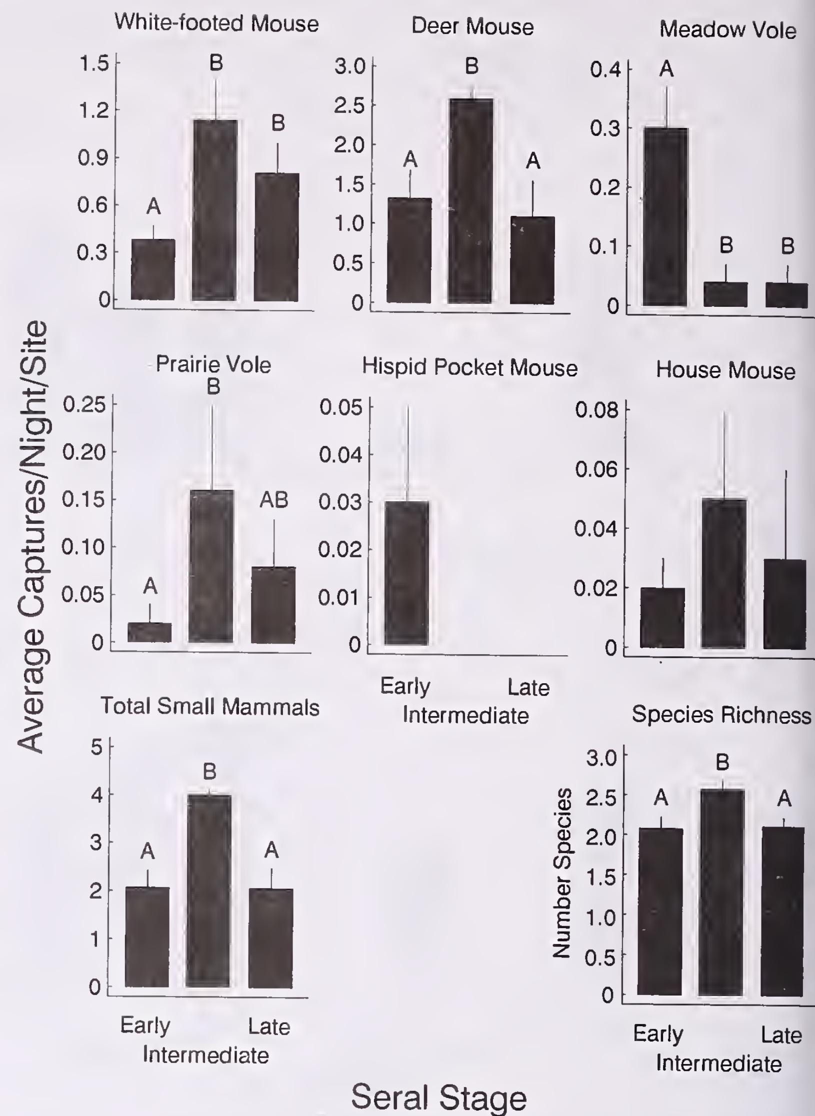

Figure 6.—Average unique individuals per night of small mammals among seral stages of Rocky Mountain juniper along the Missouri River, South Dakota, 1990-1992. Standard errors are indicated by vertical lines. Letters above abundance bars indicate significant differences among seral stages $\alpha \leq 0.20$, MRPP test.

direct impact on juniper (Severson and Boldt 1978), but excessive grazing encourages expansion of this woodland (Wright et al. 1979). Rocky Mountain juniper woodlands are "edge" or "island" habitats in the prairie. Wildlife populations were influenced by seral stage as well as stand size (Johns 1993), dispersion, and juxtaposition of other woodlands on the landscape.

Birds

Members of nesting guilds share some resource requirements, but may differ in other critical resource needs or ability to adjust to alterations of resources (Verner 1984). Managing one or a few indicator species within a guild may not represent all other guild members (DeGraaf and Chadwick 1984, Block et al. 1987).

Direct linkage between habitat associations of rare species and occurrence in seral stages cannot be made. However, barring better data, our data provide managers with starting points in their habitat assessments.

Juniper woodlands add vegetation density and structure to the northern Great Plains. Bird community patterns are associated with vegetation structural diversity (Roth 1976, Rotenberry and Wiens 1980, Sabo and Holmes 1983). Bird occurrence and abundance in juniper woodlands is greater than in prairie grasslands (Sieg 1991a) and varies with seral stages. Most vegetation structure was provided by the tree canopy and there were more tree nesting birds than birds in other nesting guilds in juniper woodland. Ground-nesting species that use trees for perches or feeding also benefited from juniper woodlands.

Vegetative conditions in intermediate seral juniper are too dense for ground nesting birds, and not yet favorable for the tree-nesting species. High numbers of juniper saplings and trees result in a dense, uniform stand of small trees in the intermediate seral stage. Late seral juniper stands have fewer saplings, taller trees, greater canopy volume, and horizontal patchiness. This structural diversity in vegetation increases abundance and richness (Willson 1974, Holmes et al. 1979, Anderson et al. 1983).

Cavity-nesting species were uncommon in juniper woodlands because cavities and snags were rare. Northern Flickers was the only woodpeckers in any seral stage of juniper. Black-capped Chickadees were the most abundant cavity-nesting species in our study and another in western South Dakota (Sieg 1991a). No snags >38 cm dbh occurred in the sites we sampled and snags 13 - 38 cm dbh occurred only in early (0.4/ha) and late seral juniper (0.8/ha). Suitable snags for cavity nesters were usually species other than juniper. Cavity nesting birds were uncommon in southwest piñon-juniper woodlands if pine trees (*P. monophyla* and *P. edulis*) were absent (Balda and Masters 1980). Other cavity-nesting species, such as House Wrens, probably nested in nearby green ash or cottonwood trees.

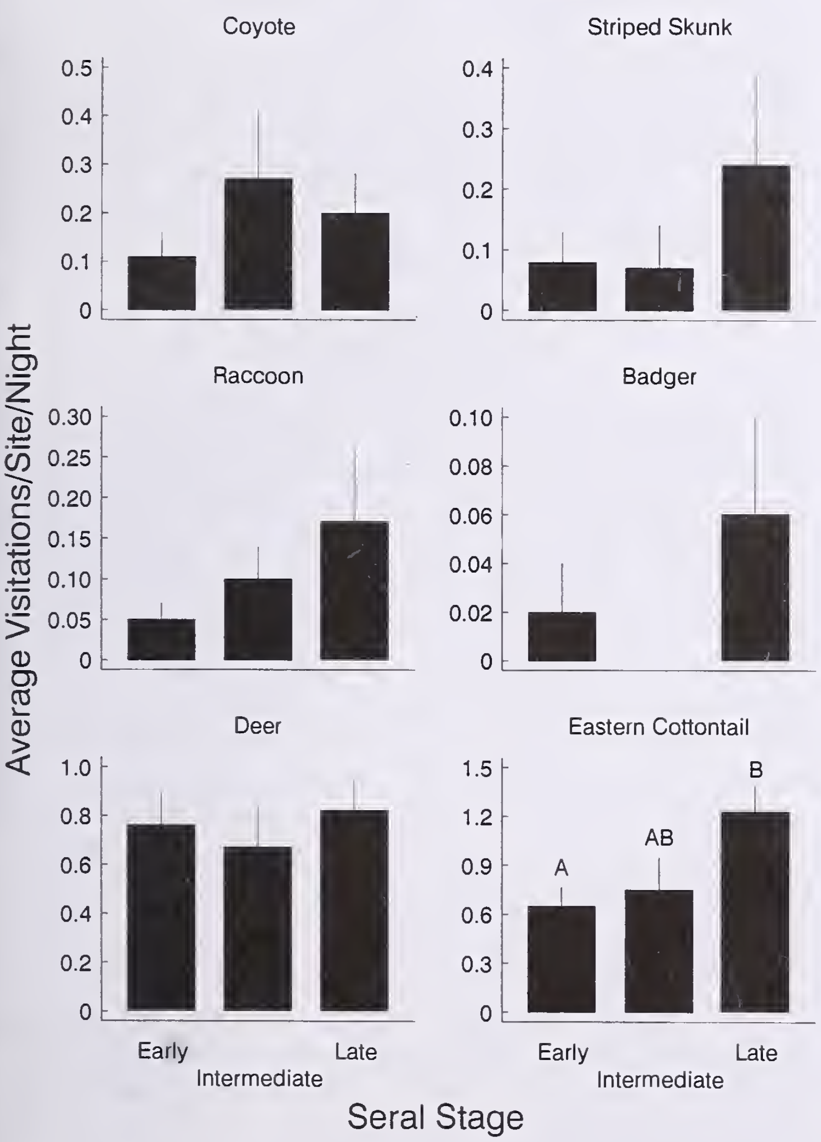

Figure 7.—Average visitations per session to scent pits by intermediate and large mammals among seral stages of Rocky Mountain juniper along the Missouri River in South Dakota, 1990-1992. Standard errors are indicated by vertical lines. Letters above abundance bars indicate significant differences among seral stages $\alpha \leq 0.20$, MRPP test.

The Loggerhead Shrike is being considered for listing under the Endangered Species Act and is considered threatened or endangered in several states (Finch 1992, Smith and Kruse 1992). Loggerhead Shrikes prefer open habitats with scattered perch sites (Finch 1992) typical of the early seral stages of juniper on the northern Great Plains.

Vesper Sparrows, Field Sparrows, and Lark Sparrows are ground-nesting birds associated with scattered shrub or woodlands. Abundance of these species declined (some not significantly) from early to late seral stages. Reduced ground cover for nesting from early to late seral stages may have been a factor affecting use of juniper woodlands by these species. Common Yellowthroats and Rufous-sided Towhees are associated with tall shrubs or small trees that may account for the insignificant increase in late seral juniper. Many of the birds in the ground nesting guild using juniper woodlands are prairie species and do not require woodlands.

Brown-headed Cowbirds have been implicated in the decline of song birds in the United States and are obligate nest parasites (Brittingham and Temple 1983). Cowbird abundance was correlated with abundance of both tree ($r = 0.6$, $P < 0.01$) and ground ($r = 0.4$, $P = 0.03$) nesting birds in this study. Cowbirds prefer open scattered woodlands (DeGraaf et al. 1991) and may have found nests easier in the open canopy early seral stages of juniper.

Mammals

Species richness of small mammals in Rocky Mountain juniper was low, but low species richness may not be uncommon in northern Great Plains. Other reports show only 6-9 species of small mammals (MacCracken et al. 1985b, Hodorff et al. 1988, Sieg 1988). Abundance and species richness of small mammals contrasted data for birds; the intermediate seral stage supported more small mammals. Reduced variability and stronger associations of small mammal to seral stages of juniper than birds resulted from their resident status and small home ranges.

Deer mice are widespread generalist rodents in North America (Baker 1968). In southeastern Montana woodlands, deer mice were positively correlated with understory vegetative cover (MacCracken et al. 1985b). Intermediate seral juniper woodlands in our study had more shrub cover, less grass cover, and greater patchiness in the understory than early or late seral woodlands.

White-footed mice are usually associated with riparian habitats in the Great Plains (Andersen and Jones 1971, Hodorff et al. 1988). Rocky Mountain juniper woodlands are not riparian ecosystems. Similar to deer mice, white-footed mice were more abundant in the intermediate seral stage. Ribble and Samson (1987) suggested these two species partition macrohabitats but use similar microhabitats. We found them using similar macrohabitats in juniper woodlands.

Meadow voles are associated with high vegetative cover (Huntly and Inouye 1987) and shrublands (Snyder and Best 1988). They usually occur in moist meadows, but inhabit upland areas if sufficient vegetation is present (Jones et al. 1983, Sieg 1988). Early seral juniper, where meadow voles were more abundant, had greater understory and grass cover than other seral stages of juniper.

Upland habitats with herbaceous cover appear to meet habitat needs of prairie voles (Moulton et al. 1981). Prairie voles partition habitats with meadow voles where their distribution overlaps to prevent competition (Jones et al. 1983) and in the juniper woodlands we studied, meadow voles and prairie voles exhibited opposite trends in abundance among seral stages.

Hispid pocket mice are associate with upland habitats, bare ground (Jones et al. 1983), shortgrass prairie (Moulton et al. 1981), or early seral grasslands (McMillan and Kaufman 1994). They select habitats with loamy soils, for burrows (Jones et al. 1983). Suitable habitat conditions for Hispid pocket mice occurred only in early seral stages of Rocky Mountain juniper. Hispid pocket mice also used woodland habitats on the Konza Prairie, Kansas (McMillan and Kaufman 1994). House mice also were uncommon, but occurred in all seral stages of Rocky Mountain juniper.

Cottontail abundance increased with habitat changes from early to late seral conditions in juniper. Cottontails are usually associated with shrub habitats in the Great Plains (Morgan and Gates 1983, Rumble 1989). Cottontails in Oklahoma preferred eastern red cedar (*J. virginiana*) habitats (Lochmiller et al. 1991). Cottontails prefer escape cover and a clear view (Morgan and Gates 1983). Late seral juniper with low, dense branches and open understory provided this habitat better than other seral stages. Juniper, however, is not a preferred food of cottontails (Lochmiller et al. 1991) and they probably fed on other vegetation.

Big game animals are attracted to forests in the northern Great Plains for thermal and hiding cover and browse (Martinka 1968, Wood et al. 1989). Late seral juniper provided vegetative cover overhead and horizontally. Juniper woodlands of Badlands National Park (probably late seral stages) were used extensively by mule deer (Severson and Carter 1978) and were important for mule deer fawns in late summer (Steigers 1981). Most deer in juniper woodlands were mule deer.

Raccoons are uncommon in dry upland forests and grasslands (Fritzell 1977, Jones et al. 1983). Badgers do not depend on prairie woodlands; they are inhabitants of grasslands and forest edges (Jones et al. 1983). Coyotes inhabit a variety of habitats. Coyotes' diets reflect prey abundance (Andelt et al. 1987, MacCracken and Hansen 1987, Reichel 1991) and they hunt where prey species concentrate (Reichel 1991). We presume coyotes used juniper woodlands for hunting because of the increased abundance of cottontails and other prey.

CONCLUSIONS

Early and late seral stages of Rocky Mountain juniper provided habitat for birds in all nesting guilds. House Wrens were the only bird that occurred in greater abundance in the intermediate seral stage of juniper. Intermediate seral juniper is a dense uniform stand of trees and lacks the vertical and horizontal structure for most bird species. Some ground-nesting species in early seral juniper are prairie species and do not depend on these habitats. Most small mammals were more abundant in the intermediate seral juniper, but meadow voles and Hispid pocket mice appeared to prefer early seral juniper woodlands. Late seral juniper provided the best habitat for cottontails. Several species of intermediate or large mammals also used Rocky Mountain juniper, but were not associated with any seral stages. These species have large home ranges that encompassed several woodland sites or types. Once objectives for wildlife species are developed, techniques that maintain or alter seral stages of juniper woodlands to meet management objectives can be done. Ensuring sustained biological diversity in Rocky Mountain juniper woodlands will require all seral stages across the landscape.

ACKNOWLEDGMENTS

Special thanks to A. Clements, C. Erickson, C. Hydock, K. Landers, K. Meskill, M. Meyer, C. Oswald, T. Pella, M. Pennock, G. Proudfoot, R. Young, and G. Soehn for assistance collecting field data. T. Hoag, D. Strickland, and D. Uresk developed juniper seral stage classification. R. King and J. Janssen provided statistical advice. U.S. Army Corps of Engineers provided funding under MIPR 9861-89. South Dakota Game, Fish, and Parks provided logistical and technical support. Tribal Councils and Chairs of the Cheyenne River Sioux, Lower Brule, and Crow Creek Reservations allowed sampling on tribal lands and several private land owners generously allowed us to conduct research on their land.

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Effects of Fuelwood Harvesting on Small Mammal Populations in a Piñon-Juniper Woodland

William H. Kruse[1]

Abstract.—Small mammal populations have an intricate role in ecosystem function and must be considered a key component of piñon-juniper woodlands. Current management practices not only affect the habitats of small mammals but also the habitat of their specific predators.

Trapping small mammals began in 1990, two years prior to woodland harvesting and will continue through the treatment and into the post-treatment years. Data from the pre-treatment period show a 50% increase in the total number of small mammals from 1990 to 1991 across all plots. A similar trend occurred from 1992-1993, demonstrating large variation among years. Little variation in small mammal numbers were found among plots.

By the third trapping year (1992), four of the eight units had been cut and by the 1993 trapping season, all eight units were cut. Preliminary results and field observations suggest that harvesting may negatively affect piñon mice populations. Conversely, the harvesting had a more positive effect on the deer mice numbers as well as on species diversity.

INTRODUCTION

Piñon-juniper woodlands receive a diversity of uses. Previous attempts at managing these woodlands were directed at increasing forage for livestock by removing the overstory. Current management efforts have been redirected to provide winter range, for both wild ungulates and migratory birds, and most recently, to provide fuelwood. As a result, user interest has also been redirected from single- to multiple-use management. As the multiple-use management concept includes more nonconsumptive natural resources, it begins to resemble an *ecosystem* management concept. To complement the National Forest's ecosystem management approach, the Rocky Mountain Forest and Range Experiment Station is cooperating with the Apache-Sitgreaves National Forest in a multi-year research project (Kruse and Perry 1994). The project is located on the Mud Tanks fuelwood management area to examine the effects of fuelwood harvesting on overstory understory relationships (overstory regeneration as well as forage production), nutrient cycling, soil erosion, runoff, and on selected wildlife populations. This small mammal study is one component of the project.

As the public becomes increasingly more concerned about the low levels of management that historically have been provided for piñon-juniper woodlands (Gottfried 1987), broadened and more diverse ecosystem research, in management strategies, is desired. Because these woodlands cover such a large area there is general agreement that they should be managed for multiple uses (Evans 1988). Also, the popularity of converting woodlands, solely for livestock purposes, has declined, partially because of the current interest in ecosystem management and partially because there are fewer easily converted sites available. More importantly however, is the need to maintain natural systems and to understand how management or changes in specific resources alter the function of that natural

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system (Gottfried 1987). Finally, the recent emphasis on fuelwood harvesting and slash disposal has added a new dimension to managing these woodlands particularly in the context of managing natural systems (Ffolliott et al. 1979).

FUELWOOD HARVESTING AND THE SMALL MAMMAL COMMUNITY

The increase of fuelwood harvesting has prompted increased concern for assessing the effect of both fuelwood removal and slash disposal, particularly burning, on nutrient cycling, understory production (specifically forages for livestock and other large ungulates), and small mammals in these piñon-juniper woodlands. In Arizona, fuelwood demands increased over 400% between 1973 and 1978 (Ffolliott et al. 1979). Land managers are currently attempting to develop sound silvicultural prescriptions for these woodlands, but basic ecological information needed to support current harvesting plans is often lacking (Gottfried 1987). Fuelwood harvest is the most significant factor affecting the overstory while the least understood management option has been slash deposition (Severson 1986; Baker and Frischknecht 1972).

Because previous research has shown that species' populations can be impacted by overstory disturbances (Turkowski and Reynolds 1970), this study will provide quantitative information on small mammals following fuelwood harvest. For example, Severson (1986), in New Mexico, found that total rodent numbers were significantly greater on treated compared to untreated woodlands. Kruse et al. (1979) found that treated areas differed from the woodland in that those rodent species which preferred the woodland condition, decreased in numbers on the treated areas. Whether trends such as these will follow fuelwood harvesting is the focus of this research.

Finally, and because small mammals have an intricate role in the food chain as prey for raptors and carnivores, information determined from this study will provide information for those predators as well.

STUDY AREA AND METHODS

The study is being conducted on the Heber Ranger District, Apache-Sitgreaves National Forest, in central Arizona. Average tree conditions are 23.2 $\pm$ 5.4 m^2/ha of basal area, producing 35.3 $\pm$ 12.7 m^3/ha of fuelwood. Sixty-three percent of the trees are piñon. One-seed juniper is the second most common species followed by alligator juniper. Ponderosa pine (*Pinus ponderosa*) occasionally occurs on moist sites. Average canopy cover is 40% (Laing et al. 1988). Average annual herbaceous and woody plant potential productivity is about 562 kg/ha.

The area is relatively flat, dissected by several small ephemeral drainages. Elevations are between 2,000 and 2,060 m. The primary soil subgroups, derived from limestone, are Lithic Ustochrepts, Udic Haplustalfs, and Typic Eutroboralfs. The mean annual precipitation varies between 34 and 46 cm.

The overall research project consists of 33 units, 4-ha in size. Thirty 4-ha study units were grouped into 5 blocks each with 6 overstory treatments. Sixteen of these were selected for the small mammal study. These sixteen contained all the overstory conditions represented in the overall research project.

The experimental design entails a randomized block layout. Blocks were designated based on similarity of pre-treatment overstory conditions and characteristics. The experimental units entail combinations of burning, no-burning, and cutting, no-cutting. Hence, the small mammal study repeats these four treatments in each of four blocks. Treatments were assigned randomly to each block and were located as conditions permit and therefore were not necessarily contiguous; roads or drainage channels could separate units within a given block. Nevertheless, all treatments for each block are in the same area. Harvesting began in the fall/winter of 1991 and continued up to 24 months. Burning will commence on those units when the slash approaches 2 years old.

A 100m X 100m trapping grid was located in the center of each block utilizing about 85% of it. At each grid point, 10m x 10m apart, was placed an 8 X 10 X 25cm Sherman live trap. At every other point, a 10 X 12 X 40cm Sherman live trap was located with the smaller one. The bait was a mixture of chicken scratch and rolled oats. Thus each unit was sampled yearly with 150 traps for 3 nights and 2 days. Demographic and physical measurements were taken and recorded on each animal caught. Each animal was toe clipped and released. Recaptures were noted.

Relative abundance and species composition (Table 1) of small mammals was estimated by live-trapping on four overstory treatments: (1) type conversion (where the fuelwood has been harvested, residual trees cut and the slash burned);

(2) cut but not burned (where the fuelwood has been harvested but the non-commercial trees are not cut *nor* is the slash burned); (3) no cut but burned (analogous to a forest fire where the overstory is removed by fire; some fire ladders were cut to facilitate the burning); and (4) the controls (where the units remain untreated) (see Table 2). Small mammal trapping is being conducted once each year (July-August).

The null hypotheses, that there are no differences in (1) total number of small mammals or (2) total number of species among treatments, will be tested utilizing years as repeated measures.

Table 1.—Small mammal species list from Mud Tanks.

Peromyscus maniculatus	deer mouse	38%
P. truei	piñon mouse	48%
P. boylii	brush mouse	5%
Neotoma albigula	white throated woodrat	2%
N. mexicanus	Mexican woodrat	2%
Eutamias dorsalis	cliff chipmunk	4%
Dipodomys ordii	Ord's kangaroo rat	<1%
Microtus pennsylvanicus	meadow vole	<1%
Spermophilus variegatus	rock squirrel	<1%

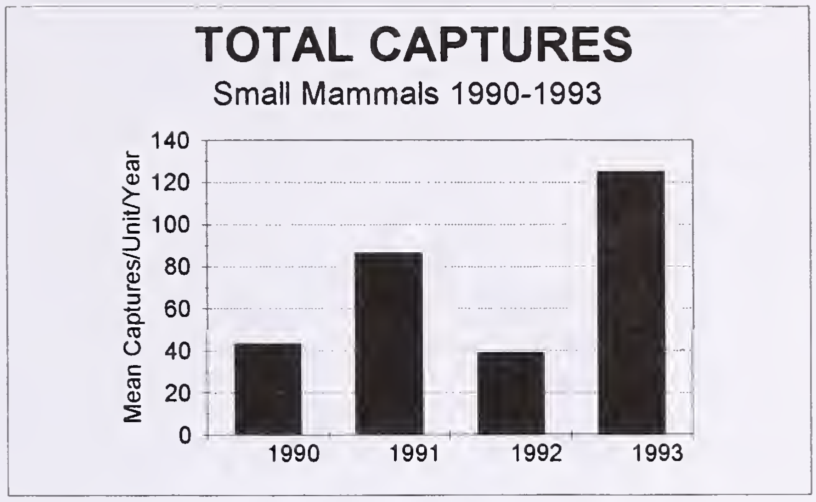
Table 2.—Treatment schedule for small mammal study units.

UNIT BLKS		1990	1991	1992	1993	1994	1995	1996	1997
10-4	III	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR
11-4	IV	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR
15-4	I	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR
20-2	V	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR	NOTR
14-1	III	NOTR	NOTR	NOTR	NOTR	NCB1	NCB2	NCB3	NCB4
15-3	IV	NOTR	NOTR	NOTR	NOTR	NCB1	NCB2	NCB3	NCB4
20-4	I	NOTR	NOTR	NOTR	NOTR	NCB1	NCB2	NCB3	NCB4
21-2	V	NOTR	NOTR	NOTR	NOTR	NCB1	NCB2	NCB3	NCB4
15-2	III	NOTR	NOTR	NOTR	CNB1	CNB2	CNB3	CNB4	CNB5
14-4	IV	NOTR	NOTR	CNB1	CNB2	CNB3	CNB4	CNB5	CNB6
16-4	I	NOTR	NOTR	CNB1	CNB2	CNB3	CNB4	CNB5	CNB6
21-4	V	NOTR	NOTR	NOTR	CNB1	CNB2	CNB3	CNB4	CNB5
14-2	III	NOTR	NOTR	CNB1	CNB2	C&B1	C&B2	C&B3	C&B4
15-1	IV	NOTR	NOTR	NOTR	CNB1	CNB2	C&B1	C&B2	C&B3
16-3	I	NOTR	NOTR	CNB1	CNB2	C&B1	C&B2	C&B3	C&B4
21-1	V	NOTR	NOTR	NOTR	CNB1	CNB2	C&B1	C&B2	C&B3

NOTR = No Treatment; NCB1 = No Cut, Burned (year);
CNB1 = Cut/Not Burned, (year); C&B1 = Cut & Burned, (year)

Table 3.—Mean captures for uncut and cut treatments by year.

	1990		1991		1992		1993	
	UC	C	UC	C	UC	C	UC	C
P. maniculatus	3.8	4.1	18.4	16.6	2.9	7.5	11.8	45.6
P. truei	16.3	12.8	20.1	19.4	12.5	10.4	30.5	20.0
All others	3.0	3.5	6.1	5.5	2.1	3.7	5.6	10.7
Total animals	23.1	20.4	44.6	41.5	17.5	21.6	47.9	76.3



Year:	1990	1991	1992	1993
Mean:	43.5	86.4	39.1	124.9
	+/- 6	+/- 8	+/- 8	+/- 18

Figure 1.—Highly significant annual variation.

PRELIMINARY RESULTS

Table 3 shows mean captures for the uncut and cut units for the four years of sampling. These data demonstrate the dominance of the two *Peromyscus* species relative to the total numbers of all captured animals.

Populations fluctuated during the first four years of the study. These first analyses show significant differences between years,($p < 0.001$). Figure 1 best expresses this yearly variation, as well as the significant interaction between treatment and year factors.

Figure 2 demonstrates an analyses on all small mammal captures and shows the similarity between cut and uncut study units prior to harvest. There were no differences among units prior to treatment (Fig. 2). A significant doubling of total population numbers from 1990 to 1991 is evident.

Figures 4 and 6 show again the similarity among pre-treatment study units as well as the similarity within each species' population. An increase in the number of captures was similar for both the piñon mouse and deer mouse between 1990 and 1991. More notable, however, was that of the highly significant ($p < 0.001$) increase in 1991 over 1990 of the deer mouse which contributed the greater portion was contributed of all small mammal captures.

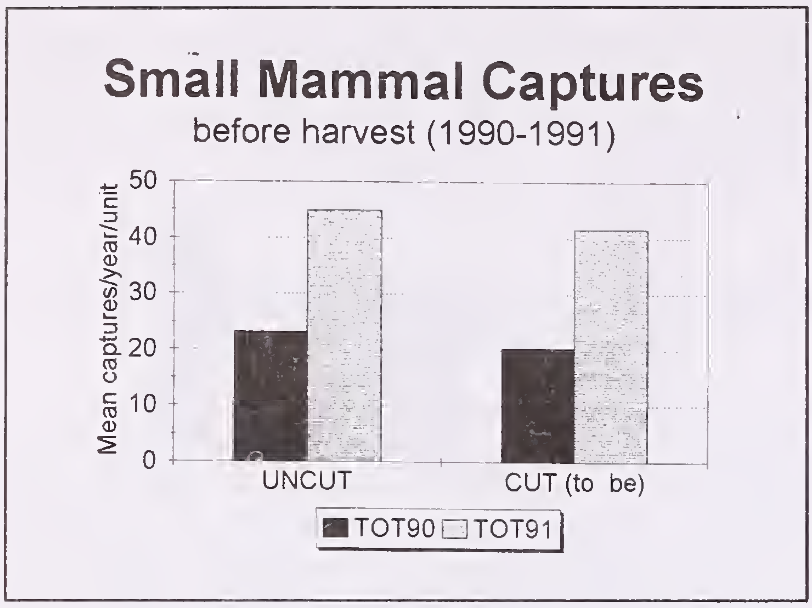


Figure 2.—Annual yearly variation in small mammal captures prior to harvest.

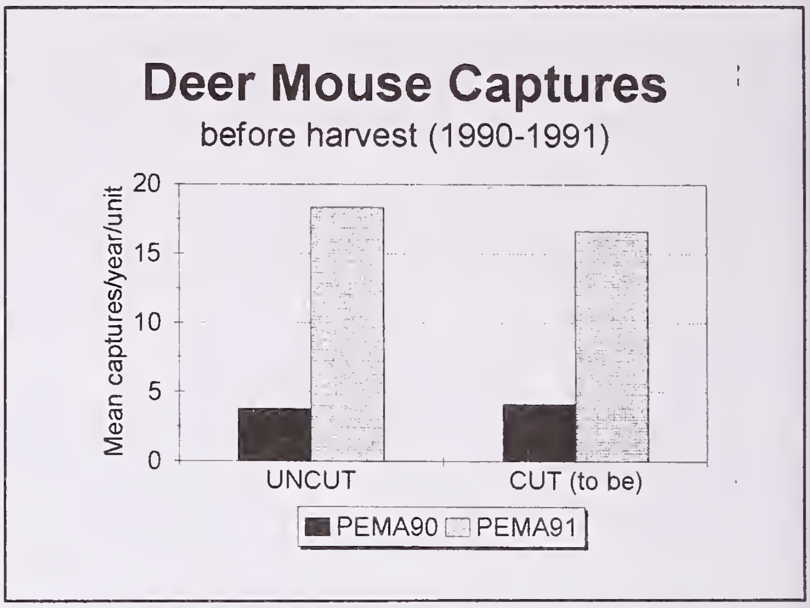


Figure 4.—Deer mouse contributions to the annual yearly variation in total captures prior to harvest.

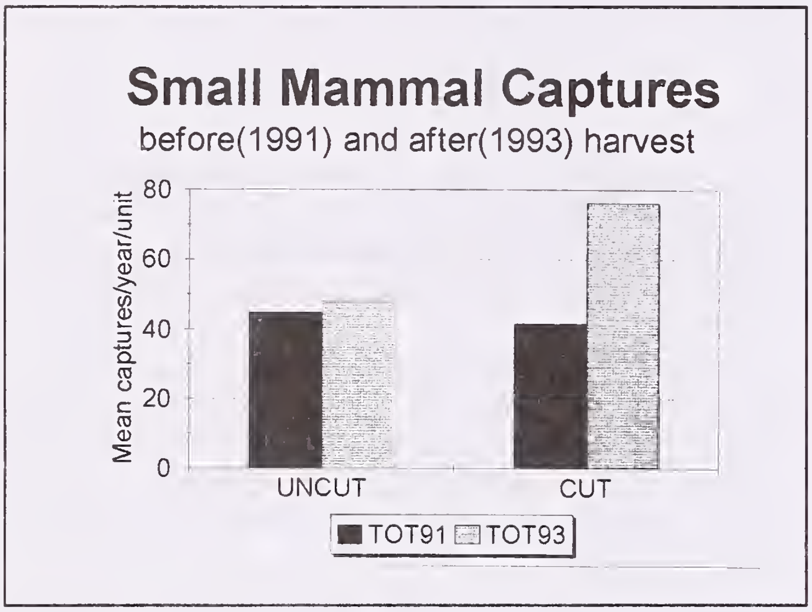


Figure 3.—Harvest effect on small mammal captures comparing units prior to and after harvest.

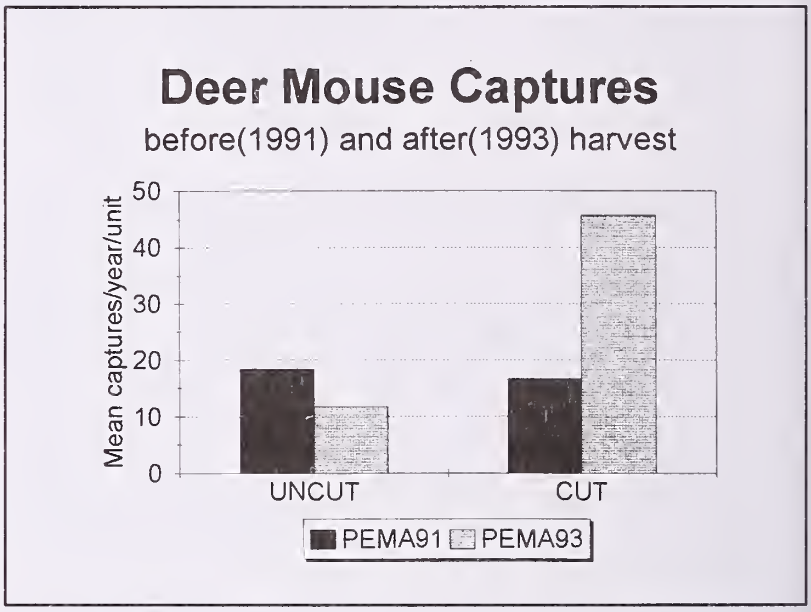


Figure 5.—Harvest effects on deer mouse captures comparing units prior to and after harvest.

During 1992 and 1993, 8 of the 16 study units were harvested for fuelwood. The slash was lopped and scattered over the cut units and by July 1993 was in various stages of aging. The trapping data from 1992 contained effects of some of the treated units and by trapping time in 1993, all "to-be" harvested units were cut. Data from 1993 reflects a cut treatment vs. an uncut treatment comparison.

Figure 3, the "Small Mammal Capture" graph for before (1991) versus after (1993) treatment, shows significant interaction between time and treatment ($p < 0.001$), indicating an increase on the harvested areas. This shows total captures on harvested areas was 84% higher than on uncut areas.

The "Deer Mouse Capture" graph (Fig. 5) displays a 174% increase in deer mouse captures on the harvested areas over the unharvested (time/treatment interaction significant at $p < 0.001$). This large increase in deer mice suggests that fuelwood harvesting and the subsequent slash has a positive affect on deer mouse populations.

Conversely, the "Piñon Mouse Capture" graph (Fig. 7) shows "no or little change" in piñon mice populations following harvest (time/treatment interaction would be significant at $p = .051$). Given the positive effects of "treatment" on small mammal populations, and the fact that the piñon mouse numbers did not change, suggests harvest of piñon-juniper trees to have a negative effect on the piñon mouse population numbers.

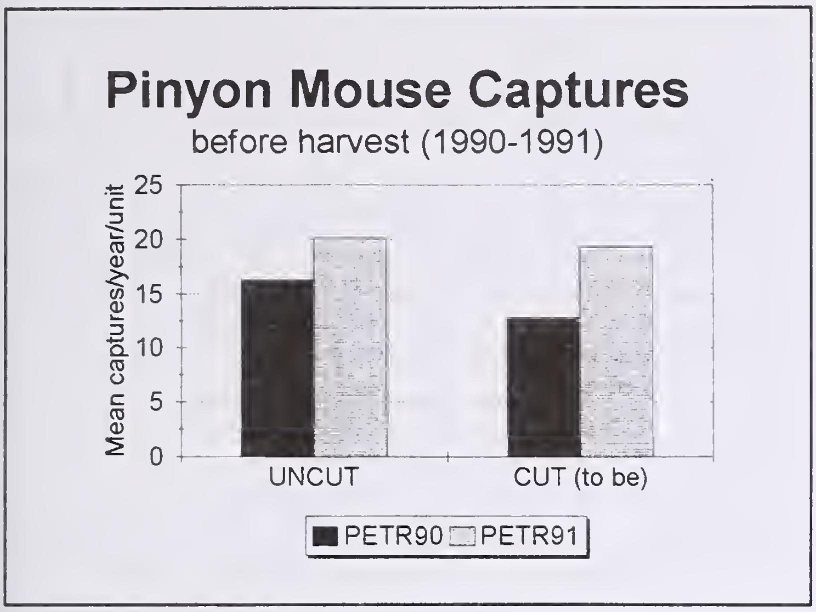


Figure 6.—Piñon mouse contributions to the annual yearly variation in total captures prior to harvest.

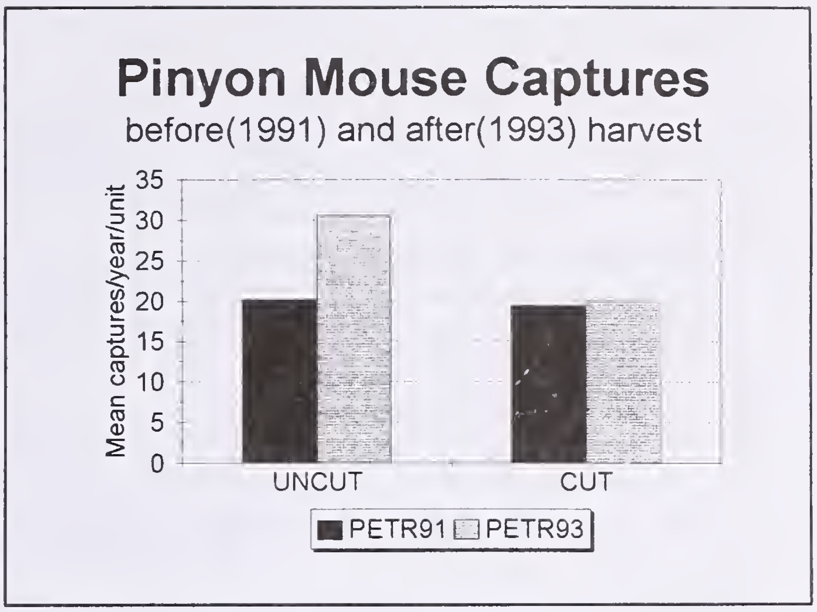


Figure 7.—Harvest effects on piñon mouse captures comparing units prior to and after harvest.

DISCUSSION

Slash is usually left where it falls. Juniper slash, unlike pine slash, is resistant to decomposition and will influence the site for a longer period of time. Some theorize that this residual slash protects both tree and forage species from severe microclimatic stresses and from early herbivory by large ungulates. Residual slash, while providing an improved site for plant regeneration and development, may provide an improved habitat for small mammal populations. Baker and Frischknecht (1973) found no effect from slash on mice populations, except where it was windrowed. Severson (1986) suggested, however, that treatments leaving slash benefited woodrats and brush mice following canopy removal. He also found that overstory was more important to the piñon mouse than the slash component.

The interaction of herbivores within the piñon-juniper woodland has been documented with respect to birds, small mammals, insects, and the competition between these consumers and the forage resources (Christensen and Whitham 1993). An earlier study suggested that because three species of birds and three species of mammals use piñon seeds for food, herbivory directly affected their resource base and the interactions among them. Therefore, severe overstory treatment resulting in heavy slash accumulation not only affected the seed/forage base but altered ground habitat requirements for those seed eating species.

An understanding of treatment effects on species is necessary for anticipating the interaction of other herbivores in the system. Severson (1986) showed that slash can be manipulated to affect small mammal populations but that an overstory of piñon-juniper was important to the piñon mouse. For our data at the Mud Tanks Study, the slash has yet to be burned. Therefore, if slash *is* an important factor in affecting population densities of small mammals, then slash has been *in effect*. After the slash is burned, we eventually will separate slash effects from the effects of overstory treatment.

SUMMARY

Information gained from this study will provide a basis for developing improved guidelines for a more intensive focus of ecosystem management in the southwestern United States. Population densities of small mammals can relate to site productivity and quality much the same as forage plant species are used. And finally with regards to this study, the value of this small mammal research is magnified since it is part of an unprecedented endeavor to simultaneously study the integrated effect of nutrient cycling, other wildlife, and wood product management strategies on the soil, water, tree, and range resources in piñon-juniper woodlands (Kruse and Perry 1994).

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Cone and Seed Insects Associated with Piñon Pine

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Abstract.—This paper summarizes current biological information on insects that feed in cones and seeds of piñon pine, *Pinus edulis* Engelm. Evidence indicates that there is a need for additional studies relating the biology and potential impacts of cone and seed insects in piñon pine.

INTRODUCTION

Piñon nut harvest holds a potentially significant commercial value (Schwab 1993; Norwick et al. 1993) in this forest type. Indeed, as a result of a request by the Southern Pueblos Governor's Council, the Bureau of Indian Affairs (BIA) has initiated a Pilot Woodlands Management Program. As part of this program the BIA is cooperating with the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station in a series of nut production studies (Schwab 1993).

Information on insect associates of cone and seed of piñon pine, *Pinus edulis* Engelm. is limited, and even less is known about their impacts on cone crops. Little (1943) indicated that cone and seed insects destroy large portions of marketable crops yearly; first year strobili are attacked mostly by gall midges (Cecidomyiidae) and second year strobili by cone moths and cone beetles (Little 1943, 1944).

The limited available information is scattered in the literature. Little (1943) and Keen (1958) summarized the available information to date. Since then there have been no further attempts to compile available information into a comprehensive treatment. This paper will: 1) summarize known biological information on insects reported on cones and seeds of piñon pine and 2) discuss considerations for future strategies for additional entomological research on cone and seed insects of piñon pine and their impacts. A summary of available information on impacts and monitoring of insects affecting cones and seeds of other coniferous seed production systems is pesented in Appendix 1. Such information can serve as foundation for similar studies in piñon pine.

INSECTS REPORTED ON CONE AND SEED OF PIÑON PINE

1. *Ernobius montanus* Fall (Coleoptera: Anobiidae).

Most beetles in this beetle's family feed on dry vegetable materials, under bark on dead trees, in seeds or stems of plants, or as larvae on fungi (Borror et al. 1981). Species that inhabit cones are all in the genus *Ernobius*. *Ernobius montanus* Fall has been reported from various hosts in southern California including Coulter pine, *Pinus coulteri* D. Don; Jeffrey pine, *Pinus jeffreyi* Grev & Balf.; piñon pine; singleleaf piñon, *Pinus monophylla* Torr.& Frem.; and ponderosa pine, *Pinus ponderosa* Laws. (Hedlin et al. 1980). Adult beetles are 3-5 mm long, slender, and reddish to dull-brown. Larvae are white, scarabaeiform, and have well developed legs (Keen 1958). Keen (1958) also states that larvae feed in old, dry cones and dead twigs. During the winter larvae can be found on that year's cone crop. Emergence is from July to August.

Another species in this group, *Ernobius punctulatus* (LeConte), feeds in mature or dead cones of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco; knobcone, *Pinus attenuata* Lemmon; Monterrey pine, *Pinus radiata* D. Don; and ponderosa pine (Hedlin et al. 1980). Hedlin and Stickland (1959) stated that this insect feeds only in mature and dead cones and that it is not important in seed production but may affect cones in storage prior to seed extraction. Hedlin et al. (1980) state that reports of this insect killing cones are probably in error and that the species is a scavenger in dead

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cones. *Ernobius granulatus* LeConte was originally reported by Allen and Coyne (1956) as a herbivore of living cones of longleaf pine, *Pinus palustris* Mill. However, Ebel (1964) demonstrated that it was also a secondary invader of dead cones. Two other species in the genus, however, are known to attack healthy, green cones of various conifers. *Ernobius conicola* Fisher infests dry cones but also attacks green cones of Monterey cypress, *Cupressus macrocarpa* Gordon, in coastal California (Frankie 1973). Ruckes (1958) demonstrated that *Ernobius melanoventris* Ruckes attacks green cones of Jeffrey pine in California. *Ernobius bicolor* White has been reported infesting year-old, older cones, and stored cones of black spruce, *Picea mariana* (Mill.) B.S.P. (Schooley 1983).

Since little biological information is known about *E. montanus* and considering that the genus displays variability in its habits, it is important to clarify this insect's role in piñon pine.

2. *Conophthorus edulis* Hopkins (Coleoptera: Scolytidae), piñon cone beetle.

Beetles in the genus *Conophthorus* are commonly referred to as cone beetles. They are bark beetles that attack cones of pines and are among the most destructive insects of cones and seeds in North America. Twelve species are known from North America and eleven of them attack cones (Hedlin et al. 1980). *Conophthorus edulis* Hopkins is the smallest in the group, about 1.25-2.75 mm long. It is dark colored with a dark red elytra. The only host for this species is piñon pine and the insect occurs throughout the range of the host in Arizona, New Mexico, Colorado (Keen 1958), and Oklahoma (Forcella 1980). Adult beetles attack second-year strobili in May or June by boring at the base of the cone, constructing a gallery through the cone axis, and laying eggs along the way. Larvae, which are C-shaped, legless, and whitish with amber to brown heads, feed and develop inside the cone, pupate in August, and later transform into adults that overwinter inside the cone. The cone is killed in the process and falls to the ground or persists on the tree. Emergence occurs the following spring in April and May, leaving through small holes on dead cones, and the cycle begins again (Little 1943, 1944; Keen 1958; Furniss and Carolin 1977). A small pteromalid wasp, *Acerocephala atroviolacea* Crawf., has been reared from cones infested with *C. edulis*, and is thought to be parasitic on the beetle (Keen 1958).

Forcella (1980) suggested that cone predation by *C. edulis* is influenced by the frequency and magnitude of cone crops. He stated that variability in cone crop size is caused by cool temperatures during a 1-2 week interval in late summer 2 years prior to cone maturation, when the cones are still in primordial stage. Since the occurrence of these cool temperatures are erratic in nature, the result is erratic cone production.

These variable cone crops do not support high average beetle populations that can devastate mast crops, thus allowing viable seed to be available for regeneration. Forcella (1980) also states that piñon populations at the edges of its geographic ranges are more stable in annual cone production. This host stability supports stable beetle populations that are able to limit the amount of viable seed available for regeneration and thereby limit the range of the tree species.

3. *Conotrachelus neomexicanus* Fall (Coleoptera: Curculionidae).

Little (1943, 1944) reported that the larval stage of an unidentified species of *Conotrachelus* commonly destroys piñon cones during June and July. The larval stage of *Conotrachelus neomexicanus* Fall, the pine cone weevil, which feeds on the scales and seeds of ponderosa pine cones, has been collected from piñon pine in Mesa Verde, Colorado (Bodenham et al. 1976), and is probably the species referred to by Little (1943, 1944). Adults of *C. neomexicanus*, which are ca 6 mm long and gray-brown, overwinter in the ground, emerge in the spring, and feed on new shoots and male flowers. After mating, the female makes a hole on the tip of a cone scale, oviposits, and uses frass to cover the hole. Larvae are 9-10 mm when fully developed and white to pink with a brown head capsule. They develop in the cone and destroy it. When larvae complete development they chew an exit hole, drop to the ground, and pupate. Transformation into the adult is completed after a few days. The adult hardens in the pupal cell, emerges, begins to feed on shoots and later returns to the litter to overwinter (Bodenham et al. 1976). In certain areas this weevil may kill much of the ponderosa pine cone crop, but there are few records of occurrence (Hedlin et al. 1980). *Conotrachelus neomexicanus* has been collected from Arizona, New Mexico, Colorado, Nebraska, South Dakota, and Montana (Bodenham et al. 1976).

4. Hapleginella conicola *(Greene) (Diptera: Chloropidae).*

Adults of this species are small shiny black flies about 1 mm long. Larvae are colorless to whitish maggots, elongated, and ca 2 mm long. Larvae are active from the fall through spring, feeding in scales and seeds and destroying cones. Pupation occurs in April and adults emerge from late April to mid-July. A second generation may occur in late summer (Keen 1958). Hosts include white fir, *Abies concolor* (Gord & Glend.) Lindl.; Shasta red fir, *Abies magnifica* Lemm.; Jeffrey pine; ponderosa pine; and perhaps loblolly pine, *Pinus taeda* L.; red pine, *Pinus resinosa* Ait.; shortleaf pine, *Pinus echinata* Mill.; sugar pine, *Pinus lambertiana* Dougl.; and piñon. It has been reported from southern British Columbia, Washington, Oregon, California, Baja California, the central and southern Rocky Mountains and south to Mexico, Arkansas, the Lake States, and the Northeast. It damages cones of firs in late summer but it appears to be of secondary nature in red pine (Hedlin et al. 1980). Its role in piñon pine is unknown.

5. Leptoglossus occidentalis *Heidemann, (Hemiptera: Coreidae), the western conifer seed bug.*

I found no published records of this insect in piñon, but its occurrence in piñon has been brought to my attention by Dr. Scott Cameron, Texas Forest Service (personal communication).

Koerber (1963) reported feeding damage to seeds of Douglas-fir caused by this species. Krugman and Koerber (1969) later reported similar damage to ponderosa pine seeds. It also has been reported from grand fir, *Abies grandis* (Dougl.) Lindl.; incense-cedar, *Libocedrus decurrens* Torr.; Jeffrey pine; knobcone pine; lodgepole pine, *Pinus contorta* Dougl.; and western white pine, *Pinus monticola* Dougl (Hedlin et al. 1980). Debarr (1967) reported that *Leptoglussus corculus* (Say), a related species, causes similar damage to slash pine, *Pinus elliottii* Engelm., and longleaf pine; a later report indicates that the insect attacks all species of southern pines (Ebel 1980).

Leptoglossus occidentalis Heidemann is widely distributed throughout the west from Vancouver Island, British Columbia, Alberta, and Saskatchewan south to Mexico and from Nebraska west to the Pacific Coast (Hedlin et al. 1980). McPherson et al. (1990) reported records from Illinois and Michigan. More recently, Gall (1992) reported records from Connecticut, New York, Pennsylvania, and Ontario and suggested that the species is still expanding its range.

The following biological information is taken from Koerber (1963), Krugman and Koerber (1969), and Hedlin et al. (1980). Adults are 15-18 mm long and 4-6 mm wide, reddish brown to dark gray with whitish pubescence, with a narrow zig-zagged line across the fore wings, and laterally expanded tibiae on the hind legs. Eggs are 2 mm long and 1.2 mm wide, light brown when first laid and turn reddish brown as the nymphs develop. *Leptoglossus occidentalis* is univoltine and overwinters as an adult in protected locations. In the spring, it emerges and begins feeding on cones and male flowers. Eggs are laid in rows glued to needles from May to July. After hatching, reddish to orange nymphs feed on developing cones and seeds, develop through five instars, becoming adults by August. Adults continue feeding until seeking hibernation quarters.

The insects feed directly on seeds by piercing through cone scales. The entire contents of young seeds are removed if feeding occurs before the seed coat hardens, which subsequently collapses and turns gray-brown. After the seed coat hardens, contents may be removed, but the seed coat does not collapse. A microscopic hole can be detected. On mature seeds, tissues shrink, turning white and spongy. Damage can be detected by radiographs.

Seed losses up to 41% and 26% have been reported from Douglas-fir and western white pine, respectively, but no other impact data seems to be available (Hedlin et al. 1980).

6. Xiela *spp. (Hymenoptera: Xyelidae), pine catkin sawflies.*

This genus includes 16 known species from the United States and Canada (Hedlin et al. 1980). No species has been reported from piñon, but two species, Xiela concava Burdick and Xiela deserti Burdick, have been reported from singleleaf piñon (Burdick 1961). Adults of this genus generally feed on pollen from a variety of tree species; larvae, however, are restricted to developing male flowers of pines, hence the name pine catkin sawflies. Adults are usually under 5 mm long and vary in color from yellow to black, often with markings, transparent wings, and a well defined ovipositor on the females. Eggs are oval-elongated and white. Larvae are yellowish-white, ca 7 mm long with rudimentary abdominal prolegs. Adults emerge in the spring and feed on pollen of anemophillus plants. When male pine flowers begin to enlarge, oviposition occurs in them. After hatching, larvae feed on pollen by attacking a few of the basal sporophylls allowing apical ones to complete development. After 2-4 weeks, mature larvae drop to the soil and burrow in, forming an earthen cell where they remain as prepupa for 1 or 2 seasons prior to pupation and emergence (Burdick 1961; Greenbaum 1974; Hedlin et al. 1980). Pollen production is probably not affected significantly by these insects (Hedlin et al. 1980).

7. Chionodes periculella *(Busck) (Lepidoptera: Gelechiidae).*

Adults in the family to which this species belongs are generally small moths with narrow fore wings and wider hind wings. The group appears to be of little importance in terms of impacts on cone and seed. Little is known about this particular species, but it is known to mine in cones of piñon, ponderosa pine, and Douglas-fir (Hedlin et al. 1980). The biology and larval characters of a related species, *Chionodes sabinianae* Powell, have been described by Burdick and Powell (1960). *Chionodes sabinianae* attacks Digger pine, *Pinus sabiniana* Dougl., in California. The genus, however, displays variable feeding habits and species are known to feed on a variety of hosts (Burdick and Powell 1960). Therefore, no generalizations can be made until additional studies on the biology of this group are conducted.

8. Eucosma bobana *Kearfoot (Lepidoptera: Olethreutidae), piñon cone borer.*

Larvae of this insect, which are pinkish and ca 15 mm long when full grown, feed on scales and seeds of second year cones of piñon and singleleaf piñon. Adults, which have tan forewings marked with dark red to black-brown patterns and a narrow white border (Powell 1968), lay eggs on scales near the tip of the cone during June and July. Larvae feed during summer and fall, overwinter as pupae in the cone or in ground litter, and adults emerge the following spring (Hedlin et al. 1980). Little (1943, 1944) indicated that *Eucosma bobana* Kearfoot was an important mortality factor of second year piñon cones. This insect occurs from central Texas to the western part of the Mojave desert in California and north to northern Utah and central Nevada (Powell 1968). Forcella (1978) indicated a significant positive correlation between amounts of cone predation by *E. bobana* and abundance of the previous year's cone crop. Two stands with above average cone crops sustained 50% and 80% predation whereas two stands with below average crops sustained only 20% and 17% predation. He suggested that irregularities in cone production may have selective advantages by maintaining low herbivore populations during years of small cone crops and ensuring satiation of the insect and seed survival in years of bumper crops.

9. Cydia colorana *(Kearfott) (Lepidoptera: Olethreutidae), piñon seedworm.*

For many years, species in this group were placed in the genus *Laspeyresia*, but Brown (1979) placed them in the genus *Cydia*. The genus includes 12 North American species, whose larvae feed exclusively on conifer seeds. The group has not been extensively studied but limited biological information has been published for some species. Merkel (1963, 1967) studied the distribution and life history of *Cydia anaranjada* (Miller) on slash pine in the South; Coyne (1968) described the life history of *Cydia ingens* (Heinrich) in longleaf pine in the Gulf Coast; Tripp (1954) did the same for *Cydia strobilella* (Linnaeus) (=*Cydia youngana* (Kearfoot)) on various species of spruce, *Picea* spp., in Ontario and Quebec; and Frankie and Koehler (1971) described the biology and life history of *Cydia cupressana* (Kearfoot) in Monterey cypress in California. Hedlin (1967) described the habits of *Cydia piperana* (Kearfoot) in ponderosa pine and indicated that up to 50% of the seed crop could be destroyed by this insect in British Columbia. Biological accounts of *Cydia toreuta* (Grote), which attacks various species of pine, have been published by Lyons (1957), Kraft (1965), and Ciesla and Bell (1966). Abrahamson and Kraft (1965), working in Upper Michigan, indicated that populations of *C. toreuta* are negatively influenced by heavy rainfall in May and June and perhaps positively influenced by high temperatures during the same time of the year. Higher populations are also correlated with larger cone crops. Kraft (1968) also indicated that open-grown trees with branches extending to the ground, low-density stands, and south-facing cones harbor more attacks by this insect. Intraspecific competition and parasitism were important mortality factors.

All *Cydia* species have similar biologies. Adults have wingspans of 10-20 mm, are usually metallic gray with silver bands, and are active in the spring. Eggs are commonly laid in overlapping masses on cone scale surfaces or on cone stalks. Larvae, which are 10-15 mm when fully developed and white to cream in color, bore between scales and attack seeds by feeding on their contents, leaving frass within. After consumption of a seed, a silk tunnel is constructed to the next seed. This behavior continues until fully developed larvae bore into the cone axis for overwintering. Larvae construct tunnels to the cone surface and place a covering with host material and then return to the cone axis. Pupation is in the spring on the cone axis followed shortly thereafter by adult emergence. Some species are reported to have an extended diapause. Degree of host specificity also varies among species. Good information on geographic distributions and hosts is available for some species but apparently not for *Cydia colorana* (Kearfoot).

Cydia colorana has been reared from cones of piñon pine in California (Hedlin et al. 1980), but I found no other information about this insect.

10. Dioryctria albovittella *(Hulst) (Lepidoptera: Pyralidae), the stem- and cone-boring moth.*

Members of the genus *Dioryctria* are commonly referred to as coneworms. They are widely distributed across North America and are probably the most injurious lepidopterans affecting cones and seeds of conifers in North America. Larvae feed on the insides of cones, and frass is usually evident on the outside. Other parts of the host such as shoots and boles are also targets of coneworm activity. Little (1943, 1944) reported that two species unidentified of *Dioryctria* attacked second year cones of piñons.

Dioryctria albovittella (Hulst) attacks piñon and singleleaf piñon. This species has been reported from Nevada, Arizona, New Mexico, and Colorado (Furniss and Carolin 1977). Adult moths, which are active from July to September, have a 23-30 mm wingspan with fore wings gray and white with white and dark markings; hind wings are nearly white. Larvae are active in May and June. They are apparently abundant enough to significantly impact seed production (Hedlin et al. 1980). Studies by Whitman and Mopper (1985) indicate that herbivory by this insect can affect trees' architecture, growth rate, reproductive output, and sexual expression. These actions could result in loss of normal cone-bearing ability. This insect has been the subject of various studies that focus on biological interactions with avian seed dispersal agents, mycorrhizal mutualism, and genetic aspects of community ecology in piñon pine (Christensen and Whitham, 1991; Gehring and Whitham 1991; Mopper et al. 1991; Mopper et al. 1990).

11. Frankliniella occidentalis *(Perg.)(Thysanoptera: Thripidae).*

Little (1943) reported this insect on piñon and indicated that they occur on mature staminate cones apparently feeding on pollen. This species is widely distributed throughout the Western United States and north to British Columbia and Alaska (Furniss and Carolin 1977).

Although there is some information on insects affecting cones and seeds of piñon pine in North America, there still is a considerable lack of knowledge of the biology of a number of species and impacts from all species. Table 1 presents a summary of the species discussed above along with the type of damage, time of year in which the damage occurs, and the known distribution of the insect.

CONSIDERATIONS FOR THE FUTURE

Meaningful work has been conducted in the area of life tables and crop monitoring systems in conifers (Appendix 1). It seems desirable to conduct similar studies in piñon pine. This effort could provide invaluable data relating roles of biotic and abiotic factors that affect nut production.

Significant efforts also have been placed on developing strategies for managing insects affecting cones and seeds, primarily through the use of insecticides. In the case of piñon pine, the most desirable product is edible seed for human consumption, which will present challenging questions regarding the management and protection of cone crops from damaging insects.

Efforts are also being directed into developing prescribed burns and pheromone-based strategies for managing key cone and seed insects in other conifer systems (Miller 1978; DeBarr et al. 1992; de Groot et al. 1991). If management of key insect herbivores becomes an issue in piñon, these are the kinds of strategies were future research emphasis should be placed. Intensive management of some conifer orchards, particularly in the South, has resulted in very productive systems; however, these systems are so manicured that they often seem to have more communality with an agricultural commodity than a forest product. This management approach may coincidently eliminate refugia for natural enemies of cone and seed insects. With the

Table 1.—Species, type of damage, time of the year in which damage occurs, and geographic distribution of insects associated with piñon pine, *Pinus edulis* Engelm.

Species	Type of damage	Time of year	Geographic distribution
Ernobius montanus[1]	Larvae feed internally on cone	Fall and Winter	Southern California
Conophthorus edulis[2]	Larvae feed internally on cone	June-August	Range of piñon in AZ, NM, CO, and OK
Conotrachelus neomexicanus[1]	Larvae feed internally on cone	June-August	AZ, NM, CO, NE, SD, and MT
Hapleginella conicola[1]	Larvae feed on scales and seeds	Fall and Spring	Reported from southern British Columbia, WA, OR, CA, Baja California, central and southern Rockies, south to Mexico, AR, the Lake States, and the Northeast
Leptoglossus occidentalis[1]	Adults and nymphs feed directly on seeds	Spring, Summer, and Fall	Southern British Columbia south to Mexico, and from central NE west to the Pacific Coast
Xiela concava3 and Xiela deserti[3]	Larvae feed on pollen	Spring-early summer	California
Chionodes periculella[1]	Larvae mine in cones	Apparently early spring	No information found
Eucosma bobana	Larvae feed on scale and seeds	Summer and fall	Central TX to western part of Mojave desert in CA and north to Northern UT and central NV
Cydia colorana[2]	Larvae feed on seeds	Summer	California
Dioryctria albovittella[2]	Larvae feed internally on cones	May-June	CA, NV, southern ID, UT, CO, AZ, NM, western TX
Frankliniella occidentalis[1]	Feed on mature male flowers	Spring, Summer, and Fall	Throughout Western US, north to British Columbia and Alaska

[1] *Reported to attack piñon pine among other hosts*
[2] *Reported to attack only piñon pine*
[3] *Reported from singleleaf piñon but not from piñon*

recent emphasis on ecosystem management, it is desirable to maintain much of the natural cover in these sites so that refugia for natural enemies is preserved. Little work has been conducted on natural enemies and biological control of insects affecting cones and seeds.

The idea proposed by Forcella (1980) that piñon pine populations on the edges of its geographical distribution have more stable cone crops deserves more attention. Studies to assess cone crop periodicity, size, and quality could be established in stands on the fringes of the geographic range of piñon pine. If the hypothesis were true, and sizeable cone crops of good quality nuts could be produced, then it would help to identify suitable sites in which to attempt nut production enhancement and management activities.

APPENDIX 1

Impacts and Monitoring of Cone and Seed Insects in Conifers

Insects play a significant role in the development and survival of cones and seeds of a number of coniferous species. Shearer (1984) indicated from a study in Montana that ⅓ of the Douglas-fir and ½ of the western larch, *Larix occidentalis* Nutt., seeds were destroyed by insects. In a five year study in Montana, Idaho, Oregon, and Washington frost and insects were the major causes of cone and seed losses in 1985-87 in western larch (Jenkins and Shearer 1989). Scholwater and Sexton (1989) indicated that the major factor in losses of seed in Douglas-fir in western Oregon was unexplained developmental failure. Early-season damage by *Lepesoma lecontei* (Casey), a weevil attacking conelets, accounted for 40-70% of the insect related damage. The weevil was also shown to cause developmental failure, therefore its impacts could be even more severe.

Working with southern pines, Fatzinger et al. (1980) indicated that without insect control strategies the potential average yield of seed can be reduced to only 8-12%. Various estimates of impacts by seed and cone insects have been obtained from southern pines. These estimates range in mortality from 2-47% during the first year of staminate cone development and from 1-78% for second year staminate cones (Fatzinger 1984).

Mattson (1968) reported that a complex of five insect species accounted for the loss of 34-83% of annual cone samples of red pine in seed production areas in the United States. Mattson (1971) indicated that cone crops of red pine vary widely from year-to-year and that the quantity of insect damaged cones increases unless limited by food availability, suggesting that crop size is an important factor in regulating insect populations. More recently, Katovich et al. (1989) studied seasonal losses of seeds and cones and their causes in a red pine plantation and in a seed orchard. In the seed orchard, cone insects were very destructive in the developmental period between the 11^{th} and the 15^{th} month during the first year of the study but insignificant during the second year. Radiographs of seeds indicated some damage caused by seed bugs. In the plantation, although insect damage was less, the most damaging insect was the seedworm *Cydia torueta*.

Werner (1964), working with white spruce, *Picea glauca* (Moench) Voss, in interior Alaska indicated that insects destroyed 3-6% of the seed crop in 4 of a 5 year study. In the remaining year the damage was 50% and most of it was caused by *Hylemya anthracina* (Czerny), the spruce cone maggot (reported then as *Pegohylemyia* sp.). Hedlin (1973) indicated that insects caused considerable seed loss in white spruce in British Columbia. The most injurious species were *H. anthracina* and the seed moth, *C. strobilella*. More recently, Fogal (1990) also working with cone crops of white spruce, found that damage by all insects combined was negatively correlated with the size of the cone crop, but in the case of individual insect species, the relationship was not true. Fogal and Larocque (1992) studied strobili and seed development as affected by insect damage in farmlands and plantations. They reported seed losses to insects of 23% in farmlands and 29% in plantations.

Working in Idaho with grand fir, Kulhavy and Schenk (1976) indicated that insects destroyed 6% and 18.2% of the cone crop in a moderate and a high cone production year, respectively. The most destructive insect was *Dioryctria abietella* (Denis and Schifermueller).

In jack pine, *Pinus banksiana* Lamb., de Groot (1986), reported that insects contributed to the loss of ca 1% of the flowers and 4.9% of the cones. He also indicated that most flower losses were due to abortion while most cone losses were due to red squirrels.

Flores-Flores and Diaz-Esquivel (1988) working with *Pinus cembroides* Zucc. in Coahuila, Mexico indicated that *Conophthorus cembroides* and *Leptoglossus occidentalis* accounted for 51% of the cone mortality. Working with another species of mexican piñon, *Pinus nelsonii* Shaw, in Tamaulipas, Mexico, Sanchez-Ramos et al. (1989) indicated that the same insects accounted for the loss of 25.3% of the seed.

From these studies it is apparent that insects are important mortality factors for cones and seeds of numerous conifer species. The same phenomena is likely to be true in piñon. As such, there is a need for additional studies relating the biologies and impacts of these arthropods on piñon cone crops. Additionally, tree species have evolved strategies to assure the reproductive success of part of their seed crop by preventing total consumption of the seeds. These strategies are not yet completely understood.

The use of life table approaches and the development of inventory-monitoring systems for flowers and cones of coniferous species has been used extensively and provides us with alternatives to address some of these questions. DeBarr and Barber (1975) working in Florida with slash pine, quantified losses to different factors and determined when losses occurred. They state that life tables are particularly useful for this task because they provide a methodology to determine the interval of time in which losses occur, provide for direct accounting of losses, and provide for the study of interacting mortality factors instead focusing only on individual effects. Fatzinger et al. (1980) also used a life table approach to survey mortality factors in flowers and cones in five species of southern pines. His studies indicated that most losses occurred during the first year of strobili development, and identified key mortality factors.

Bramlett and Godbee (1982) developed an inventory-monitoring system for southern pine orchards. Their system uses total flower counts on selected sample trees and periodic visits to sample branches to estimate potential crop yield and survival of the flower crop. Actual seed production from sample trees is obtained and used to evaluate orchard-level productivity and performance. Bramlett (1987) demonstrated how an inventory-monitoring system can be used in combination with life tables of cone survival and cone analysis to obtain orchard efficiency values. These values can be used to quantify degrees of protection achieved through use of pesticides. Huffman (1988) used the system developed by Bramlett and Godbee (1982) to monitor cone crops of eastern white pine, *Pinus strobus* L., and of shortleaf pine, and found the system to be a valuable tool for monitoring changes in orchard productivity. Fatzinger et al. (1988, 1990) developed an inventory-monitoring system for southern pines which incorporate pest surveys that quantify their impacts and the time in which they occur. The system uses sample clusters of female strobili in the southeastern quadrant of sample trees. Estimates of cone crop condition and size are obtained three times a year; subsamples are taken when losses are more severe to document causes. Computer programs have been developed with the system that also provide information on orchard productivity. Fleming et al. (1990) developed methodology for monitoring jack pine crops of and provided cost estimates of sampling with different precision levels. Stratified random sampling based on relative crown height with equal stratum width was found to be cost effective and operationally feasible. Recently de Groot and Turgeon (1991) concisely described the procedures of cone crop monitoring in conifer seed orchards in Ontario.

A usable system should provide flexibility in sampling methodology so that it is adequate for varying objectives and budgets, provides information for management decisions, and produces a life-table of long-term predictions (Fatzinger et al. 1990). These studies have set a sound foundation from which a life table based monitoring system for piñon pine cone crops can be developed that will help us develop a better understanding of factors regulating cone crops. Identification of these regulators could lead to the development of successful management strategies.

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Insect and Disease Associates of the Piñon-Juniper Woodlands

Terrence J. Rogers[1]

Abstract.—In order to successfully manage piñon-juniper ecosystems for sustainability and social needs we must also look at and understand the role of insects and diseases associated with this ecosystem. At the present time, however, little is known about the role of insects and diseases in the piñon-juniper ecosystem. This is not really surprising since until just recently, last ten years or so, the piñon-juniper type was managed primarily for forage production with some considerations also being made for fuelwood and piñon nut production. With the advent of the Forest Health Initiative and the Piñon-Juniper Initiative, however, a more in-depth understanding of the role insects and diseases play in the piñon-juniper woodlands and their potential impacts on management objectives is necessary if we are to manage this system for sustainability and desired social needs.

INTRODUCTION

Insects Associated with Piñon-Juniper Woodlands

Insect activity in the piñon-juniper forest cover type appears to be correlated with extended periods of drought which predisposes large areas of host type to attack. During periods of average rainfall, insect activity in the piñon-juniper type is usually undetectable. Drought acts as a "trigger" triggering ecological processes which eventually leads to insect outbreaks that often extend over thousands of acres of susceptible host type.

Probably the most important group of insects associated with the piñon-juniper ecosystem are the *Ips* bark beetles belonging to the family Scolytidae. During extended periods of drought *Ips* bark beetles *(Ips confusus)* often increase to outbreak levels causing widespread tree mortality on thousands of acres of host type. Mortality is often patchy consisting of small groups of five to ten fading trees. In some cases, entire viewsheds and landscapes may be affected. Other Scolytid bark beetles affecting piñon are the twig beetles. Twig beetles, *Pityophthorus spp.* and *Pityogenes spp.*, are frequent pests of piñon pines. Normally they attack shaded-out and storm-damages twigs and branches. Occasionally, however, twig beetle populations locally build-up in drought-stressed injured trees. When at out break levels, entire viewsheds and landscapes can be affected.

Outbreaks of the piñon needle miner, *Coleotechnites edulicola*, and the piñon pine needle scale, *Matsucoccus acalyptus*, also occur during periods of below average precipitation levels and can cause widespread defoliation damages to viewsheds and landscapes. Several years of heavy defoliation damages can predispose infested trees to *Ips* bark beetle attack and subsequent mortality.

Other incidental insects found associated with piñon include the tiger moth, *Halisidota ingens*, the piñon sawfly, *Zadiprion spp.*, piñon spindle gall midge, *Pinyonia edulicola*, bark moths, *Dioryctria spp.*, and *Vespamima spp.*, and the piñon pitch nodule moth, *Petrova arizonensis*.

Insects of note associated with junipers include the western cedar borer, *Trachykele blondeli*, and the juniper twig pruner, *Styloxus bicolor*. The western cedar borer is an aggressive pest of junipers and Arizona cyprus in New Mexico. It belongs to the

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buprestid beetle group also known as metallic or flatheaded wood borers. Unlike most other buprestids, the western cedar borer will attack and seriously injure or kill seemingly healthy trees. Considerable damage is found in some juniper stands; older, larger trees appear to be favored by these beetles. The juniper twig beetle, also found attacking junipers and Arizona cyprus causes twig dieback. This beetle belongs to the cerambycid beetle group also known as roundheaded wood borers.

Diseases Associated with Piñon-Juniper Woodlands

Unlike insect outbreaks which are generally cyclical and at times cause seemingly spectacular damages and mortality across viewsheds and landscapes, diseases are more insidious. That is once a tree is infected with a disease pathogen, it may take years before the symptoms appear and several more years before the disease infected tree dies. Mortality resulting from disease infections is usually highest in young, immature trees.

Some diseases occurring in the piñon-juniper woodlands include the mistletoes and root rots. Mistletoes, *Arceuthobium divaricatum* on piñon and *Phoradendron juniperinun* on juniper, are parasitic plants that injure and eventually kill their woody hosts by stealing water and essential nutrients. Mistletoe plants vary in color from yellow to green to red-green. Piñon pine dwarf mistletoe plants consist of small conspicuous male and female shoots approximately two to three inches in length protruding through the bark of the infected branches. True mistletoe plants very in length from a few inches to several feet. Symptcms of infection include swelling at infection sites, branch dieback, and formation of witches' brooms. Dwarf mistletoes spread by shooting seeds from explosive berries. True mistletoes are spread by birds that eat the mistletoe berries. Seeds pass through the birds unharmed and are spread in their feces.

Root disease infected trees are difficult to diagnose since symptoms above ground can resemble symptoms caused by other insect and disease agents. Futhermore, little is known about their affects within the piñon-juniper ecosystem. Only recently have we observed and documented amalleria root rot killing piñon pines in northern New Mexico. Armillaria root rot occurs in expanding pockets, often with mortality at the center. The entire crowns of infected piñon saplings usually turns reddish-brown all at once. Dieback, thinning foliage, or yellowing of the crown is characteristic of older, infected piñon trees. This disease spreads by means of spores and rhizomorphs. When the fungus contacts the tree's root or root collar, it penetrates the bark and enters the living tissue. Cellulose is consumed leaving the root light-colored and causing the tree's butt to rot.

SUMMARY

In summary, there many insects and diseases associated with the piñon-juniper woodlands. Their presence does not mean they are a forest pest. As we intensify our management activities within the piñon-juniper woodlands, we will have to monitor the impacts of resident insects and diseases to determine (1) What kinds of damages are occurring, (2) whether or not they are significant, and (3) their impacts on management objectives.

Hydrology and Ecology of Piñon-Juniper Woodlands: Conceptual Framework and Field Studies

Bradford P. Wilcox and David D. Breshears[1]

Abstract.— Piñon-juniper woodlands represent an important ecosystem in the semiarid western United States. Concern over the sustainability of, and management approaches for, these woodlands is increasing. As in other semiarid environments, water dynamics and vegetation patterns in piñon-juniper woodlands are highly interrelated. An understanding of these relationships can aid in evaluating various management strategies. In this paper we describe a conceptual framework designed to increase our understanding of water and vegetation in piñon-juniper woodlands. The framework comprises five different scales, at each of which the landscape is divided into "functional units" on the basis of hydrologic characteristics. The hydrologic behavior of each unit and the connections between units are being evaluated using an extensive network of hydrological and ecological field studies on the Pajarito Plateau in northern New Mexico. Data from these studies, coupled with application of the conceptual model, have led to the development of a number of hypotheses concerning the interrelationships of water and vegetation in piñon-juniper woodlands.

INTRODUCTION

Semiarid landscapes, although generally sparsely populated, are of tremendous global importance. They occupy a huge landmass and provide many valuable resources. By definition, these are water-limiting environments; even small changes in the water budget, whether caused by changes in climate or by disturbance, can greatly affect vegetation patterns. The global phenomenon of "desertification," produced by the combined effects of overgrazing and drought (Grover and Musick 1990, Schlesinger et al. 1990), provides troubling evidence of the sensitivity of semiarid landscapes to such changes. Concern over the sustainability of these areas continues to mount.

The ability to control change and to prevent degradation of semiarid environments depends on understanding—and, eventually, predicting—the close interactions between water dynamics and vegetation patterns. Characterizing these complex interactions, however, presents a particularly formidable challenge given the great heterogeneity of these landscapes. Hydrologic phenomena, such as precipitation and runoff, are highly variable in semiarid environments, in both space and time; and many of these landscapes exhibit considerable—and often abrupt—variations in elevation, topography, and soils. As a result, one finds a wide range of vegetation patterns and an accompanying large number of transitional zones between vegetation patterns. These zones (known as tension

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The authors gratefully acknowledge the many technicians and staff members in the Environmental Science Group who have contributed to the studies described here. Technical editing was provided by Vivi Hriscu and illustrations were done by Andi Kron. This work was funded by the Environmental Restoration Program, Los Alamos National Laboratory.

zones, or ecotones) are thought to be particularly sensitive to disturbance and to climatic fluctuations, including those resulting from an elevation in greenhouse gases (Gosz and Sharpe 1989, Gosz 1992, Yeakley et al. 1994).

At Los Alamos National Laboratory, we are developing a conceptual framework that simplifies spatial heterogeneity through the delineation of "functional units" based on hydrologic characteristics. (This framework is drawn from hypotheses already in the literature as well as hypotheses from our own research). We are particularly interested in the application of this framework to the piñon-juniper woodlands that dominate the Laboratory environment and which are among the semiarid systems showing strong signs of disturbance-induced change (Everett 1986). Movement of contaminants, currently a key area of investigation at Los Alamos, is occurring mainly within these woodlands. Because contaminant movement can take place at many different scales—from as small as a waste disposal pit to as large as the entire 116-km^2 Laboratory complex—and because it is so closely linked with hydrological patterns, the framework offers an effective approach to understanding, and thereby mitigating the effects of, contaminant migration.

To test the hypotheses on which our framework is based, and to continually refine and improve it, we are establishing a network of field studies that will provide the needed data. These field studies are described below.

SITE DESCRIPTION

The area in which our field studies are being conducted includes most of the Pajarito Plateau of north-central New Mexico (fig. 1). Formed by a series of violent volcanic eruptions beginning some 1.4 million years ago (Crowe et al. 1978), the plateau measures about 12 x 36 km and ranges in elevation from 1910 to 2730 m. To the west, it butts up against the Jemez Mountains. To the east, a parallel drainage network has created a series of finger-like mesas separated by canyons, through

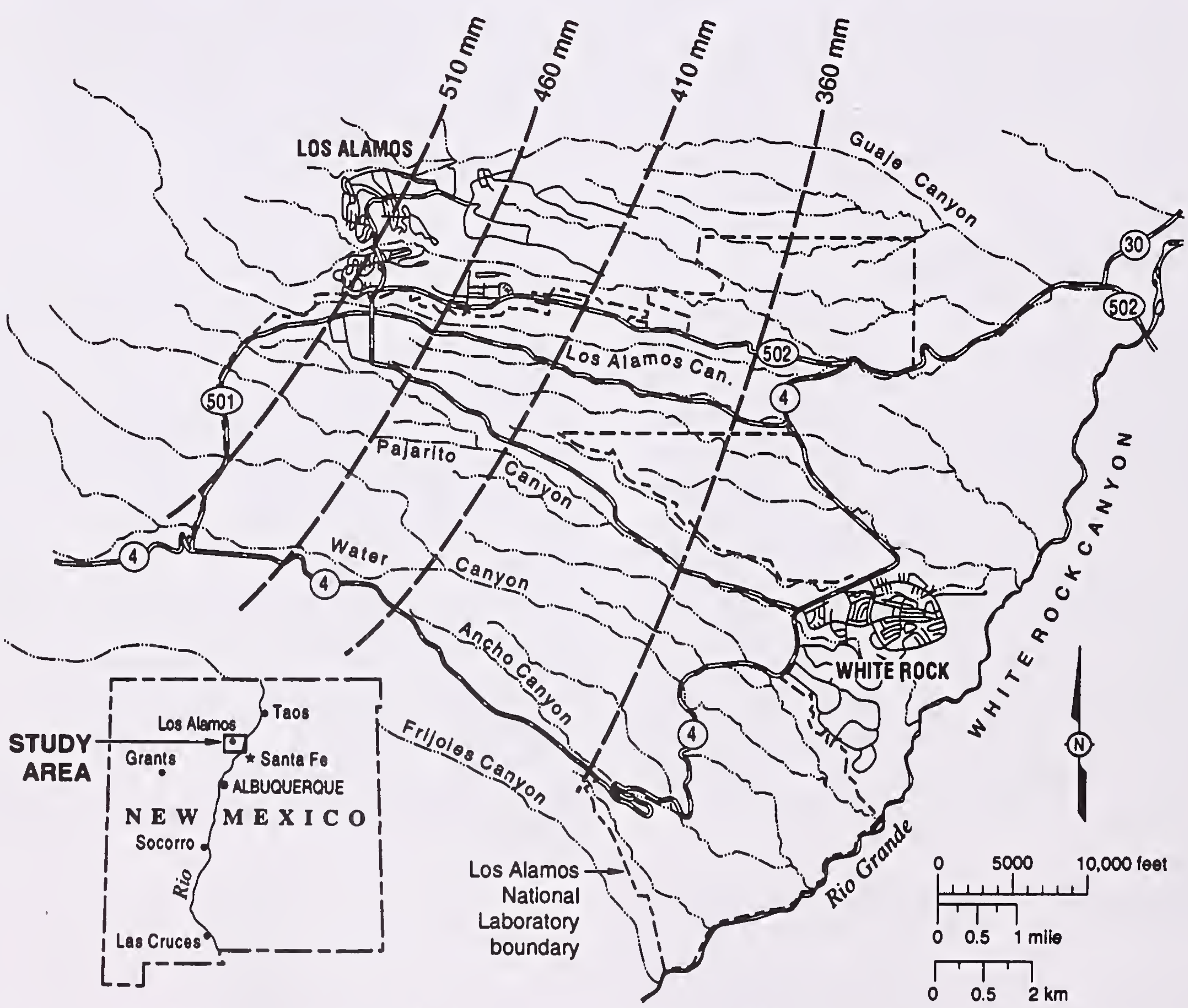

Figure 1.—Pajarito Plateau study area, including annual precipitation isoclines (from Bowen, 1990).

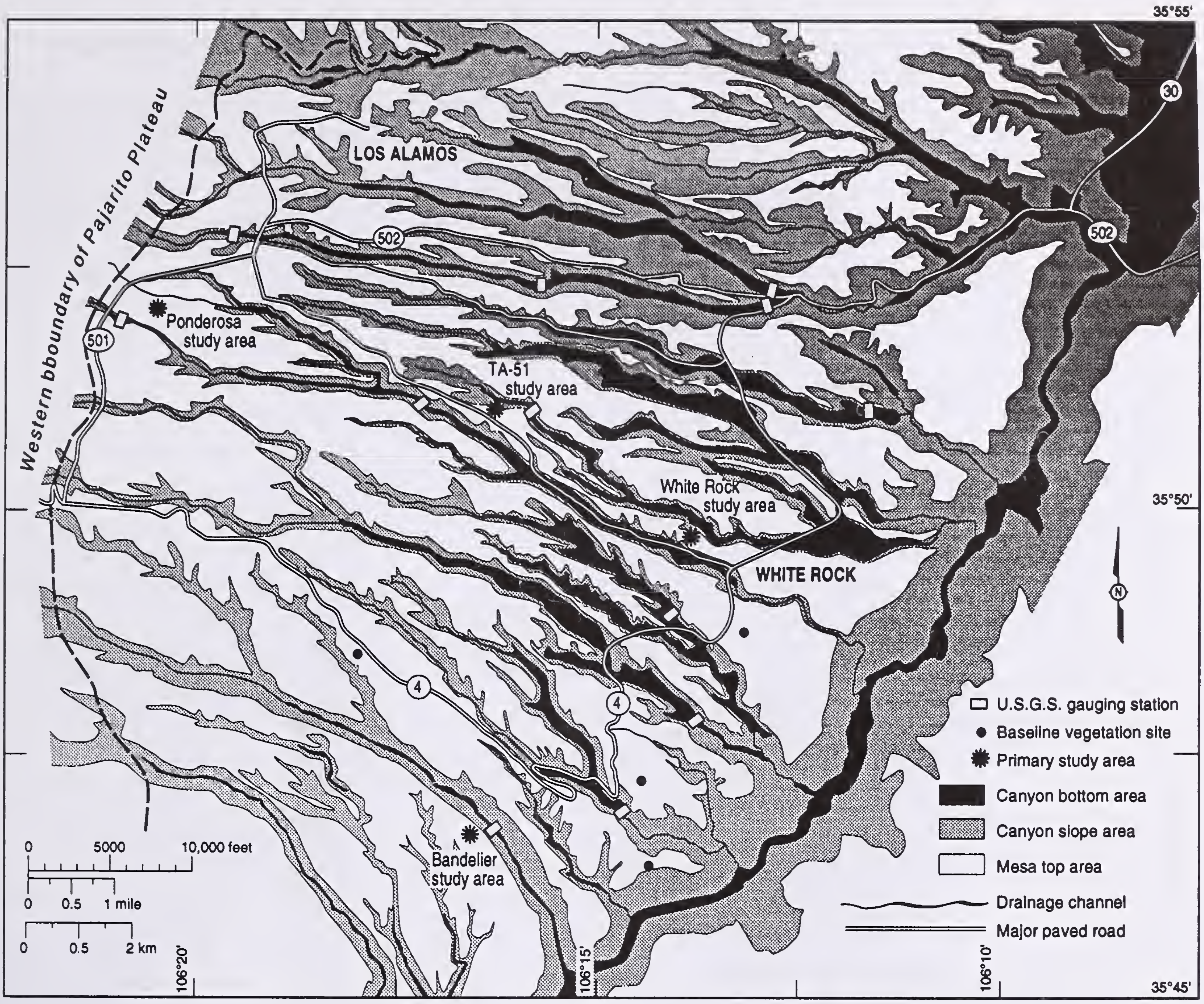

Figure 2.—Topographic features of the Pajarito Plateau and locations of field studies.

which intermittent and ephemeral streams flow toward the Rio Grande. The resulting topography is complex, characterized by four major features: mesa tops, canyon bottoms, north-facing slopes, and south-facing slopes (fig. 2).

The Pajarito Plateau has a semiarid, temperate mountain climate. Average annual precipitation varies with elevation, from about 330 to 460 mm (fig. 1), of which about 45% occurs in July, August, and September (Bowen 1990, fig. 3a). Most summer precipitation occurs as intense afternoon and evening thunderstorms, with an average year seeing 58 thunderstorm days (Bowen 1990). Differences in precipitation with elevation are most dramatic during July and August. In winter, precipitation occurs mostly as snow, with the greatest accumulation at the higher elevations. Temperatures are moderate: in the summer, daytime temperatures are generally below 90° F and nighttime temperatures are around 50° F; in winter, daytime temperatures range from about 30 to 50 °F and nighttime temperatures from 15 to 25 °F (fig. 3b).

A complex mosaic of soils have developed on the plateau, as a result of interactions between parent material, topographic position, and climate (Nyhan et al. 1974). The parent material for most soils is the Bandelier Tuff, an enormous ash flow constituting the uppermost geologic unit on the plateau. Soils may develop from residual tuff or from tuff that has been reworked by surface processes and is redeposited as slope wash, alluvium, or colluvium. The El Cajete pumice (from the latest volcanic eruption, some 50,000 years ago) and wind-blown sands also provide material for soil development.

Topographic position is a second important factor in soil development. Mesa-top soils are generally the oldest and best developed; they range in depth from a few centimeters at the mesa edge to over a meter near the center of the mesa. The surface-soil horizons are characterized by a loam to sandy-loam texture, whereas deeper horizons are typically argiliic (clay to clay loam). Canyon-bottom soils, developed mainly on alluvium, are young and poorly developed. South-facing canyon walls, which are often steep, have little soil material; north-facing slopes have shallow soils that are dark and high in organic matter.

The major vegetation zones of the Pajarito Plateau include juniper grassland (1600 - 1900 m), piñon-juniper woodland (1900 - 2100 m), ponderosa pine forest (2100 - 2300 m), and mixed conifer forest (2300 - 2900 m) (Allen 1989). By far the most extensive are the ponderosa pine forest and the piñon-juniper woodland. As can be seen from fig. 4, the vegetation patterns are largely dependent on elevation and topography.

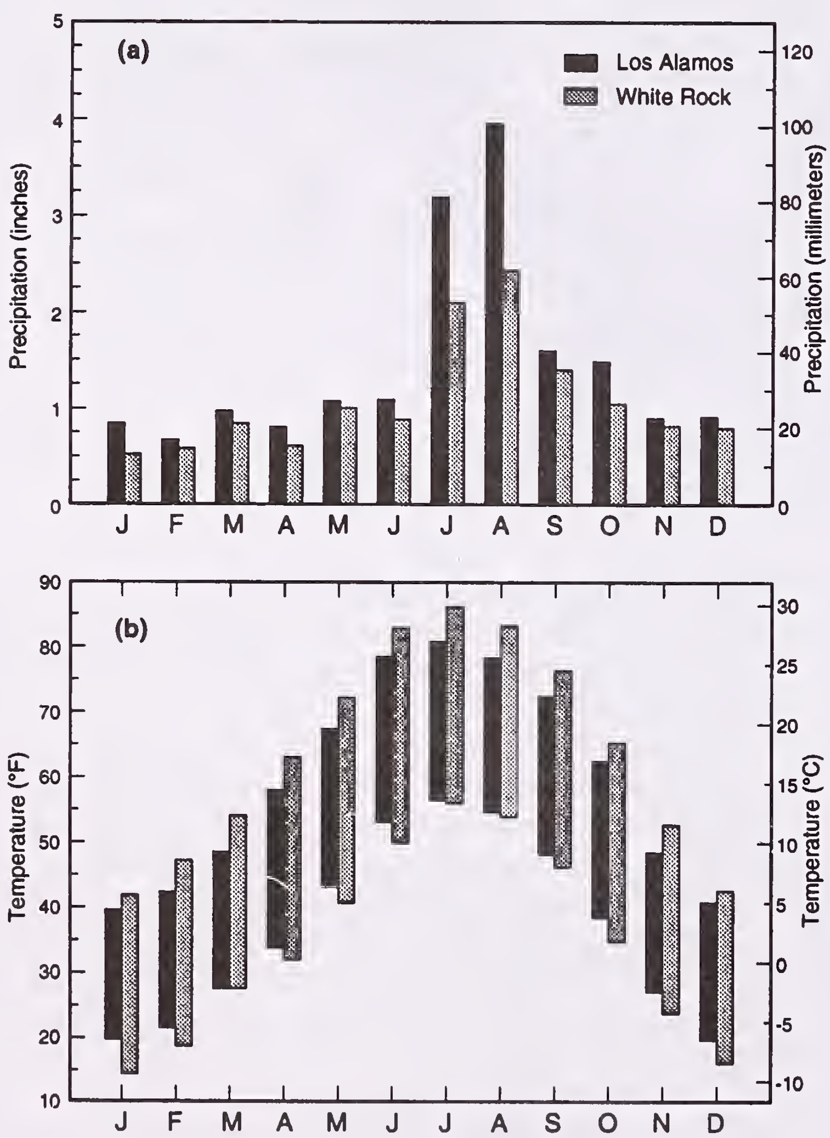

Figure 3.—(a) Monthly mean precipitation and (b) monthly mean maximum and minimum temperatures at Los Alamos and White Rock, New Mexico (from Bowen, 1990).

CONCEPTUAL FRAMEWORK

The dissimilarity of the elements that make up a highly heterogeneous system does not necessarily make the system difficult to understand; rather, the dissimilar elements can be arranged such that the relationships between and among them are more predictable. The heterogeneity that is visually apparent in vegetation patterns across semiarid landscapes is related to differences in hydrological characteristics, that is, the amount and availability of water. Small differences in plant-available water can influence the type and density of vegetation cover. Conversely, changes in vegetation cover can significantly influence the distribution of water.

Although our conceptual framework is based on, and serves as a guide for, our field studies in a specific area, it also applies to other semiarid environments–especially ones having a range of elevations and/or topographic features. The framework simplifies investigation of the movement of water and sediment (and, thereby, contaminants), as well as the interrelationships between water availability and vegetation cover, by dividing the semiarid landscape into a series of "functional units" on the basis of hydrologic behavior. Because differences in elevation and topography are the major determinants of hydrologic behavior at the larger scales, these differences form the basis for distinguishing between functional units at those scales; at smaller scales, the units are delineated on the basis of differences in vegetation and soils. Differences between units may be gradual in some cases and abrupt in others, but for the purposes of the framework the units are depicted as distinct entities.

The sources of most of the environmental contamination at Los Alamos are located on mesa tops in piñon-juniper woodlands. Therefore, our conceptual framework for the Pajarito Plateau delineates five scales that are relevant to contaminant movement within and from piñon-juniper woodlands on mesa tops (fig. 4). At each of these scales, we identify functional units as units that are hydrologically distinct: the hydrologic behavior of a given functional unit in one area will be similar to that of its counterpart in another area; the differences in hydrologic behavior between functional units in one area will be consistent with those in another area. Table 1 shows the functional units identified at each scale and the hypotheses formulated with respect to hydrologic differences between units and hydrologic connections between units.

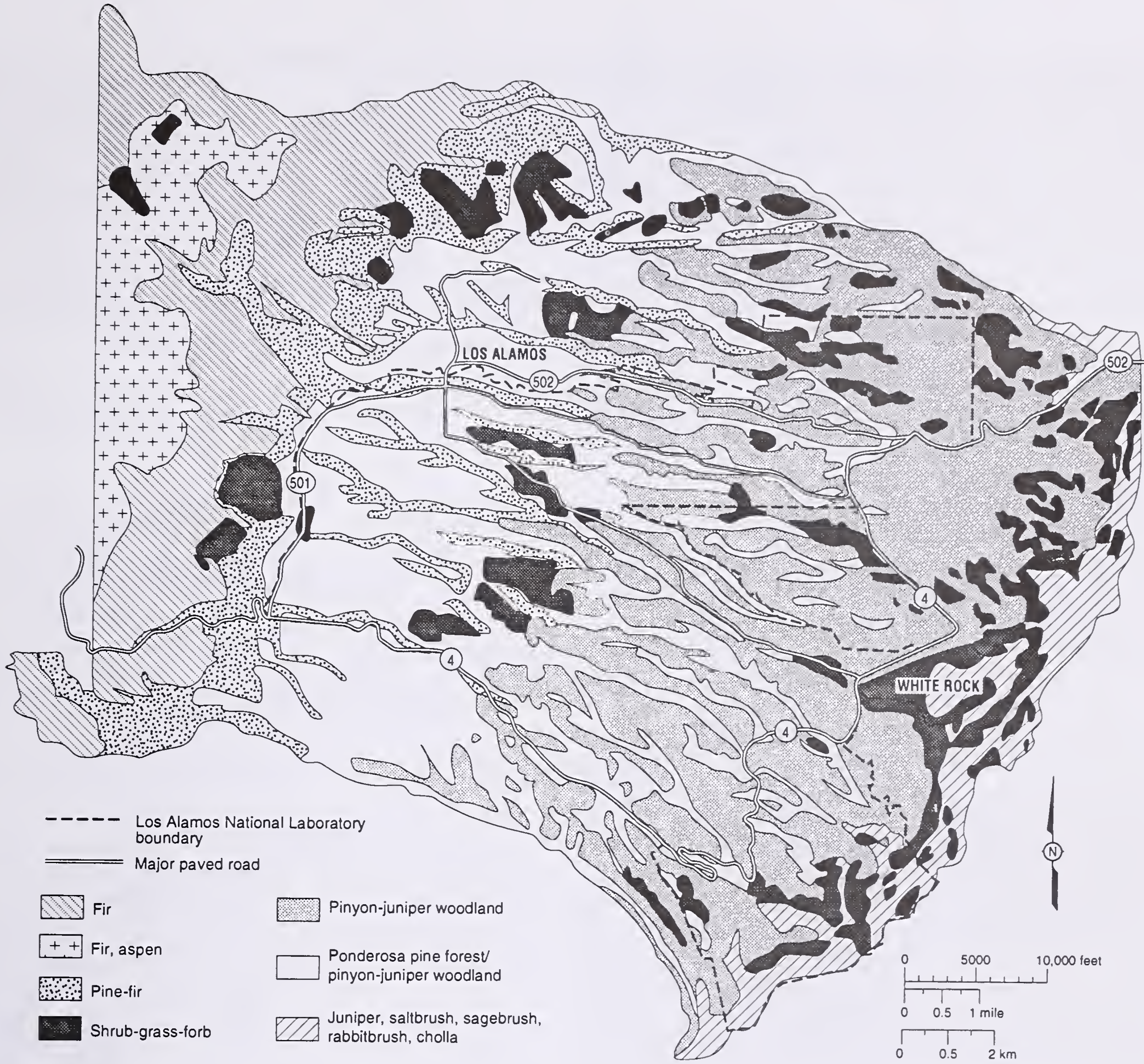

Figure 4.—Major vegetation types on the Pajarito Plateau (Los Alamos Environmental Research Park documentation, 1976).

The largest scale, to which we refer as the *regional scale*, includes the entire plateau and parts of the adjacent Jemez Mountains (fig. 5). At this scale, the major hydrologic dichotomy is between streamflow that is perennial (or intermittent, i.e., continual for at least part of the year) and streamflow that is ephemeral. Very generally, perennial flow is generated from melting of snow packs that accumulate at the higher elevations. In the functional unit characterized by perennial flow, water is available in excess of the evaporative demand (at least during part of the year), and the most likely pathway of flow is subsurface.

Ephemeral flow, on the other hand, is generated mainly by intense summer thunderstorms; in this hydrologic unit, the pathway of flow is surface, which carries much higher amounts of sediment. Whereas the high-elevation "perennial stream" functional unit contributes more water, the lower-elevation "ephemeral stream" functional unit contributes more sediment. From the standpoint of water movement (and associated transport of sediment, contaminants, and nutrients), the dichotomy is important. For example, to predict how much runoff is produced from the Jemez Mountains and Pajarito Plateau, the major considerations are the amount of snow accumulation in the higher elevations and the amount of water lost in transmission through the alluvial channels in the lower elevation zones. (In this area, the boundary between the "perennial stream" and the "ephemeral stream" functional units corresponds roughly to

Table 1.—Conceptual framework scales and functional units: hypotheses.

Scale	Size (km)	Functional units	Hypotheses concerning hydrologic differences	Hypotheses concerning hydrologic connections
Regional	25-50	mountains plateau	Sustained flow is generated from mountain environments because of accumulation of snow. Flow from the plateau is mostly ephemeral and results from intense summer thunderstorms (Wilcox et al. 1991).	Flow of water and sediment is from the mountains to the plateau and occurs primarily through the canyons. Most runoff generated from mountain snowmelt infiltrates into the canyon bottoms of the plateau.
Plateau (elevational gradient)	10-25	ponderosa piñon-juniper juniper	Precipitation increases with elevation resulting in deeper soil moisture, which is related to the proportion of woody cover (Walter 1971, Breshears 1993)	Boundaries between these units may fluctuate because of climatic variability or disturbance. Hydrologic connections occur mainly through the canyons.
Plateau (topographic gradient)	1-5	mesa top north slope canyon bottom south slope	Solar radiation input is affected by topography and modifies plant-available water (Whittaker 1975)	Runoff and sediment is generated from the mesa tops and south-facing slopes and flows mostly to the canyon bottoms.
Woodland	0.01-1	canopy intercanopy	Water and energy fluxes are modified by the presence of woody plants (Blackburn 1975, Dawson 1993, Breshears 1993, Seyfried, 1991)	There is little exchange of water and sediment between the canopy and intercanopy areas, with the exception of extraction of intercanopy soil water by woody plants. Intercanopy areas are interconnected.
Intercanopy	0.005-0.01	bare grassy	Water and energy fluxes are modified by herbaceous cover (Richie 1973, Wilcox et al. 1988, Wilcox et al. 1989)	Most runoff and erosion is generated from bare areas. Grassy areas often serve as sinks for water and sediment, preventing larger scale runoff.
Herbaceous patch	0.001-0.005	bare cryptogam grass	Water and energy fluxes are modified by individual herbaceous plants (Hook 1992)	At this scale much of the runoff and most erosion is generated from bare ground.

that between the ponderosa pine and the mixed conifer forest.)

The next smaller scale of the framework, which we call the ***plateau scale*** (because in our area it is represented by the Pajarito Plateau itself), is the same as the "ephemeral stream" functional unit. At this scale, the two most important determinants of hydrologic behavior are *elevation* and *topography*. For this reason, functional units are delineated according to differences in both elevation and topography (fig. 5).

Three functional units are delineated along the *elevational* gradient, each characterized by one of the major vegetation types: ponderosa pine forest, piñon-juniper woodland, and juniper grassland.

As elevation increases, precipitation is higher and potential evapotranspiration is lower, resulting in more plant-available water and deeper percolation of water into the soil profile. The different vegetation patterns are related to these different moisture patterns (Lauenroth et al. 1993, Breshears 1993). These functional units are not hydrologically connected except by stream flow through the canyons. In other words, only canyon-bottom areas will receive additional inputs of water from upstream functional units.

Four functional units are delineated along the *topographic* gradient (fig. 5). These units are mesa tops, canyon bottoms, north-facing slopes, and south-facing slopes. Differences in plant-available water (and thereby in vegetation) among these functional units are related mainly to differences in solar radiation and soil characteristics. Inputs of solar radiation are greatly affected by slope position. Soils also differ with topography (canyon-bottom soils, for example, are deep, sandy soils that readily absorb water; in contrast, south-facing slopes may be mostly exposed bedrock or have very shallow soils with limited water-holding capacity).

Inputs of water by precipitation, although similar for all four topographic functional units, are substantially augmented for the canyon-bottom areas as runoff is received from the other areas, especially the mesa top and south-facing slopes. In other words, water and sediment are redistributed among these functional units, with the mesa tops and south slopes acting as source areas and the canyon bottoms as the major sinks. The north-facing slopes may be sources or sinks, depending on whether they are providing water and sediments to the canyon bottoms or gaining water from the mesa tops (as is the case especially during winter snowmelt-Wilcox, 1994).

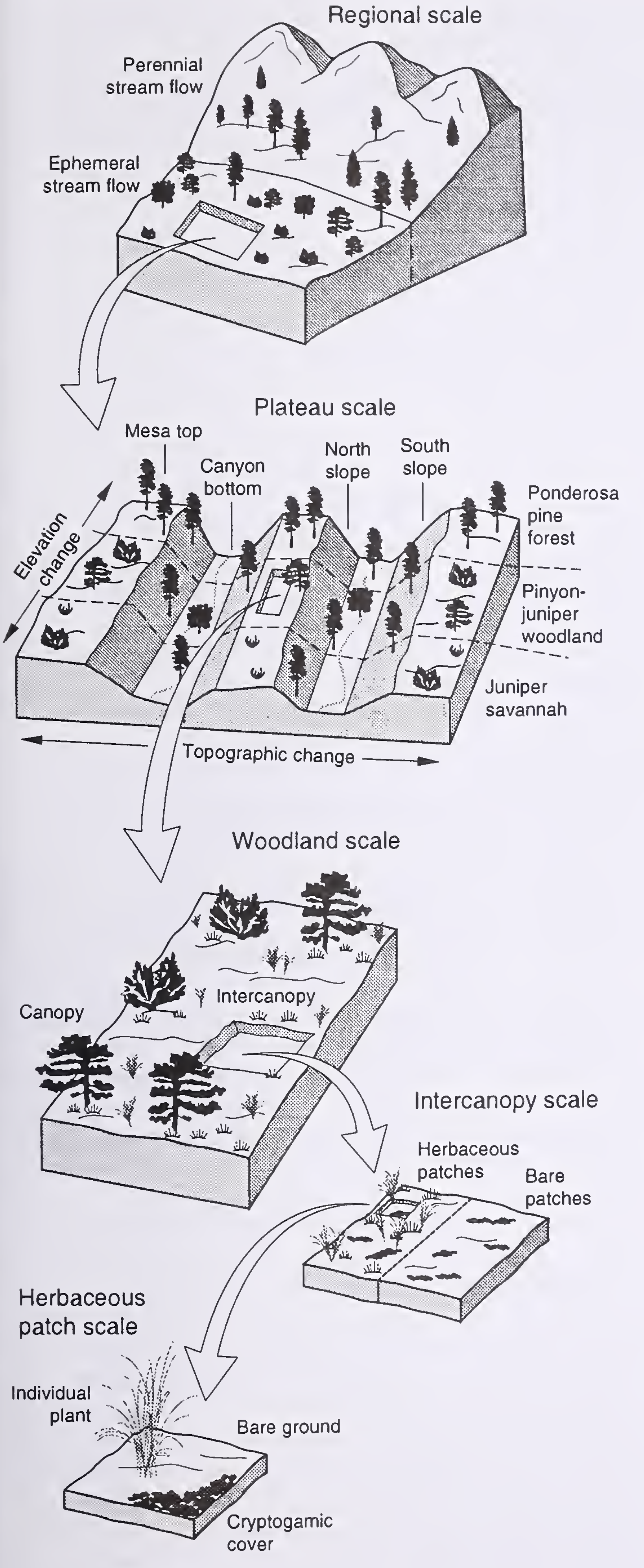

Figure 5.—Conceptual model for the Pajarito Plateau, showing functional units at each scale.

The next scale is that of the piñon-juniper woodland. At this ***woodland scale***, we delineate two functional units: canopy and intercanopy. Hydrologic differences between these two zones have been observed in piñon-juniper woodlands (Roundy et al. 1978, Breshears 1993) as well as in other shrubland types (Blackburn 1975, Seyfried 1991). Infiltration rates are typically much higher in the canopy zones as a result of soil and cover differences. We believe that there is little if any exchange of surface water or sediment between the two units. More runoff and sediment movement are generated from the intercanopy zones, but very little of the water or sediment is carried into the canopy zones because these form mounds, slightly higher in elevation than the intercanopy zones. (This hypothesis is consistent with Seyfried's [1991] observation that in sagebrush rangelands, the intercanopy areas are interconnected.) On the other hand, a subsurface hydrologic connection between the two units has been demonstrated by Breshears (1993), who has documented that both piñon and juniper-juniper in particular-extract water from neighboring intercanopy soils.

We have selected the intercanopy functional unit as the next scale in our framework. At the ***intercanopy*** scale, we define two further functional units: herbaceous patches and bare patches. During runoff-producing rainstorms, most of the runoff is generated from the bare patches, whereas the herbaceous patches act as sinks for this water and associated sediment. Given a large enough runoff event, the herbaceous patches will generate some runoff as well.

Finally, the smallest scale of the conceptual framework is that of the ***herbaceous patch***. Within a herbaceous patch, distinct functional units are individual herbaceous plants, areas of cryptogamic cover, and bare ground. We believe that the infiltration capacity of each of these units is different, bare ground having the lowest, cryptogamic cover somewhat higher, and individual plants the highest.

FIELD STUDIES

While the conceptual framework outlined above facilitates thinking about water and sediment movement through semiarid landscapes, and how such movement affects-and is affected by-vegetation patterns, it also gives rise to further questions: exactly how do these functional units differ hydrologically? What are the hydrological connections between/among them? We have

Table 2.—Pajarito Plateau field investigations: ongoing collection of hydrological and ecological data at mesa-top sites.

Data category	Mesa-top sites			
	Ponderosa Site (ponderosa; elev. 2315 m)	TA-51 (piñon-juniper; elev. 2140 m)	White Rock (piñon-juniper; elev. 1985 m)	Bandelier (piñon-juniper; elev. 1950 m)
Runoff - Catchment				X
Runoff / erosion Hillslope	X	X		
Runoff / erosion - Plot	X	X		
Runoff / erosion - microplots		X		X
Interflow	X	X		
Soil moisture - neutron attenuation	X	X	X	
Soil moisture - TDR	X	X	X	
Soil temperature	X	X		
Weather station	X	X	X	X
Snow depth and density	X	X.		
Stem dendrometers	X	X	X	
Conductance	X	X	X	
Plant water Potential	X	X	X	

formulated hypotheses to respond to a number of these (see Table 1), and are now collecting data that will allow us to test many of them (some have already been tested by others).

Most of the hydrologic and ecologic investigations that are providing us with data for our conceptual framework are concentrated at four locations along the elevational gradient of the plateau: one in a ponderosa pine forest and three in piñon-juniper woodlands (table 2). In addition to these, a network of USGS stream-gauging stations has been established across the plateau; and at several other sites, periodic measurements are being made of plant physiological variables. Most of these studies have been initiated within the last 3 years, but build on previous hydrological and ecological investigations (Allen 1989, Lajtha and Barnes 1991, Lajtha and Getz 1993, LANL 1994).

Regional Scale

At this scale, the functional units are the mountains and the plateau. Information about the hydrologic behavior of these units is being gathered through the USGS stream-gauging network on the plateau (fig. 2). Stations have been installed in ten of the major canyons; some of these, such as Los Alamos, Pajarito, and Canada del Buey, have more than one gauge. These data will contribute to our understanding of the hydrologic connections between the functional units.

Plateau Scale

The functional units at this scale correspond to the major vegetation types on the plateau: ponderosa pine forest, piñon-juniper woodland, and juniper grassland. Currently, runoff and erosion data are being collected from one ponderosa pine hillslope (Ponderosa site) and two piñon-juniper hillslopes (TA-51 and Bandelier). The catchment areas range in size from 0.5 to 1.0 ha. At the Ponderosa and TA-51 sites, subsurface flow from the hillslope is also being measured. These data have already proved useful in understanding water movement within areas characterized by each of the three vegetation types. In addition, soil moisture data are being collected along the elevational gradient of the plateau, at the Ponderosa, TA-51, and White Rock sites. Although these are point measurements, they can be averaged to enable comparison of soil moisture values between the different functional units.

At this time, data are being collected only from the mesa-top functional unit (the small catchment studies described above could also be considered as within this unit).

Woodland Scale

The two functional units at this scale are canopy zones and intercanopy zones. These functional units are being studied at the TA-51 and White Rock sites. At TA-51, runoff and erosion are being measured from 30-m^2 plots in intercanopy zones (Wilcox 1994). Although the initial runoff measurements were only total volume, the plots have subsequently been modified so that runoff can be monitored continuously. Differences in soil moisture between canopy and intercanopy zones are measured both by neutron attenuation and time-domain-reflectometry (TDR). The two methodologies are complementary: neutron attenuation allows soil moisture to be determined incrementally with depth (in our case up to 3 m); TDR provides continuous soil moisture monitoring, but only an integrated average of soil moisture along the length of the probe. Measurement of deep soil moisture by TDR requires horizontal insertion of probes into an excavated profile; such measurements are being taken in a few locations. Finally, we are also collecting data on plant physiological variables that will allow us to relate soil moisture changes with plant water dynamics.

Intercanopy Scale

At TA-51, runoff and erosion are being monitored from small plots (1 - 2 m^2) representing the two functional units identified at this scale: herbaceous patches and bare patches. These plots are paired with larger plots (4 m^2) that encompass both bare and herbaceous zones. The data thus obtained provide information about the hydrologic connections between these two functional units. Soil moisture is also being measured as a basis for examining relationships between soil moisture and vegetation cover (or the lack of it) within each unit.

Herbaceous Patch Scale

Hydraulic conductivies are being determined in the field for the hydrologic units at this scale: individual herbaceous plant, cryptogamic cover, and bare patch.

Major Findings to Date

Although these studies have been under way for only a short time, they have already yielded data that significantly advance our understanding of water movement and its interrelationships with vegetation on the Pajarito Plateau (and in other semiarid environments as well). At the TA-51 study site, a 2-year pilot study has provided valuable insights concerning runoff and erosion in intercanopy zones of piñon-juniper woodlands (Wilcox 1994); and preliminary data from the Ponderosa site is demonstrating that subsurface flow can be an important contributor to winter runoff. (No subsurface flow has yet been observed in piñon-juniper woodlands.)

Observation of the relationship between hydrological behavior and ecological response at our various study areas has stimulated much thought about ecosystem processes. For example, we are perplexed about the much higher rates of erosion (orders of magnitude higher) at our Bandelier study site than at the other sites. We find these differences throughout the plateau: some piñon-juniper woodlands are eroding at alarming rates, while others appear to be quite stable.

Using soil-moisture and plant-water response data collected from many locations across the plateau and ecological theory developed at other areas, Breshears (1993) developed a simple, yet powerful model for predicting vegetation cover in semiarid landscapes. Ongoing ecological studies are unraveling the complex relationships between juniper, piñon, and blue grama, as they compete for soil water in intercanopy zones (Breshears et al., unpublished manuscript). These studies are complemented by work relating tree canopy geometry to inputs of solar radiation (Lin et al. 1992, Rich et al. 1993).

IMPLICATIONS

The approach outlined in this paper, of dealing with landscape heterogeneity by dividing the landscape according to hydrologic response, holds promise for effectively addressing many scientific and management concerns in piñon-juniper woodlands. It can complement the sophisticated mathematical models used by scientists to predict movement of water, sediment and contaminants (Seyfried and Wilcox 1995); and can help managers evaluate the potential impacts of management actions. The approach is greatly strengthened by the network of field studies, which is furnishing one of the most comprehensive ecological and hydrological data bases for piñon-juniper woodlands.

At Los Alamos National Laboratory, we need to predict long-term contaminant migration from two different types of sources: (1) low-level contamination covering large areas (many km^2) and (2) localized, high-level contamination, such as in a landfill or contaminant spill area. In some areas of the first type, contaminant concentrations may be sufficiently low as to not warrant remedial action-the environmental effects of remediation could be much greater than those associated with contamination (Breshears et al. 1993). At the same time, erosional processes can cause preferential deposition of contaminated soils in specific locations, such as canyon bottoms. The need to improve our ability to predict the movement of contaminants from mesa-top woodlands to canyon bottoms led to the development of our conceptual framework. On the basis of our observation that runoff and erosion are greatest from patches of bare soil and will move through the interconnected intercanopy areas to the canyons below, we defined the woodland scale of the framework in terms of canopy and intercanopy areas (the latter comprising bare and herbaceous zones). The addition of percolation theory (Gardner et al. 1992) to predict the movement of contaminants may further increase the predictive capability of the framework for this application.

At Los Alamos, landfills exemplify the second type of potential source of contamination. Because erosion is the major mechanism by which contaminants could be released, the ability to predict rates of landfill erosion over the long term is critical to devising effective remedies. Covers for these landfills (a combination of various soil layers and vegetation types) are being designed to reduce the potential for movement of contaminants beyond the landfill boundaries. Erosion rates are most effectively reduced by herbaceous cover, but given the long periods over which these landfills must remain stable (> 100 years), the potential for changes in vegetation cover must be factored into the design. By clarifying the linkages between hydrological and ecological processes, our framework can contribute to the development of a model for predicting these changes in piñon-juniper woodlands.

In addition, the framework and the data being collected could prove useful in addressing the overall problem of erosion in piñon-juniper woodlands. Management strategies for reversing this trend focus on increasing the amount of herbaceous cover. Our studies of the relationships between vegetation cover and soil moisture could lead to improved methods for doing that.

In summary, we believe that the extreme heterogeneity of semiarid landscapes can be described in terms of variations in the hydrologic properties of the components of these landscapes. The resultant variations in vegetation, both in space and over time, have created the need for a model, or framework, that will allow us to predict the relationships between water, sediment, and vegetation dynamics. Several testable hypotheses have already resulted from the framework we are developing. As we test these hypotheses using the data from our network of field studies, we hope to improve our predictive capabilities, and thereby our ability to solve environmental problems in semiarid landscapes.

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Understory Production and Composition in Piñon-Juniper Woodlands in New Mexico

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Abstract.—Herbaceous standing crop was determined on three locations within piñon-juniper woodlands on the Fort Stanton Research Station in the Sacramento Mountains near Capitan, NM for a 12 year period. End-of-season standing crop varied from over 1000 kg/ha to a low of less than 200 kg/ha. These differences are comparable to those for other locations in the Southwest. During the period from 1964 to 1975 variations in July-August precipitation explained over 40% of the variation in herbaceous standing crop. Across 25 piñon-juniper stands on Fort Stanton, overstory canopy cover was negatively related to total understory herbage weight. A 2nd polynomial equation explained over 93% of the variation in understory herbage weight attributed to overstory cover while two C_3 species *Piptochaetium fimbriatum* and *Stipa neomexicana*, were positively related to canopy cover. Two-way cabling resulted in increased herbaceous standing crop of more than 185 kg/ha over a 6-year period after cabling on four location on the research station. Other studies indicated varying responses to tree reduction. Manipulating overstory cover appears to be one way of altering understory production and composition. Piñon-juniper vegetation responds to topographic variation, but the response is quite variable across these southwestern woodlands.

INTRODUCTION

Piñon-juniper woodlands serve as important habitat for wildlife and domestic livestock in the Southwest. These woodlands occupy over 12.5 million hectares in Arizona and New Mexico alone (Dortignac 1960 and West and others 1975). In some cases these woodlands occur as extensive stands while on other cases, they occur as scattered and disjunct elements. Initially these woodlands were valued mainly as habitat for animals, but recently other resource values have been recognized within the piñon-juniper woodland (Bledsoe and Fowler 1992 and Fowler and others 1985). These other products include fence posts, fuelwood, poles, wildings, piñon nuts, and Christmas trees. Yet most of these woodlands continue to be used for livestock grazing and wildlife habitat. Understory components are especially important for livestock, but an understanding of their relationship to other environmental variables is necessary for a more complete understanding of the ecology of these woodlands.

Summaries of information concerning floristics of understory vegetation on piñon-juniper woodlands have been presented by Pieper (1977) and West and others (1975). While juniper and piñon-juniper communities in the West are represented by only 9 or 10 tree species (Tausch, this volume, Tueller and Clark 1975), the understory component is much more varied. West and others (1975) listed over 30 species of shrubs, 8 succulent species, 30 grass species, and 14 fob species on 20 locations in the western U.S. In northern portions of the woodlands understory grasses are dominated by C_3 cool-season species while C_4 warm-season grassers are more important in southern and southeastern areas (West and others 1975). Pieper (1977) compared understory vegetation for areas in northern regions with that from the southwestern and southeastern regions.

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The objective of this paper is to compare understory vegetation in piñon-juniper woodlands in New Mexico and the Southwest and to discuss factors influencing development of understory vegetation.

HERBAGE PRODUCTION

Clary (1978) summarized results of understory herbaceous biomass for 6 different studies in different locations. These data ranged from less than 50 kg/ha before removal of overstory trees to more than 2200 kg/ha following tree removal. In addition to large spatial variations in herbage biomass, there is considerable variation from year to year. At Fort Stanton in the foothills of the Sacramento Mountains in south-central New Mexico, end-of-season biomass varied from less than 200 kg/ha to over 1000 kg/ha at three locations over a 12 year period (Table 1). There were two severe short-term drought periods during this period in 1970-71 and in 1974 (Pieper an Donart 1973, Pieper and others 1992). In general growing conditions were more favorable during the 1960s than during the 1970s and herbage production shows a general decline from the peak in 1967 to 1975 (Table 1).

FACTORS INFLUENCING UNDERSTORY BIOMASS

Understory biomass is a function of several abiotic as well as biotic factors. Some of these relationships have been studied in detail and others only superficially. Quantitative relationships have been developed for the influence of precipitation and overstory canopy on herbaceous biomass.

Table 1. – Herbage standing crop at three locations with piñon-juniper woodlands in the Sacramento Mountains in southcentral New Mexico (mean ± standard error).

Year	Locations 1	2	3
		kg/ha	
1964	486±35	435±44	336±30
1965	592±50	595±47	660±44
1966	570±65	400±22	630±52
1967	725±52	899±60	1048±47
1968	529±33	556±57	543±27
1969	462±37	391±44	527±33
1970	543±35	667±55	585±67
1971	335±25	250±22	375±35
1972	285±35	225±18	330±44
1973	440±40	385±39	410±50
1974	185±15	235±28	300±32
1975	330±40	385±35	425±38
Average	457	452	514

Table 2. – Simple linear correlation coefficients between dependent variables of total herbage, blue grama, and forb biomass and precipitation for certain periods of the year at Fort Stanton, NM (from Pieper and others 1971).

Dependent variables	Ann. Ppt Oct-Sept	JJAS[1]	JAS	JA	July	Aug
Total biomass	0.47*	0.68**	0.68**	0.69**	0.51*	0.65**
Blue grama biomass	0.37	0.51*	0.55*	0.54*	0.44	0.46*
Forb biomass	0.36	0.46*	0.24	0.29	0.14	0.33

[1]*June, July, August, and September.*
*$P < 0.05$
**$P < 0.01$

Precipitation

Several combinations of monthly precipitation were related to total, blue grama, and forb biomass at Fort Stanton in south-central New Mexico using a combination of location and yearly data sets (Pieper an others 1971). Summer precipitation was significantly related to total herbage biomass with 47% of the variation in understory herbaceous biomass determined by differences in July and August precipitation (Table 2). The regression equation was

$$Y = 123.4 + 3.2X$$

where Y = herbage biomass in kg/ha and X = July and August precipitation in milliliters. August precipitation was the best single month predictor of total herbaceous biomass. Correlation coefficients were lower for blue grama and forb biomass. The only significant relationship for forb biomass was with June, July, August, and September precipitation (Table 2). These data were obtained from mature piñon-juniper woodland stands on Fort Stanton and stand density and overstory variation was minimal.

Clary (1971) reported that different plant groups responded to precipitation distributions in different manners. Perennial grass biomass was controlled largely by winter-summer precipitation while annual grasses responded to summer precipitation. Shrubs were related more closely to winter precipitation than that received during other periods.

Tree Overstory

Several studies have evaluated the relationship between overstory cover or tree basal area and understory production or cover (Pieper 1983). These relationships are similar although the functional form of the relationship varies among locations and

Table 3. – Equations depicting relationships between herbage production and overstory cover in southwestern piñon juniper ecosystems.

Location	Dependent Variable	Independent Variable(s)	Equation	Author(s)
Northern Arizona	Herbage Biomass	Percent Canopy cover	$Y=597-527(-e^{-0.36x})^{1/2}$	Jameson 1967
Northern (Utah Arizona Juniper)	Herbage Biomass	Basal Area (X_1) June-Aug. PPT (X_3)	$Y=345.4=129.4X_1 + 28.3X_3$	Clary and others 1974
Northern (Alligator Arizona Juniper)	Herbage Biomass	Basal Area (X_1) June-Aug. PPT (X_2)	$Y=593.3=357.0X_1 + 75.4X_2$	Clary and others
Great Basin	Understory cover	Overstory cover	$Y=20.36-0.752X$	Tausch and others 1981
New Mexico	Herbage	Overstory	$Y=1062-170X+0.82X^2$	Pieper 1990

years. Herbage biomass is reduced by small increments of canopy in dense stands but at lower canopy cover, the curve is much flatter. Several studies report equations for prediction of understory biomass from overstory cover (Table 3) (Clary 1974, Jameson 1967, Pieper 1990, and Tausch and others 1981) while others showed the curves without equations (Arnold and others 1964, Dalen and Snyder 1987, and Short and others 1977). Reduction of canopy cover from 60 to 70% increases herbaceous biomass by small amounts, but reduction from 20 to 10% increases herbage biomass considerably. The only linear relationship was that reported by Tausch and others (1981) for several areas throughout the Great Basin but the dependent variable in their study was herbaceous cover and not biomass. Large variations in understory response to tree reductions is to be expected since the studies represent different areas with different soils, climatic patterns, and time since treatment. Arnold and others (1964) reported that maximum response in understory production occurred 10 to 12 years following treatment. Bledsoe and Fowler (1992) found that herbage response was highest 4 to 7 years following cutting on two sites and sooner on another site in New Mexico. Degree of disturbance and precipitation patterns following control undoubtedly influence the response of understory species.

While the general pattern is for herbaceous biomass to decrease as overstory cover increases, some species actually increase as canopy cover increases. Clary and Morrison (1973) reported that cool-season grasses such as *Poa fendleriana, Sitanion hystrix, Koeleria cristata, and Agropyron smithii* were more abundant under the canopy of large alligator junipers (*Juniperus deppeana*) than in the open spaces in northern New Mexico. In New Mexico, several cool season grasses were positively correlated with overstory tree canopy cover (Armentrout and Pieper 1988, Pieper, 1991, and Schott and Pieper 1985).

Table 4. – Percent increase in understory herbaceous biomass following piñon-juniper control in the Southwest.

Location	% Increase	Authors
Arizona	1227	Clary and Jameson 1981
Arizona	339	Clary 1971
Arizona	105	O'Rourke and Ogden 1969
Nevada	441	Everett and Sharrow 1985
New Mexico		Bledsoe and Fowler 1992
Taos	316	
Chama	1617	
Cloudcroft	2907	
New Mexico	33	Rippell and Others 1983

The strong relationship between overstory canopy cover and herbaceous biomass suggests that reduction of trees in the piñon-juniper woodlands would increase forage for livestock and possibly game. Consequently, during the 1950s and 1960s, large scale woodland control projects were undertaken on public lands (Aro 1971). Many of these projects were not evaluated, but several studies have been conducted to determine the response of herbaceous vegetation to piñon-juniper reductions. The results of these studies have been varied (Table 4) with understory biomass increasing form less than 35% to nearly 30 times the untreated control. In Arizona O'Rourke and Ogden (1969) reported understory vegetation did not respond to piñon-juniper control on some sites because of high calcium carbonate content of the soil and probable low phosphorus availability. The overall response in herbaceous biomass was higher following control on three locations and nearly double on the four locations studied (Table 4). Table 5 shows that herbaceous biomass increased over 185 kg/ha during a six-year period following two way cabling at Fort Stanton. The increase was greater than 200 kg/ha for most years, but the average was reduced by the lack of response during the second year following the cabling.

Table 5. – Herbaceous biomass (kg/ha) on four locations on Fort Stanton following two way cabling for tree control.

Year	Control	Cabled	Difference
1975	600	797	+197
1976	642	375	- 267
1977	556	859	+303
1978	455	685	+230
1979	512	825	+313
1980	530	717	+187

Topography

Considerable research has been conducted on topographic influences on tree species in the piñon-juniper woodland, but little on understory responses. Lymbery and Pieper (1983) reported that several species were found on most locations sampled in south-central New Mexico, and were not restricted to a particular topographic position or aspect. In western New Mexico, cool season grasses tended to be more abundant at higher, mesic habitats while warm season grasses were more abundant at lower elevations (Hill 1990). In Nevada, Everett and Others (1983) reported that understory species responded differently to the presence of one-seed juniper (*Juniperus monosperma*) depending on the aspect (north, west, or south).

Shrubby components appear more responsive to topographic variables than herbaceous species. Density of cholla cactus was greater on relatively dry south facing slopes compared to north slopes in piñon-juniper woodlands in the foothills of the Sacramento mountains in south-central New Mexico. Other shrubs were not greatly influenced by topographic position. Mountain mahogany (*Cercocarpus moujntanus*) density was greater at higher and intermediate elevations in western New Mexico while grey oak (*Quercus grisea*) was more abundant at intermediate elevations (2000 to 2200 m). Other species occurred on different aspects and elevations.

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A Checklist for Ecosystem Management in Southwestern Piñon-Juniper

Earl F. Aldon[1], Reggie Fletcher[2], and Doug Shaw[2]

Abstract.—It has been estimated that 3.5 million acres of piñon-juniper in the Southwestern Region are in unsatisfactory watershed condition. the current Piñon-Juniper Initiative in the Region places priority on restoration of these acres in conjunction with the Forest Service's move toward ecosystem management. Using a checklist format, this paper lists important ecological aspects useful in developing and implementing desired future conditions designed to move degraded areas toward a more sustainable condition. While the needs of each site are different, utilization of this checklist will ensure projects implemented have a broad focus based on scientific information. References are provided for additional in-depth review for many items while others relay on the author's experience. The checklist can be utilized as an aid for implementation of the IRM process.

INTRODUCTION

The current emphasis on ecosystem management has resulted in much talk and writing on the philosophy and principles of ecosystem management from both the physical/biological and human dimension. A team of scientists, chartered by the Regional Forester, recently published "An Ecological Basis for Ecosystem Management" in which six guiding principles are stated. The premise for sustaining ecosystems and protecting biodiversity now and into the future is to manage ecosystems such that structure, composition, and function of all elements including their frequency, distribution, and natural extinction, are conserved. (Kaufmann et al. 1994)

Another Regional team has published a brochure in which eight human dimension principles and strategies are discussed (R-3 Human Dimension Study Group). The philosophies and principles outlined in both these reports provide an important basis for policy decisions.

Few rules or side boards are available to guide specific efforts in ecosystem management at particular forest locations for the Piñon-Juniper (P-J) type. An ecosystem principles filter is described in the Kaufmann report. Economic and social needs can be tested against a filter of physical and biological principles. Also, economic and ecological needs can be tested against a filter of human dimension principles. The concept of using filters is good and clear, but how do you do it?

This checklist is an attempt to provide some ingredients for the filter and move toward ecosystem thinking based on principles before embarking on a specific project in Southwestern Piñon-Juniper ecosystems. The current Southwestern Regional initiative for the P-J type is focused on restoration ecology and requires guidelines to insure management strategies are based on biological, physical and social science. By following this checklist in planning one should be fairly certain major omissions will be avoided. The checklist is based on research information and where possible referenced. It is not meant to be complete and final, but an evolving checklist that will require periodic updating as more and better information becomes available. It assumes all applicable laws (Endangered Species Act, National Forest Management Act, Federal Land Policy Management Act, National Environmental Policy Act, etc.) will be followed.

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An ecosystem needs assessment proposed by Kaufmann, et al. is a useful way to organize this checklist. The assessment consists of: (1) Defining the analysis area. (2) Finding and describing reference conditions. (3) Describing and understanding existing conditions. (4) Applying a course filter analysis. (5) Applying a fine filter analysis if necessary. (6) Describing ecosystem needs and capabilities.

CHECKLIST

Defining the Analysis Area

- Begin by looking over a broad scale (for example a province or section on the ecological scale) to see how a particular proposed project area fits in a larger ecological prospective.
- Human dimension and physical/biological considerations extend beyond jurisdictional boundaries. Effects of actions at a particular site can be far reaching and cumulative.
- Identify the stakeholders at this level of scale? What are their desires for the future?
- What is the potential biological diversity?
- What are the economic factors that need to be considered at the larger scale?
- Focus in on the particular project area where restoration ecology appears needed (watershed, range allotment, etc.).
- Determine the priority of the site specific proposal in the context of the broader scale assessment and the predicted sustainability deficiencies surfaced by other disciplines.
- Is priority given to the 3.5 million acres of National Forests in the Southwest in unsatisfactory soil and watershed condition? (Spann 1993) (Shaw 1993)
- Is priority given to areas of social or cultural need?
- Is priority given to threatened, endangered or sensitive species habitat needs?
- Is priority given to heritage resource sites?
- What are the key indicators of system health or sustainability at the broader scale?

REFERENCE CONDITIONS

- Are there undisturbed examples of the same or similar ecosystems available for direct evaluation of natural ecosystem structure, composition, and function?
- Has literature been searched for information on historic and/or reference conditions?
- Has the nature, frequency, intensity, and scale of disturbance been identified and considered at the local and landscape scale?
- Has an attempt been made to identify the natural biological diversity of reference conditions and of the project area?
- Have changes in climate, soils, hydrology, and human use patterns been considered in deciding the appropriate understanding and use of reference conditions?

COURSE AND FINE FILTER ANALYSIS

- Will planned actions over time result in an array of vegetative structure and composition aggregates similar to that under which the project area developed?
- Will planned actions effect critical habitat features for T.E.&S. species?

EXISTING CONDITIONS

- Have state water quality reports been consulted to determine water quality standards and water quality status relative to meeting beneficial uses?
- Have stakeholders been consulted about past, current and future use of the area?
- Have field investigations been conducted to assess canopy structure and composition changes that have occurred over time to understand factors of change (drought,

fire, ecosystem dynamics)? (Betancourt et al. 1993)

- Have you referred to historical records for the area - aerial photos, range allotment plans, old cultural treatments (chaining, pushing, farming, etc.) to understand causative factors of change.
- Have ecosystem dynamics such as fire and drought been considered in understanding changes? (Cook et al. 1991)
- Have you decided what P-J habitat types are represented in the project area? An uneven aged mature piñon stand requires much different management than a juniper savannah. (USDA - Forest Service 1987) (Dick-Peddie 1993)
- Has Terrestrial Ecosystem Survey data been used, if available to further define habitat? (USDA - Forest Service variable dates)
- Have collaborative partnerships been sought among stakeholders? (Giusti 1993) (USDA - Forest Service 1993) (USDA - Forest Service Southwestern Region 1993)
- Are public involvement recommendations for desired future condition biologically feasible? (Garcia 1993)
- Do proposed project areas include sacred places for American Indians or other cultures? Are archeological sites noted? (Koyiyumptewa 1993, Cartledge et al. 1993, Miller et al. 1993)
- What is the status of key indicators of system health or sustainability at the broader scale?

ECOSYSTEM NEEDS AND CAPABILITIES

- Will plans protect or improve soil quality?
- Will state water quality standards be met? Are Best Management Practices prescribed?
- Will plans result in a visually desirable mosaic on the landscape?
- Will riparian areas be protected or improved?
- Will heritage resources be protected?
- Will threatened, endangered, and sensitive species habitats be protected?
- Will actions improve or enhance the publics understanding or appreciation of the P-J ecosystem?
- Will human life style needs be protected?
- Can existing human uses be sustained?
- Is sufficient flexibility in human use provided to weather drought years.
- Are there potential commercial areas for piñon nut production? (Cunningham et al. 1993)
- Can areas be managed for nut production within the project area? (Norwick et al. 1993, Cunningham et al. 1993)
- Can Christmas trees be harvested from the area? (Barger and Ffolliott, 1972)
- Are there areas needing revegetation with grasses?
- Are there remnant native herbaceous or shrubby seed sources that can, when managed, expand native species? (Scholl et al. 1986, Johnson, T. N. Jr. 1987)
- Are grass species present in mosaic patterns rather than continuous one-species stands? Have ¼ acre openings been provided to insure a positive blue gramma response?
- Where herbaceous species are growing directly under tree canopies (little-seed or piñon ricegrass) have ¼ acre clumps of trees been retained to prevent desiccation?
- Are treatment sites needed as a corridor or barrier to movement of animal species?
- Are climatic cycles considered in scheduling actions? (Betancourt 1993)
- Have cryptogram cover been considered in management plans? (Ladyman et al. 1993)
- Are insects and diseases in the stand inventoried and included in management plans? Are mistletoe infected trees scheduled for removal? (Rogers 1993) (Shaw, C. G. et al. 1994) (Gottfried, G. J. et al. 1994)

- Are there areas of bitterbrush and cliffrose present that could be enhanced through management for winter range for wildlife? (Suminski 1993)
- Is dead and down material present and could it be enhanced by management for nutrient enhancement and erosion protection? (Ernest et al. 1993)
- Do fuelwood harvest plans consider making small openings, utilizing smaller size trees, lopping and scattering piñon limbs to prevent slash buildup?
- Can harvest plans be outlined in steps to prevent desiccation of understory vegetation?
- Will slash placement provide erosion protection and increase organic soil content?
- Do piñon seedlings need protected with slash to enhance survival?
- Is protection from grazing for at least two grazing seasons possible?
- If fire is considered for management has nutrient depletion as a result of fire been considered? (Perry 1993)
- If fire is an appropriate tool to move us toward a desired condition, is herbaceous recovery sufficient to control erosion and survive the fire?
- Can fire prescriptions be followed while meeting other resource objectives? (Wright 1982)
- Are follow-up maintenance needs and funding planned?
- Are your monitoring goals purposeful and retrievable from a corporate data base? (Brady unpublished)
- Are provisions made to monitor, store, and retrieve understory vegetation changes?
- Are plans made to monitor key indicators of system health or sustainability at the broader scales?
- Considering everything contemplated are we sure we will do no harm?

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Woodland Inventory Procedures and Analyses Conducted for Management Planning Purposes on Indian Lands

John Waconda[1]

INTRODUCTION

The Bureau of Indian Affairs (B.I.A), Albuquerque Area Office (A.A.O.), Branch of Forestry maintains the responsibility of managing approximately 1.2 million acres of tribally owned woodland forest resources on twenty-four separate Indian reservations in Southern Colorado and New Mexico. Initiatives undertaken by Indian tribes and the B.I.A. in the 1980's spawned an increased awareness of Indian woodlands management culminating in a woodlands study report produced in 1988, and later led to special woodlands management funding beginning in 1989. Fortunately, Congressional woodland management funding has continued to be appropriated on a year-to-year basis since then. This special funding has been utilized to fund various types of woodland management projects nationwide including inventory data collection and inventory analyses.

The 1988 B.I.A. woodlands study addressed several deficiencies associated with tribal woodlands management, two specifically related to woodland resource inventories. The first was that specific volume information was lacking for all woodland types and ownerships; and secondly, substantial woodland acreages failed to be included in current forest management plans, and that harvesting and land management activities were generally done without silvicultural direction or environmental clearance (Bureau of Indian Affairs 1988).

Reasons for these deficiencies within the B.I.A. comparable to other land management agencies may be attributed to the lack of funding specifically earmarked for woodlands management due to past emphasis placed on commercial timber management. Traditionally the woodland resource was perceived of as having little if any commercial value and accordingly received minimal attention. Nevertheless, over the years public attitudes have changed and have resulted in transforming land management policies and practices; whereby the woodland ecosystem has received more attention ranging from preservation to increased development initiatives.

Regardless of management direction, sound inventory data is essential for determining forested areas, evaluating land productivity and forest health, estimating forest volumes, and to measure forest trends toward meeting desired management objectives. Inventory data collection and associated inventory analyses procedures are just two steps within the overall B.I.A. Forest Management Inventory and Management Planning initiative. Other steps include remote sensing, mapping, environmental analyses, and developing forest management plans.

Presently, the B.I.A - A.A.O. has completed inventory data collection procedures on thirteen reservations, and completed the associated inventory analyses for three of those reservations (fig. 1). Planned for execution within the next three years are an additional nine more reservation woodland inventories. To accomplish this task the A.A.O. has employed two full-time inventory foresters located at various field locations to conduct the inventory work on a projected schedule.

The purpose of this paper is to describe standard A.A.O. planning, implementation, and data analysis procedures used in previous woodland inventory projects. These procedures were developed to meet the needs of the B.I.A. as well as individual tribes, and may be unique depending on particular circumstances. Also addressed are several unusual situations encountered on these projects and the related project design modifications needed to deal with these special circumstances.

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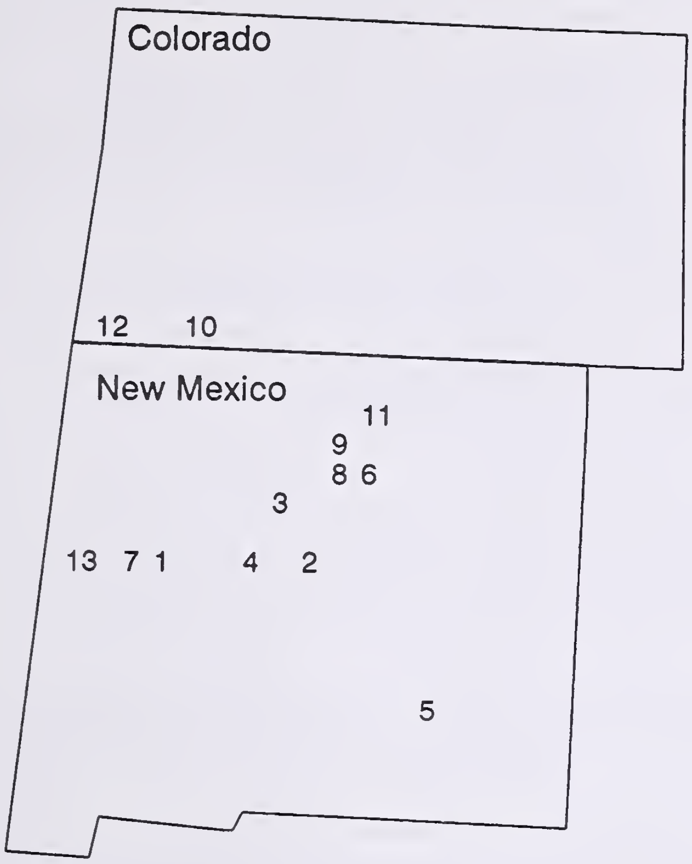

TRIBES WITH INVENTORY DATA COLLECTED

1. Acoma Pueblo
2. Isleta Pueblo
3. Jemez Pueblo
4. Laguna Pueblo
5. Mescalero Apache
6. Nambe Pueblo
7. Ramah Navajo
8. San Ildefonso Pueblo
9. Santa Clara Pueblo
10. Southern Ute
11. Taos Pueblo
12. Ute Mountian Ute
13. Zuni Pueblo

TRIBES WITH COMPLETED INVENTORY ANALYSES

4. Laguna Pueblo
6. Nambe Pueblo
10. Southern Ute

Figure 1.—Bureau of Indian Appairs, Albuquerque Area Office woodland inventory locations.

INVENTORY PLANNING AND DESIGN

To facilitate program definition and management priorities, the B.I.A. employs a national categorization system that prioritizes reservations and/or Indian properties based on current forest land data. Indian reservations/properties are classified into a five category system based on forest resource acreages and regional resource value standards (Table 1). This system is then used as a basis to determine the inventory design and minimum accuracy standards for a particular project. Although, due to the extreme forest resource variability among Indian nations within the B.I.A. jurisdiction, regional B.I.A. Area Directors may amend inventory standards to accommodate unique local situations. Presently, the A.A.O. has implemented and/or planned inventory projects on tribal lands classified as Category 1, 2, 3, and 4.

Planning

Planning cannot be over emphasized in the forest inventory process. Quite often, planning does not receive the consideration and time that it deserves; instead, efforts are sometimes focused on collecting field data and analytical phases of the project. When this happens, inventories can be inefficient and, in some cases may not serve management objectives. In the B.I.A. we are fortunate to have a more decentralized forest management system relative to the more familiar forest management agencies. Usually the B.I.A. foresters that plan an inventory are the same people who will implement it, and then analyze and use its data. Consequently, the B.I.A. Forest manager often assumes the role of the planner, data collector, and decision maker for the complete inventory and management planning process.

Table 1.–Bureau of Indian Affairs Reservation/Indian Property Forest Resource Categorization System.

Category	Forest Resource Description	Inventory Standards
1	Major Forested Reservation - Comprised of more than 100,000 acres of commercial timberland in trust, or more than 1.0 MMBM harvest of timber product annually.	Based on a 10 yr. reoccurring permanent plot inventory subject to an accuracy standard of 5% error at 1 standard deviation on both basal area and the primary unit of volume measurement used in the calculation of allowable cut.
2	Minor Forested Reservation – Comprised of less than 10,000 acres of commercial timberland in trust, and less than 1.0 MMBM harvest of timber products annually, or whose forest resource is determined by the Area Office to be of significant commercial timber value.	Based on a 10 yr. reoccurring temporary plot inventory supported by permanent growth plots, as deemed necessary, and subject to an accuracy standard of 10% error at 1 standard deviation for basal area and/or the primary unit of volume measurement used in the calculation of the allowable cut.
3	Significant Woodland Reservation – Comprised of an identifiable forest area of any size which is lacking a timberland component, and whose forest resource is determined by the Area Office to be of significant commercial woodland value.	Based on a 10 yr. reoccurring stand reconnaissance inventory, or as may be more restrictively defined by the Area Office. An inventory may be required more frequently due to the occurrence of environmental and/or developmental impacts.
4	Minimally Forested Reservation – Comprised of an identifiable forest area of any size determined by the Area Office to be of minor commercial value at this time.	Based on a 10 yr. reoccurring stand reconnaissance inventory, or as may be required more frequently do to the occurrence of environmental and/or developmental impacts.
5	Reservation or Indian property with forest land that the Bureau is charged with some degree of legal responsibility, but the land is not in trust status.	Based on Area Office determination.

A distinctive process to B.I.A. forest inventory planning is the inclusion of tribal participation. Tribes are encouraged to not only participate in the inventory planning initiative but, also in the entire forest management planning process. This is important because often times tribes may desire to make changes that will affect their commercial woodlands land base such as: establishing conditional or total woodland reserve areas, protect religious and cultural significant sites, construct housing developments, develop recreation areas, and maintain roadless areas, etc..

Cases of active tribal participation include working with tribes that are interested in developing or expanding woodland enterprises on their reservations. Inventory information for these tribes may be specialized to include information about the resources utilized in these enterprises. Many tribes may restrict harvests of live green trees and only allow tribal members to harvest dead and down material for fuelwood. Therefore, may request that the inventory include information on the availability and volume of dead sound fuelwood material. These are just a few examples of active tribal participation incorporated into the B.I.A. woodland inventory planning process.

The most important step in planning a new inventory, or in remeasuring an existing system, is to identify its objectives. The planner must first identify what forest resource information will be needed to effectively manage the woodland resource over a planned management period. In almost all instances, cost is of primary importance in planning B.I.A. woodland inventories. The objective is to obtain reliable estimates to a predetermined precision standard for the lowest possible expenditure. Once the needs and objectives for woodland management have been identified, the inventory then becomes a sampling problem.

Design

Standard woodland inventory project design planning includes three main steps: 1) obtaining necessary remote sensing imagery and related information; 2) preparing specialized forest maps or map overlays; and 3) selecting a sampling method and design that addresses data collection requirements.

On large timbered reservations, Continuous Forest Inventory (CFI) systems are used to provide the information needed to prepare and modify forest management plans. However, on reservations with lesser timber resources, inventories using temporary installed plots can be used and growth information is obtained from increment cores. Ordinarily, CFI systems are not used on these reservations due to the high cost of permanent plot installation, maintenance, and remeasurement in comparison with overall timber values and timber sale income. Planning for a one-time inventory using temporarily installed plots, is essentially the same as any inventory for management planning except a commitment does not have to be made for plot maintenance and remeasurement, this greatly reduces overall costs.

Within the A.A.O., woodland inventories have consisted of both CFI and temporary plot systems. As such, the designs have generally remained the same for either system, based on a systematic sampling method using fixed area plots established by developing a systematic grid. Grid size is usually based on specific forest acreages and the strata that will be inventoried. Commonly the standard grid system is developed using the Universal Transverse Mercator System (UTM) overlaid on the desired sampling strata, utilizing the most current USGS 1:24,000 scale, 7.5 minute quads as base maps.

Stratification is usually done using cover type maps delineated on the most recent aerial photography. However, B.I.A. woodland projects often lack this information due to the absence of previous forest management planning on woodland habitat. In most cases, accurate, current, and thorough reservation-wide woodland resource typing is limited and therefore, area stratification is often refined while the field inventory is implemented.

In cases where reservations may be lacking woodland resource typing data, woodland inventories are based on stratification done using existing forest resource data in the Geographic Information System (GIS). For example, commercial woodland stands may be determined using crown closure percentages or density classifications, a slope limitation factor, and its accessibility to an existing road system. This information may be available in the GIS, and not on aerial photos or cover type maps.

Essentially, the standard within the A.A.O. is to implement low cost inventory planning practices often using innovative design procedures while ensuring a quality product.

PLOT LAYOUT AND DATA COLLECTION

The current woodland inventory plot design used in A.A.O. projects is a single-unit, fixed area, circular plot (fig. 2). The plot contains two subdivisions superimposed within the major plot to collect additional selected data. Based on the typical woodland forest conditions a 1/20th acre major plot size has been determined to be the most effective. On this major plot, all timber species 5" DBH and greater and woodland species 3" DRC and greater are measured as well as mortality trees.

Minor plot 1 is composed of the northeast quadrant of the major plot (1/80th of an acre). In addition to the measurement procedures con-

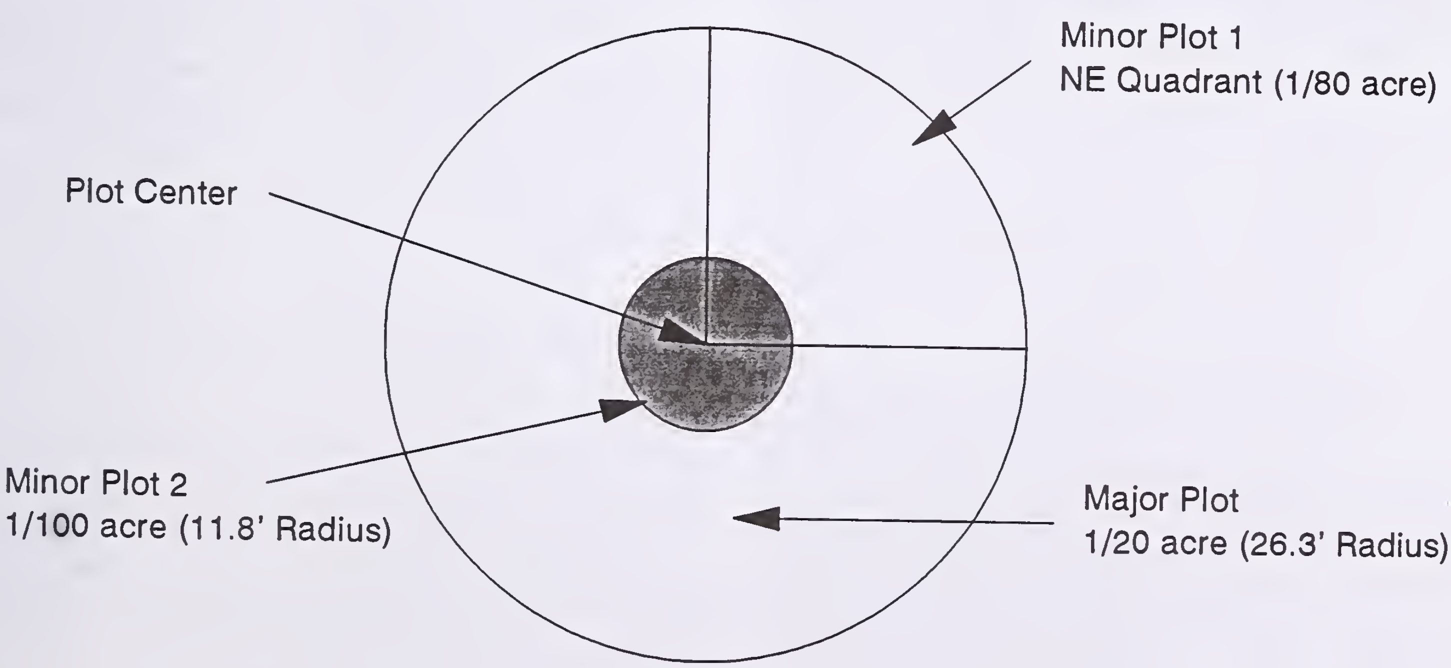

Figure 2.—Woodland inventory plot design.

ducted on the major plot, trees within this minor plot are bored to determine radial growth and age, with the exception of the junipers.

Minor plot 2 is circular in shape, 1/100th acre in size. This minor plot is superimposed over the major plot center. This is a regeneration plot in which timber tree species <5″ DBH and woodland species <3″ DRC are tallied.

For our inventories, establishing plot locations in the field is basically the same whether a temporary inventory and permanent inventory system is used, with only minor modifications between the two. In permanent inventories, a location header form is completed by the installation crew. This information will be used later to locate the plot when remeasurement is initiated. A procedure recently employed on permanent inventories in the Albuquerque Area is the use of a Global Positioning System (GPS) to document permanent plot locations. This information is then incorporated into the existing GIS data base for later referencing.

The inventory data collection system used by the A.A.O. is a modified version of the U.S. Forest Service, Region 3, Stage II Stand Exam. Modifications to this basic system were made to accurately measure woodland species and to obtain information as identified in the planning process.

After the permanent plot center is established and the perimeter of the plots identified on the ground, the marking of the tally trees begins. Each live woodland species tree larger than 3″ DRC on the plot is identified and tagged with an aluminum tag numbered sequentially in a clockwise direction from the north. The tag is secured to the base of the tree below stump height and facing the plot center. This point is used because accurate identification of the trees that may be harvested between measurements is important. An aluminum nail is driven into each measured tree ¼ inch below the point of DRC measurement. Since the nail marks the point for all future diameter measurements, it is important that it be positioned accurately.

Measuring woodland tree species is not as clearcut as measuring timber species. Junipers, piñons, and oaks in this region often grow with multi-stems and are extremely variable in form. Often special attention is necessary when determining accurate diameter measurement points due to butt swelling and stem forking. When stems are clumped together and appear to be from the same origin with a unified crown, they are treated as a single trees. Accordingly, an equivalent diameter at root collar (EDRC) must be calculated. The EDRC is equal to the square root of the sum of all qualifying squared stem diameters.

The apparent differences in form, growth, regeneration, causes of mortality, management objectives, and forest products between timber species and woodland species undoubtedly result in differences in inventory procedures. The following is a brief discussion related to some of the major factors that should be considered when conducting woodlands inventories; growth and tree form influence diameter measurements, determining what a stem is as opposed to a branch is subjective. Realistic guidelines must be developed to insure consistency in stem measurements. Form damage such as sweeps, crooks, severe lean, and forks are not recorded, due to the lack of effect on major woodland forest products. Although, tree heights must take into account common sweeps and horizontal growth.

Measuring accurate woodland growth is a difficult process, and may not be possible if relying on tree bore-backs exclusively. On A.A.O. woodland inventory projects, woodland growth is based on increment cores obtained solely from piñon trees for two reasons. First, junipers are free growers whose rings do not correspond to annual growth, especially in drought situations. Secondly, junipers are very difficult and almost impossible to bore because of its wood structure. In any case obtaining and reading increment cores from piñons are difficult and much more time consuming.

Consequently, current growth estimates are based on piñon growth rates that are applied to all woodland tree species. A more accurate estimate of forest growth can only be assessed after the next inventory measurement is conducted which will then appraise actual growth of all species.

Another important aspect in A.A.O. woodland inventories is the collection of mortality tree information, basically for fuelwood management purposes. On most Southwestern reservations wood is still the preferred cooking and heating source. Accordingly, fuelwood harvesting is an important forest activity for many tribal members, and on some reservations fuelwood enterprises have been developed creating a demand and income for woodcutters. Tribes have thus begun to recognize the importance of this resource and in response have initiated fuelwood harvesting policies and regulations. Some traditional tribal policies have included: restricting harvests to only tribal members, establishing limits on the amount of fuelwood that may be cut per household, and prohibiting the cutting of live green trees thus allowing only harvests of dead and down fuelwood.

Clearly with fuelwood collection being such an important aspect of tribal lifestyle, and with the Bureau being responsible for managing tribal woodlands under a sustained yield principle, fuelwood inventory data is extremely important and essential.

Mortality assessment includes determining if the tree has died in the last five years. Trees dead within the last five years usually still retain a majority of their branches and bark, and sometimes foliage. In addition, inventory crews informally determine in the field if a dead sound tree meets local fuelwood specifications related to its size and soundness. If the tree is suitable for fuelwood, diameter and length measurements are recorded to compute volumes, as well as percentage of bark remaining intact. This will give forest managers an estimate of current dead fuelwood available, while the next measurement will yield and accurate estimate of annual accumulation and projected use of dead fuelwood.

Woodland insect and disease problems are unique and often times are difficult to identify much less discern without training and experience. Mistletoes, *Arceuthobium divaricatum* on piñon and *Phoradendron juniperinun* on juniper are common, and in the case of the piñon variety, it is oftentimes difficult to detect. Interestingly, the mistletoe sometimes seems to transcend into a dormant stage or inactive period where the fruiting bodies disappear.

In the initial stages of conducting woodland inventories, A.A.O. foresters spent considerable time developing and refining standardized procedures. Since then an area-wide inventory handbook has been developed that outlines standard procedures. This has proven to be invaluable especially when training inventory personnel. Although standard procedures have been developed for B.I.A.- A.A.O. woodland inventories, it is safe to assume that modifications and fine-tuning may be necessary when initiating other projects.

CONCLUSION

Indian tribes in the Southwest have become increasingly interested in woodland resource management. Appropriately, the B.I.A. is responsible for implementing prudent forest management practices in accordance with state-of-the-art standards, while recognizing the unique character of Indian lands and incorporating tribal participation in the planning process. Assuring sustained yields of multi-use forest resources is also an important overriding management objective in the B.I.A.. Therefore, major emphasis is devoted to administering sound resource management planning.

An essential component of the planning process is a resource management inventory, whereby a determination within a reasonable degree of accuracy may be made of volumes, growth, condition, health, and forest trends. Inventory data will be analyzed, discussed, and presented in terms that can be incorporated into forest management plans.

Inventory analyses are crucial to the management planning process. The analysis report should describe the sampling method and procedures, describe current forest conditions, summarize stocking and growth information, include comparisons to previous inventories, analyze forest trends, and determine allowable harvesting levels.

Depending on forest resource acreages and values, the complexity of the inventory analyses differ. Reservations with vast forest resources will undoubtedly require an inventory analysis with a higher degree of intricacy. Another important factor is that tribal participation is essential during this step. Input from the tribe is required when final land classification procedures require designation of management units, and identifying culturally significant areas warranting special attention.

The goal is to have an inventory analysis that is useful for management planning purposes. Whether a particular tribes' desire is to preserve or develop its woodland resource, a thorough and complete inventory should provide the information to assist the tribe in making an educated decision.

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Watershed Restoration Through Integrated Resource Management on Public and Private Rangelands

Sid Goodloe[1]

Abstract.—Until recently much of the rangeland in the western United States was in a serious downward trend. Water quality and quantity were declining as the result of the continuous livestock grazing practices employed at the turn of the century followed by 80 years of fire suppression. Thirty-five years of integrated/holistic resource management at the Carrizo Valley Ranch site has reversed this trend. In addition to restoration of rangeland productivity, the riparian area on the ranch has been restored, wildlife populations enhanced and perennial streamflow restored. The practical experience gained at the ranch should be useful to private landowners, public land managers, and water quality agencies throughout the brittle ecosystems of the southwestern United States. Some of the techniques used at Carrizo Valley Ranch are being demonstrated on an adjacent watershed in the Smokey Bear Ranger District of the Lincoln National Forest.

BACKGROUND

The shortgrass rangelands found in the western United States are generally harsh ecosystems. Careful management of these areas is essential if they are to maintain sustained production or recover from past land management mistakes (Stoddart et al. 1975). Many watersheds in the west contribute massive loads of sediment washed from the land surface or scoured from eroding gullies and streambanks to the streams and rivers which drain them. The New Mexico Environment Department reports that 95% of the state's surface water is impacted by nonpoint source pollution (NMED 1990) and that turbidity is one of the major causes of use impairment in these waters (NMED 1988). Reports by early surveyors, naturalists and trappers detail the abundance of grass and clear, clean water found on these same watersheds (Leopold 1933/1991), a sharp contrast to the conditions seen today.

Many factors have contributed to the drastic changes that can be seen in the rangeland watersheds of the western United States, but most range management professionals agree that the heavy stocking rates and the continuous grazing practiced at the end of the 1800's followed by increasingly efficient fire suppression are the leading causes of these changes. H. L. Bently and E. O. Wooten, early agricultural agents in Texas and New Mexico, described the situation: "In a short time every acre of grass was stocked beyond its fullest capacity . . . The grasses were entirely consumed, the very roots were trampled into the dust and destroyed" (Bently 1898). "The stockman could not protect the range from himself, because any improvement of his range was only an inducement for someone else to bring stock in upon it; so he put the extra stock on himself" (Wooten 1908). As a result, native grasses were replaced by sagebrush, mesquite, juniper, and other invading brush species that were less suited for holding soil in place (Chaney et al. 1990) and which were more efficient at water extraction (Stoddart et al. 1975). Topsoil, which requires thousands of years to develop in harsh ecosystems washed away; gullies formed from unchecked, concentrated runoff; streambanks eroded and downcut; water tables lowered; and perennial streams became intermittent or dry (Chaney et al. 1990, Platts 1990).

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The ability of the land to recover from these effects has been greatly reduced because the entire ecosystem had been so radically altered. The harshness of the environment contributes to the difficulty in reestablishing the climax or the highest ecological condition of the range. As a result, simple manipulation of a single range management factor, such as reducing livestock numbers, is not sufficient to result in significant environmental improvement (DeBano and Schmidt 1989). These systems will take many years to recover by themselves. Direct actions aimed at total watershed rehabilitation and applied in a holistic and integrated system are necessary to ensure the restoration of western watersheds and associated natural resources of water, timber, grass, wildlife and fisheries (Platts 1990). This type of integrated or holistic resource management has been successfully demonstrated on the Carrizo Valley Ranch.

INTEGRATED RESOURCE MANAGEMENT ON PRIVATE LANDS

There are many definitions of Integrated/Holistic Resource Management (IRM), but I like to define it as the integration of all components, economic, human and environmental, into a synergistic, comprehensive plan that allows management for long-term sustainability rather than short-term production. This type of management is essential for protecting valuable natural resources found in our western watersheds and is also an essential management tool for protecting the entire planet. Considering the unlimited supply of examples of bad natural resource management in every state of the US and in every country in the world, it is clear that we are now charged with the responsibility of not only managing the resources under our jurisdiction in an integrated manner, but we must also inform politicians and populations everywhere that we are no longer in the pioneering/unplanned development mode. We have reached the point that resource interrelationships must be recognized and development planned accordingly. Pressing needs of growing populations must be met, but not at the expense of the ecosystem's sustainability.

INITIAL ACTIONS

My ranch is located in the South Central Mountains of New Mexico at about 7000 feet elevation. Average annual precipitation is about 46 cm (18 inches), one half of which falls as snow. The soils range from gravelly hillsides to clay and clay loam bottoms. Watercourses on the ranch were actively eroded and brush infestation flourishing when I purchased the property. My most demanding problem was the homogeneous vegetative composition and low herbage production. The major grass found was an almost pure, tightly packed turf of bluegramma that grew very little because of its sod-bound condition. A major portion of the ranch had scattered to thick stands of piñon-juniper that were even-aged populations. Areas between the trees as well as directly under the canopy were bare and subject to erosion.

I began to study the origination of this eroded, brush-infested condition. I realized that year-long grazing and brush infestation were severely limiting herbage production. My initial strategies were 1) to divide the ranch into summer and winter pastures so I could at least reserve some winter grazing and 2) to begin a systematic brush control program. Although these changes were beneficial, it was not until I spent time in Rhodesia (Zimbabwe) in 1964 that I experienced first hand and began to understand the principles of Short Duration Grazing in action and the dynamics of an open savannah ecosystem. I recorded my findings in a paper published in the November 1969 issue of the *Journal of Range Management*, returned to my ranch, and, after some very low budget fencing, put these principles into practice.

ROTATIONAL GRAZING SYSTEM

I divided large paddocks into much smaller ones using posts cut on the ranch to support a three-wire suspension fence. Paddock division was planned according to topography, existing fences and available water—not in the wagon wheel or grazing cell pattern often advocated. Once the rotation had become established, the cattle practically moved themselves—anticipating paddock changes. I found that graze and rest periods could be adjusted to fit the current precipitation and season of use. I also found that as the vegetative growth rate increases, so should the frequency of rotation and that rotation during the dormant season was not necessary. My initial goal now became "to produce the maximum pounds of marketable beef per hectare while improving range condition." This naive, but commendable, goal was economically impractical in a period of low beef prices, so I needed to find other profitable uses of available resources.

ADDITIONAL INCOME SOURCE

Fee hunting of deer and turkey became a significant income producer immediately after I built a cabin to facilitate game harvest. As a result, improved wildlife habitat and overall aesthetic quality became my secondary goal.

RETURN TO CLIMAX CONDITION AS THE PRIMARY GOAL

The pieces of the puzzle then began to fall into place. I realized that if fish and beaver appeared on the 600-year-old Indian petroglyphs on my place, there certainly must have been running streams where I now found only arroyos with steep banks and dry rocky bottoms. I researched 100-year-old surveyor's notes that described the terrain as an open savannah rather than an almost solid canopy of invading brush species. I realized that the invading brush, made possible by year-round grazing and 80 years of total fire suppression, was not only removing most of the moisture from the soil, but was also shutting down herbage growth, thereby causing sheet and gully erosion. I recognized that although I had previously discounted a return to climax or near-climax condition, I might be able to make economic sense out of that approach if it became my primary goal. I visualized the open savannah as it was over 100 years ago, with mixed conifers on the north slopes and the highly productive riparian areas that made up the mosaic of the Carrizo Valley.

BRUSH MANAGEMENT AND WATERSHED STABILIZATION

I then began to implement a cautious return to climax in a manner that was economically justifiable in my situation. Mechanical removal of invading piñon-juniper in an area that requires 10 to 15 hectares per animal unit could not be justified because costs were higher than land values. However, some mechanical brush control in the better soil types was required, as was erosion control (i.e., reseeding, pushing invading brush into active gullies and building water retention dams). It was necessary to finance this using other available resources.

Selective thinning of young invaders, followed by prescribed burning and reseeding with native grass species became the major thrust of the plan to return to a climax ecosystem. The by-products—fence posts, fuel wood, vigas, trees for landscaping, and Christmas trees—financed the plan. Another beneficial by-product was the increase in mule deer population, not only because of habitat improvement, but because ponderosa pine vigas must be cut and peeled during the winter months. This provided an adequate supply of green browse (tree tops) throughout the winter, resulting in a significant (30 to 50%) increase in the fawn crop. The open savannah created contains 500 to 800 year old juniper trees, scattered ponderosa pines, and is carpeted with a mix of warm and cool season grasses and forbs. I have found that because deer and turkey evolved under this type of ecosystem, they seem to prefer it to the contiguous, brush-infested public land. This is what I call an "eco-recreation benefit." These factors sharply increased income from hunting and paid for more of the necessary mechanical rehabilitation work.

THE ROLE OF FIRE

The long sought after open savannah is now well established in the Carrizo Valley, but it must be maintained with periodic fire, as it was in the climax. Tree ring research in New Mexico indicates that most forest areas burned, on the average, at 7 to 10 year intervals (Stoddart et al. 1975) before fire suppression began. The key to the successful maintenance burn is the fuel load (as well as the climatic conditions, of course). There must be enough herbaceous material to carry a fire which is hot enough to kill brush but cool enough not to damage the beneficial species. The damaging fires in Yellowstone a few years ago demonstrated that the no-burn policy, which originated in the ecologically different European forests, was an incorrect choice for western watersheds. Now after many years of fire suppression, similar fuel loading is evident throughout the Western United States, which makes the initial prescribed burn risky, to say the least.

LIVESTOCK SUITED TO THEIR ENVIRONMENT

The pivotal economic component of my operation is the production of weaner calves, both for breeding and beef. Low-input, sustained production is my goal and is achieved by using an animal that is fine tuned to the environment and that produces a desirable, marketable product. The hostile factors in our environment are snow, cold, wind and dry weather. A cow that can produce under these conditions must be, first of all, fertile in that environment. She should be black so that wind and snow will not cause or aggravate pink eye and cancer eye. Black, of course, absorbs as much sparse winter sunlight as is possible and black udders do not blister in spring snow storms. The animal that fulfills all these requirements is a composite breed that I have developed through 20 years of selective breeding called the Alpine Black—three-quarters Angus and one-quarter beef-type Brown Swiss. Just as the Zebu composites fit the Gulf Coast and southern deserts, the Alpine Black fits the western mountains of Northern America.

TANGIBLE BENEFITS

The road back to climax has revealed many changes in 30 years. Water sources that were dry now have permanent running water and lush riparian areas. Grass production has increased dramatically and provided more carrying capacity. Alpine black cattle are in sync with their environment and their habitat has improved as well. Recreation potential is greatly enhanced due to a more pleasing aesthetic atmosphere and larger wildlife populations.

APPLICABILITY OF CASE STUDY RESULTS TO WESTERN WATERSHEDS

The piñon-juniper (PJ) complex comprises more than 63 million acres of the rangeland in the southwest. This ecotype is a critical component of the arid region. Piñon and juniper generally form the intermediary boundary between the flatter grassland type climax community found on the lower slopes and the conifer forest climax community of the mountain tops. Considerable debate regarding the density of the PJ canopy in climax conditions has hindered some watershed restoration efforts. Most range conservationists agree, however, that much of the PJ found on the lower slopes has escaped it's original range and modified some of the original savannah type ecosystem to a more woodland type. Originally the PJ occupied a discrete ecotone in many watersheds, but lack of fire and overuse by livestock have left these once stable areas in poor condition. Many, however, have a high potential for range improvement and revegetation. In areas where the PJ complex is in especially poor condition, range improvement can substantially reduce the erosion and sedimentation originating from these degraded areas (Stoddart et al. 1975). Some of the most informed members of the environmental community support restoration of western watersheds, but question the removal of piñon and juniper vegetation from those areas where the species are in the climax community. As opposed to brush removal and range reseeding on areas historically known or reasoned to be grassland, brush removal on certain areas can have the potential to increase sedimentation and erosion rather than decrease it. Information gained from the Carrizo Valley Ranch can be useful to managers needing to determine if brush management efforts can be reasonably and safely completed and a sustainable system established.

Riparian areas and the water they surround are of especial consequence in arid ecosystems. These areas constitute only about 2% of the total western acreage, yet they are among the most productive and valuable lands. DeBano and Schmidt (1989) have described the relationship of upland watershed condition to riparian condition and found, not surprisingly, a direct correlation between degraded upland watershed condition and degraded riparian area condition. They concluded that adequate treatment of all critical areas in the upper watershed is necessary to provide a stable and sustainable riparian area and is critical when attempting any riparian restoration project. On Carrizo Valley Ranch, we completed most of the upper watershed work (stabilizing gullies, removing invading brush, and revegetating bare ground) before being able to maintain a stable riparian area. Chaney and his coworkers (1990) and Platts (1990) found that maintenance of riparian areas, once restored, requires a different grazing strategy than upland sites. Although I have done some riparian corridor fencing which works to protect the riparian area from livestock access, I have demonstrated that as long as the principle of limited and managed access is applied, fencing is not always a required component. The key to the effective riparian protection demonstrated at Carrizo Valley Ranch is protection during the growing season if possible and rapid rotation when not.

ECOSYSTEM MANAGEMENT ON PUBLIC LANDS - CARRIZO DEMONSTRATION AREA

The watershed above the Carrizo Valley Ranch is part of the Smokey Bear Ranger District of the Lincoln National Forest. In 1989 the USFS began a watershed restoration and demonstration project on 55,000 acres of National Forest and private land as part of its ecological approach to multiple-use management of the PJ ecosystem. The project area contains large expanses of continuous canopy piñon-juniper that prior to the introduction of livestock in the 1800's and subsequent fire suppression supported a wide variety of native grass plants. As the range degraded, trees out-competed grass for available moisture and soon much of the productive soil beneath these dense woodland stands eroded away, leaving behind an extensive and active gully system that continues to transport silt-laden water into streams and rivers (Edwards, 1990). With the urging of private land owners, who for years had to contend with the deposition of millions of tons of sediment that originated on National Forest land and who had demonstrated that complete watershed rehabilitation was not possible on their private landholdings, a unique, cooperative, watershed-based project was begun. The project focuses on soil stabilization practices, vegetation management, water resource development, vehicular travel management and sound grazing management practices. The project's goals include control of soil erosion, stabilization of steep gully slopes, restoration of permanent riparian vegetation and the rehabilitation of native rangelands to support a sustainable mix of native grass and woody plants.

As the result of treatments begun in 1989, cool season native species of grass and forbs long absent from the National Forest have returned; in several drainages, springs have begun to flow again; and a wide variety of upland and riparian wildlife species have returned to the area to make use of the increased edge areas, water supplies and additional food sources. On private lands adjacent to the forest, benefits have also been reported. In one area, 4,800 cubic yards of sediment from gully and sheet erosion originating on National Forest land were cleaned out of a pond. The following spring, after implementation of watershed restoration treatments on the forest, a spring which had not run for 50 years began to flow and continued to flow throughout the summer, filling the pond with clear water. The pond has now been stocked with trout and catfish.

SUMMARY

Integrated resource management is the professional vernacular describing what managers do who are in tune with efficient, sustained use of the resources that are their responsibility. If the use of one resource affects the health or production of another adversely, then the whole is diminished and economic and environmental costs are guaranteed to surface somewhere, sometime. Common sense and vision provide the foundation for bringing all parts of the whole together into a comprehensive management plan. Interestingly enough, as are many things in life, it is elusive because it is so simple. And yet, if we intend long term survival, we must implement this approach in every phase of Natural Resource Management. As watershed restoration and rehabilitation work continues, it is important to understand that there will never be sufficient government resources to treat every problem in every area. Thus, success lies in demonstrating techniques such as those developed on Carrizo Valley Ranch which provide internal and self-sustaining motivation for adoption on both private and public lands.

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"Can't We All Just Get Along"

Jon S. Bumstead[1]

During the past several years I've worked for the Forest Service in many different jobs: as a Forest Planner, University Liaison, Regional Social Science Coordinator, and as a University Liaison for Land Management Planning. Currently I am working on the Eastside Ecosystem Management Project as the co-lead of the social science staff on the Science Integration Team. This team is assessing the ecological health of the Interior and Upper Columbia River Basin.

Lately, there is some debate among science team members questioning "whom we can do science with," and who can be legitimately involved in this learning/scientific process. I won't go into that discussion now, but it's something to consider while reading this article.

In the midst of these Forest Service experiences, and during the time of "New Perspectives," I became a realtor and spent many of my off hours moonlighting for a successful real estate company. While working in Flagstaff, I went to night school and obtained a Master's Degree in Applied Sociology. I think each of these experiences has given me some unique insights that I would like to share.

Like most insights, this one begins with a story. One evening about three years ago, in a class on the development and structure of sociological theory, I stumbled across a sociological proposition by Dr. Max Weber, one of the founding fathers of social theory. His proposition was, "The more a political authority loses prestige in the external system, the less able it is to remain legitimate." (Zeitlin, 1990).

I looked at this statement (which is about equivalent, in sociological terms, to a mathematician saying 2 + 2 = 4), and asked myself if the Forest Service was approaching the point where we would be organized out of existence. Later, in a New Perspectives session in Denver, I was exposed to the work of Dr. Julia Wondolleck, from the University of Michigan. In her book, "Public Lands Conflict and Resolution, 1988," she explained how our management paradigm and training experiences were focused on a set of values to which the organization steadfastly clings, while American social values have shifted to a less utilitarian view. Is she right? If so, our organization has been bypassed by a change in basic values. Have we shifted our views enough in the past years to regain our legitimacy?

A class I took in the development of social theory through qualitative analysis again focused my attention on our operational culture. In this class I learned to observe and record qualitative data. While collecting data, I observed that the organization was putting out a lot of messages about "customer service." At the same time, in my personal interactions with a variety of people at all organizational levels, I kept encountering actions that I felt were more self-serving than customer oriented. I kept asking myself why this was happening, despite our good intentions.

Finally, as I worked throughout the region in my University Liaison position, I hit on what I believe is the core element that keeps us all from achieving some really worthwhile work. It is the failure to communicate effectively both internally and externally. This is probably no surprise but it really is a central, recurring problem. Poor communication continually leads to breakdowns in achievement of reasonable solutions to continuing problems and opportunities. I recognize that we all are aware of how difficult it is to communicate effectively. What I have to offer may be new to some of you, and may even turn some of you off. However, if you reflect on my opening questions regarding who it is appropriate to, "do science with," I'll ask you now considering applying some science taken from salespeople. What I have to offer today is a selling process that I learned about while I was moonlighting as a realtor. I believe there is much in this process from which we can benefit. The essence of the process is honesty, careful listening, and the ability to articulate that you understand how another person feels.

Before I describe this process, I would like show you some results from a social survey project I helped construct with the Apache-Sitgreaves National Forest and the Sociology Department at Northern Arizona University.

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The management team on the Apache/ Sitgreaves National Forest recognized the importance of understanding people's FEELINGS as a crucial first step in resolving management issues. They asked myself and members of the sociology staff at Northern Arizona University (NAU) to work with them in the construction and analysis of a survey to determine how employees and Forest users felt about the Apache Sitgreaves National Forest timber management program. In my opinion, a lot of Forest Service officials fail to recognize the importance of addressing feelings. We tend to just want the "facts." While the gathering of factual data is an integral part of forest management, the importance of addressing people's feelings and perceptions cannot be ignored (Figure 1).

As we worked with the forest staff, we found that some of us were, unintentionally, trying to construct questions that explained the Forest Service perspective of each question. Dr. Fernandez, a sociology professor from NAU, finally got it through to us that we should seek other people's opinions and perspectives; not explain our own views. Thus, the final questions in the survey were very direct, brief, and nearly free of Forest Service interpretations. I want to show you some of the results, in case you think we've moved past the time of internal and external conflict (Figures 2, 3, 4, 5).

We could look at the internal split of opinion and hope it was a sign of organizational balance and health. I want you all to understand, however, that while I was a University Liaison I had people from a variety of ranger districts, national forests, and from within the regional office talk to me in emotionally ridden terms about the "gridlock" and inability of interdisciplinary teams to work together effectively. Further, one of the questions we are currently asking on the Columbia River Basin assessment, asks people whether they trust our agencies' motives and ability to implement ecosystem management. With about 50% of the survey responses in, we find that only 30% of the National sample has moderate or a great deal of trust in the Forest Service. Western Washington and Oregon are at 31%. People living in the Columbia River Basin, currently, are responding at a rate of 33% with moderate or a great deal of trust. Another sample is of people who have been directly involved and are on our mailing list (over 2000), they have 41% who trust in our abilities to implement ecosystem management but only 29% who have a moderate or great deal of trust in our motives. A previous rangeland reform survey conducted by Dr. Brent Steel from Washington State University found similar responses in a National survey... 32%. If you bat 300 in baseball you are doing pretty good. Does a 30% degree of trust meet our expectations for ourselves?

Figure 1.—Dealing it... rather than dealing WITH it.

I believe that a first step for each of us is to improve our communication skills before we will start to see an upward movement in public trust. With the above demonstrations that a problem does exist, I ask you to consider if there is anything we can learn from the following sales process I learned while moonlighting.

The selling process I was taught to use as a realtor is found in the book "The Best Seller" by Ron Willingham (1984, Prentice Hall). My broker, who had thousands of books in his home, said, "Jon, you only need to read one book on selling and here it is." Willingham's book is rooted in the need to be completely honest, always. Never, *never* do anything that moves you off that center. A second foundation is to find out what the customer needs and wants. Your beliefs and values do not enter the picture until you truly understand the desires and perspective of the customer.

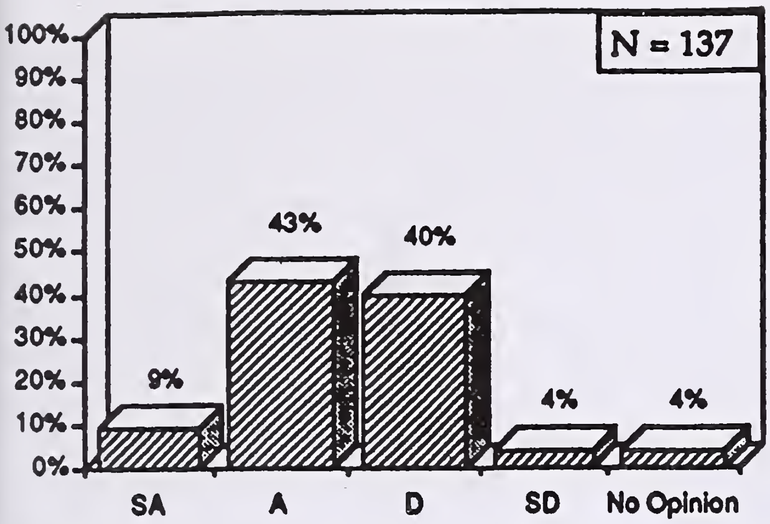

Figure 2.—Forest Service employees only: Statement — The Forest Service is doing a good job of managing ecosystems.

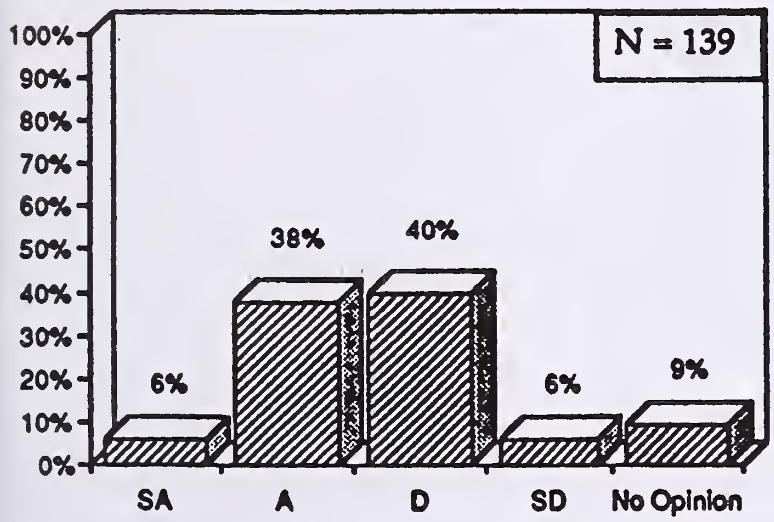

Figure 3.—Forest Service employees only: Statement — When timber harvesting is in conflict with recreation activities, priority should be given to recreation activities.

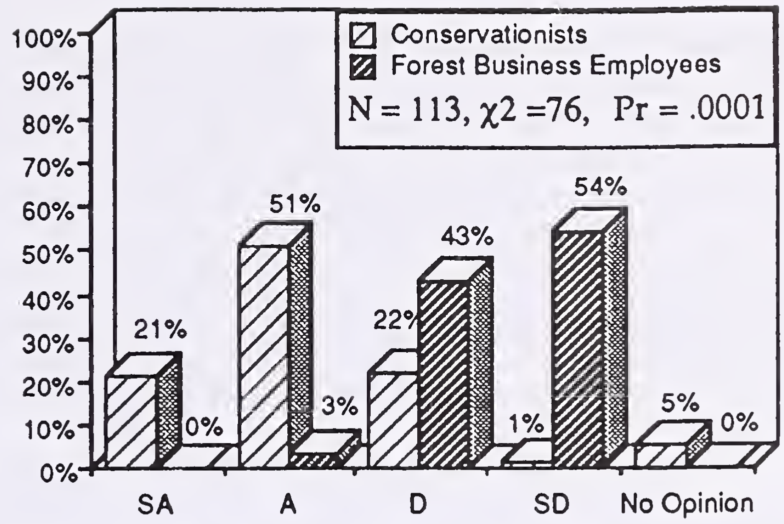

Figure 4.—Conservationists and Forest business employee comparisons: Statement — Recreation activities on the forests contribute more to economic stability than do timber harvest activities.

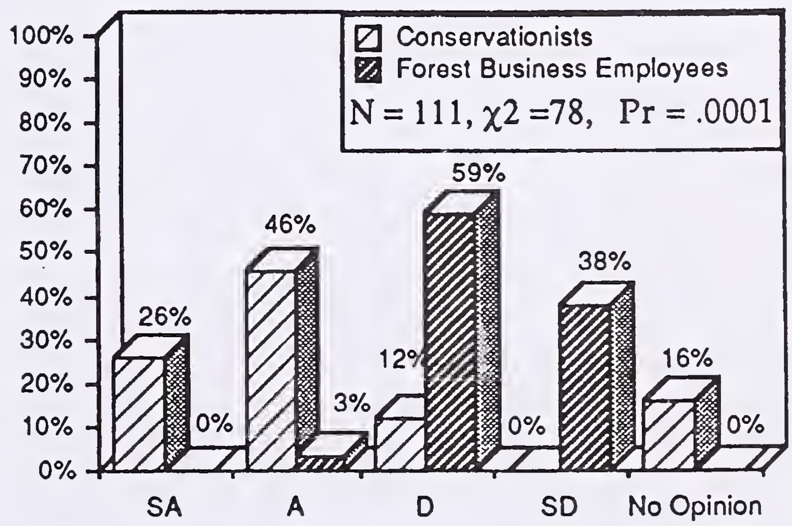

Figure 5.—Conservationists and Forest business employee comparisons: Statement — When timber harvest is in conflict with recreation activities, priority should be given to recreation activities.

While I was forest planner on the Santa Fe National Forest, we frequently planned a conflict resolution strategy prior to appeals negotiations. We would meet before negotiations to determine "our" position and bottom line. In other words, we walked into conflict resolution focused on where we would draw the line in the sand. How open do you think we were to any new ideas? Of course, the appellants were doing the same thing. That was our basic approach to conflict resolution a few years ago: Determine Position—Go Negotiate.

In contrast, the sales approach I was taught had these steps:

A. Approach
I. Interview
D. Demonstrate

I. Validate*
N. Negotiate
C. Close

*The "I" in validate is saying that, "I will take the time to understand and validate your concern from your perspective." I still try to apply in my daily work activities.

In Willingham's process, negotiation is the next to the last step. In the appeals process we often opened with negotiation discussions. There was hardly a breath of "Hi, how are you" prior to starting negotiation. In Willingham's process, a lot of foundation work precedes the negotiation step. During the Approach and Interview steps we were taught to "tune yourself out and tune your customer in." The most important job of successful sales people, according to Willingham, is to listen, listen, listen!

The process has a variety of application techniques for each phase in the sales process. For instance the acronym "F.O.R.M." was used in the Approach phase. The letters stand for **F**amily, **O**ccupation, **R**ecreation, and **M**essage. Most people like to talk about one of these things, and, if you listen carefully, you'll pick up messages from them about what they value most. This process emphasizes the importance of getting to know your clients on a personal basis. I think this relates closely to what the early district rangers excelled in... "Spittin' and Whittling." Maybe we should think more about going back to the old method. It pays! The positive side of taking the time to get to know each other on a personal basis is extremely important.

In the book, Willingham talks about a sales person so committed to the Approach that he would decline trying to potential customers if he was unable to build a good rapport at the outset. He simply felt people would never buy from him, if he was unable to build an immediate relationship that "felt" right. During the transition from Approach to the Interview phase we were expected to gain a clear understanding of customers needs, desires, and lifestyle priorities. The ability to tune your own values and preferences out is extremely difficult. Try it! Only your customer's perspective is important during these first phases..

I'll skip to the Validation process next, as I feel this is the area where we could all make the biggest strides in learning to communicate effectively. Willingham insists that it is not enough to just repeat back what you've heard the customer say. Many of our communication classes suggest we paraphrase the words we have heard from someone else to demonstrate that we have indeed "heard" them. While that is better than just interrupting and stating your opinion, it falls short from Willingham's perspective. He recommends that you personally step in their shoes and validate why their concerns are valid, from ***their*** perspective. You can't do this unless you have a clear understanding of their views and can articulate to them that you understand their perspective, ***not yours***! You should relate their concern to a similar experience you have had with the technique of "Feel, Felt, Found." It goes like this: "I see how you feel about A, B, C. I felt that way too about D, E, F (your similar experience); Here's what I found about D, E, F.

By the way, my broker had a Doctorate degree in psychology, and had been a professor at the University of Oklahoma for several years. His brother worked for him as a sales representative and held a Master's degree in sociology. The brother, Dave, used this sales process to perfection. As I watched him work, you could see that he was always totally engaged with his customers. If you watched him for 20-30 minutes he might be in a speaking mode for only five of those minutes. The rest of the time he listened to his customers. He had a knack for keeping dialogue open and flowing. About every week you could count on Dave closing another contract.

Some of you may have concerns about this process being used to manipulate people. I know I did. I said to my broker, "Jeez, you guys are dangerous!" The broker believed that you couldn't use this process to trick people. He felt that if you tried any of these techniques with anything but complete sincerity and honesty, your customers would read that insincerity and be gone in a minute. Further, he stated that by law we were required to reveal everything we knew about a home. Keeping your opinions and feelings out of discussions in the beginning doesn't mean you give up stating your opinion during the negotiation and final stages of the sale. Your willingness to learn about and understand your customer's perspective goes a long way towards building trust. Further, it will make the customer more receptive to your views as you enter the negotiation and closing phases of this process. As he went on, my broker explained how important it is to all of us to know that we have been heard and understood. As I have reflected on this process recently, and done some objective/scientific observations around our work areas, I find that we all (me too!) are so eager to tell people what we think and feel, that we often don't listen carefully enough to gain an understanding of the other person's perspective.

Back to the process, once you've moved through these first four phases of the sales process, it is time to enter into negotiations and, finally, come to a sales agreement. In three years of real estate sales I successfully utilized this process only twice (I made other sales, but none felt as good as these two). I am too eager to insert my own opinion and talk about myself, and I'm not alone in this weakness. While I was a University Liaison traveling throughout the region, I observed frequent failures to achieve complete communication. This was occurring at all levels within the organization. Specifically, the lack of the ability to listen to the point of true understanding was preventing us from doing, or becoming, all that we could and should be.

So what can we do? First, we need to bolster our education and training in the human dimension fields, especially vital communication skills. In the long-term, we should continually work at staying involved with citizen groups all throughout the year, not just for the length of each individual project. I know the Prescott National Forest has been actively working on this for several years.

Short term recommendations include allowing ample time in our planning processes for meaningful relationship building both within and without the organization. You can't expect to throw a bunch of people in a room and have them automatically function like a team. It takes time!

Finally, I think each of us needs to identify and work on our own communication shortcomings. Personally, I noticed that "yeah, but" was maybe the single greatest stopper of effective communication in our organization. It's everywhere! Listen, you'll see. I used to be one of the greatest users of "yeah but." To the best of my knowledge, I have stopped myself from using this phrase. I may still interrupt, but I won't do it with "yeah but."

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WE'RE ALL IN THIS TOGETHER, SO WHAT COMMUNICATION IMPROVEMENTS CAN *YOU* MAKE?

Responding to Tribal Voices in Managing Woodland Resources

Ronald K. Miller[1]

Abstract.—Native American peoples and tribes have utilized and depended on woodland resources for a wide variety of practical and ceremonial uses for centuries. Often, deeply rooted traditional value systems are associated with uses or methods of harvest of the resource. The Bureau of Indian Affairs, Division of Forestry, has responded to tribal concerns about woodland ecosystems and is currently seeking to manage these forests in a sustainable, multi-disciplinary manner guided by tribal culture and tradition. Specific woodland areas are currently being managed for the production of fuelwood, posts and poles, piñon nuts, furniture wood, and even for traditional wood and herbs used in cremation rites. Nonconsumptive uses include woodland areas set aside for religious activities such as ceremonial dances or the planting of prayer sticks, or areas set aside for wildlife habitat or scenic beauty.

"Every spring our spiritual elders bless the everlasting prosperity of the pine nuts. The annual Walker River Paiute Pine Nut Festival honors the traditional fall pine nut gathering. Piñon pitch is used to seal our baskets and start campfires. Piñon wood warms our household during the cold winter months. Piñon pine is essential to the lifestyle and cultural preservation of the Washoe, Northern Paiute, and Shoshone tribes."

—Ben Rupert, Washoe/Northern Paiute

"I think, due to past piñon-juniper management practices (chaining projects), some woodlands are depleted of plants, animals, and birds so vital to Hopi spiritual ceremonies."

—Bruce Koyiyumptewa, Hopi

"Clearly, the piñon-juniper areas represent a major potential resource for the Pueblos. With unemployment rates exceeding 50% on some Pueblos, the Bureau needs to focus on programs which have the greatest economic potential for the Pueblo people."

—Alvino Lucero, Isleta

"The management of our woodlands provide benefits directly and indirectly to tribal members. Directly, by heating our homes, cooking our food, and by providing income through the sale of firewood. Indirectly, through improved wildlife habitat, healthier woodlands through the control of disease and insects, and improved grazing areas.

—Lyman Clayton, San Carlos Apache

[1] *Woodland Forester, Bureau of Indian Affairs, Phoenix Area Office.*

INTRODUCTION

Native American peoples and tribes have utilized and depended on woodland resources for a wide variety of practical and ceremonial uses for centuries. More importantly, perhaps, most Southwestern tribes have **lived** in the piñon-juniper ecosystem for centuries. Given that long-term association, the connections between tribes and the resource are often very strong, with deeply rooted traditional value systems associated with uses or methods of harvest of the resource. A natural resource professional working with a tribe must understand the cultural connections to the resource just as he or she must understand the silvics and ecology of the woodland species being managed. One must also understand that tribal cultures differ and what is acceptable to one tribe is not necessarily acceptable to another tribe.

The quotes prefacing this paper are from members of four different Southwestern tribes. They touch on the importance of the piñon-juniper ecosystem to tribal people whether that value relates to cultural, spiritual, economic, aesthetic, medicinal, or subsistence issues. Most likely, the relationship with the resource is a combination of all of the above. Often the resource and the culture are so intertwined that the various components cannot be separated. Indeed, the Native American world view tends to look at things holistically, rather than as individual components.

Tribal relationships with piñon-juniper resources have existed for centuries and current literature and ethnobotanical studies expound on these age-old ties (Ackerly 1991, Koyiyumptewa 1993, Miller and Albert 1993, Watahomigie et al. 1982). The Hualapai have even published a beautiful, full-color, 20-page booklet in their own language that discusses their relationship with piñon (Watahomigie et al. 1983). The booklet is entitled *Ko*, the Hualapai name for piñon.

The importance of piñon-juniper woodlands is magnified by their sheer abundance in the Southwest. Arizona's woodland area of 14.3 million acres, for instance, is more than 2-1/2 times that of timberlands (Conner et al. 1990), while Nevada's woodland (9 million acres) represents almost 12 times that of Nevada's timberlands (Born et al. 1992). Here in Arizona, Indian tribes own 35% of the woodland, making tribes the largest woodland ownership class in the state. Current estimates of Indian-owned woodland in Arizona range from 5.0 million acres (Conner et al. 1990) to 5.6 million acres (Bureau of Indian Affairs 1988).

PAST WOODLAND MANAGEMENT

Although the resource is so large, the potential so great, and the cultural ties so deep, integrated management and full consideration of piñon-juniper woodlands is still in its infancy.

In the past, woodlands were either ignored, or worse, a war was waged against them in the form of chaining, cabling, pushing, burning, tree crushing, grubbing, chopping, and herbiciding. Anything, to get rid of those short, scrubby trees.[2] In Arizona alone, nearly one million acres of piñon-juniper woodland were cleared between 1950 and 1959 (Arnold et al. 1964). Another 300,000 acres were cleared between 1960 and 1985 just on Forest Service lands in Arizona and New Mexico (Dalen and Snyder 1987). The Bureau of Land Management (BLM) was busy as well, chaining half a million acres of piñon-juniper in the West between 1960 and 1972, 61,000 acres of which were in Arizona (Aro 1975). As stated by former Forest Service Southwest Regional Forester, William Hurst (1977), "Perhaps no vegetative type (P-J) has given man so much and been so harshly treated and neglected."

The Bureau of Indian Affairs (BIA) was not immune to the management strategies of the day. In some places the techniques were different but the intent was the same. On the Hualapai Indian Reservation in northwest Arizona, nearly 22,000 acres of piñon-juniper were burned between 1953 and 1963 for conversion purposes (Despain 1987). Meanwhile, on the Fort Apache Reservation, tribal members were kept busy with hand axes clearing 95,000 acres of piñon-juniper by 1958 (Arnold et al. 1964).

Chaining also occurred on many southwestern Indian reservations. This is especially ironic since piñon-juniper woodlands contain such an abundance of archaeological sites, and chaining proved so destructive to these valuable, nonrenewable resources (DeBloois et al. 1975). Irreplaceable tribal history and culture were destroyed in the name of range improvement. McNichols (1987) traced the evolution of P-J management on the Hualapai Reservation from no management, to an emphasis on removal or eradication, and finally to a strategy of multiple use and sustained yield. It took an active intervention by tribes themselves, however, to generate the support necessary to establish a national woodlands program.

[2]The reason given for all this activity was, of course, "range improvement". However, many of the clearing projects, along with the reasons given for them, are seriously questioned by such notable authorities as Dr. Ronald Lanner and Dr. Elbert Little among others (Lanner 1981, 1993; Little 1991, 1993).

BACKGROUND

On April 15, 1987, Alvino Lucero, Vice President of the Isleta Pueblo Tribal Council, testified before the Bureau of Indian Affairs Agriculture - Range Programs Committee. He presented a strong case detailing the importance of the piñon-juniper woodland resource to the Pueblo people. Primarily focusing on the economic potential of the resource, he stated:

> *"Most of our forests in terms of acreage and wood volumes consist of piñon-juniper trees as opposed to commercial species such as ponderosa pine. For example, the four Pueblos of Acoma, Isleta, Jemez and Zia have an annual allowable cut of ponderosa pine of about 2 million board feet. This represents combined potential revenues of $20,000 per year. In contrast, these same Pueblos could harvest approximately 1,560 cords of piñon-juniper per year. Based on $100 per cord, this would bring in gross revenues of $156,000 each year. Clearly, the Piñon-Juniper areas represent a major potential resource for the Pueblos. With unemployment rates exceeding 50% on some Pueblos, the Bureau needs to focus on programs which have the greatest economic potential for the Pueblo people."*[3]

The following month, the Southern Pueblos Governors Council wrote a letter to the Assistant Secretary - Indian Affairs on behalf of the nine Southern Pueblos in New Mexico. The Assistant Secretary was asked to expand the BIA's focus and work to include management of woodland resources.

Within three months, on August 10, 1987, a directive was sent from the Assistant Secretary to all Area Offices. The policy direction was clearly stated:

> *"Recent shifts in the economy have stimulated considerable interest by tribal leaders in the development of their woodland resources. This is primarily the result of opportunities which now exist for the sustained harvest of marketable forest products, particularly those associated with the Pinyon-Juniper woodlands of the west. Management of this resource is best provided under the direction of the Bureau's Forestry Program, as the dominant woodland values are relative to the culturing and utilization of true tree species, and as co-management principles, as well as multiple-use practices, are currently stressed nationwide by the program.*
>
> *You shall therefore adjust your programs accordingly and insure that all future resource management plans and plan revisions include the addition of woodland management responsibilities to the Forestry Program. Arrangements should be made to provide assistance and oversight on these wooded reservations to meet the needs of the Indian owners."*

Several key points stand out in this directive. First, there was a recognition of tribal interest in woodland management. Second, woodland management was moved under the direction of the forestry program where the value of trees was more likely to be recognized and the resource managed in a multi-disiplinary manner. Third, the resource was to be actively managed and considered in forest planning activities, rather than ignored as had often happened in the past. Finally, the focus of this planning and management was to meet the needs of the Indian owners. Recognizing that tribal goals and objectives for their woodland resources vary across the country, the Assistant Secretary provided latitude to respond to tribal direction in the management and oversight of woodland resources. This directive now guides woodland management on Indian reservations throughout the United States.

A few years later (1990), Public Law 101-630, the National Indian Forest Resources Management Act, became law. This legislation further cemented woodland's status by mandating proper planning and management of all Indian forest land. "Indian Forest Land" was specifically defined in the law to include both woodlands and timberlands.

WOODLAND FUNDING AND RECOGNITION

Congress appropriated the first woodland program dollars ($500,000) to the BIA in fiscal year 1990, thanks in large part to continued lobbying efforts by the Intertribal Timber Council and individual Indian people.

It is interesting to note that in 1990 the Director of the BLM signed an initiative called "Forests: Our

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[3] Timber prices in the Southwest have greatly increased since this testimony was given. Nonetheless, the Pueblo's point about the need to focus on their predominant resource remains valid.

Growing Legacy," giving woodland under their jurisdiction the same status and policy guidance as other forest land; and in 1992, Region 3 of the Forest Service issued their Piñon-Juniper Initiative, also bringing woodland management into the limelight. Larry Henson (1993), the Southwest Regional Forester at the time, later publicly stated that the Forest Service "must improve piñon-juniper woodland management in the Southwest while recognizing the inherent values, including cultural values, of the piñon-juniper ecosystem."

It is encouraging that the major land managing agencies are recognizing woodland's importance and are moving toward proper management of the same. It is also interesting to note that Mr. Henson pointed out the cultural connection inherent with woodlands.

MANAGING WOODLANDS TO MEET TRIBAL NEEDS AND DESIRES

Woodland ecosystems, given their long association with people, need to be managed considering the human component rather than considering man as an outside force. Archaeologists Cartledge and Propper (1993) state that in order to understand piñon-juniper ecosystems today, it is crucial to understand what those ecosystems were like in the past and what forces, including human beings, affected them. They continue, "Piñon-juniper woodlands did not exist in a pristine unaltered condition prior to the arrival of Europeans. Human beings have made extensive, and in some cases intensive, use of piñon-juniper woodland resources for thousands of years."

Given that use, the key is to manage the woodland ecosystem in an integrated manner so that the resource is sustained even while it provides for the people dependent on that ecosystem. Even though the BIA's constituency (tribes and tribal members) is much more well defined than the Forest Service or the BLM constituencies, tribes also respond differently with requests for woodland funding and assistance. For example, the White Mountain Apaches have used woodland funding to open a wood yard on their reservation, but are reluctant to cut green piñon or juniper. Instead, dry Gambel oak (*Quercus gambelli*) currently makes up most of the fuelwood volume. On the other hand, their neighbors to the south, the San Carlos Apaches, recently harvested 840 cords of green alligator juniper (*Juniperus deppeana*) for sale through their tribal wood yard. Other Southwestern tribes are not interested in cutting any cordwood for resale to outside markets. The point is, tribes are given the latitude to customize woodland projects to fit local needs, desires, and traditions.

Nonconsumptive uses of woodland areas are just as important to tribes as consumptive uses. Nonconsumptive uses include areas set aside for religious activities such as ceremonial dances (Utes) or planting prayer feathers (Zunis), or woodland areas set aside for wildlife habitat (Apaches) or scenic beauty (Navajos). The widespread practice of gathering piñon nuts—nonconsumptive, at least as far as the tree is concerned—also fits into this category. The vast majority of Southwestern tribes depend on piñon nut harvesting for traditional food or economic purposes. Although tribal members from many tribes do not sell piñon nuts as a matter of principle, Tanner and Grieser (1993) estimate that over 90% of the commercial piñon nut crop is harvested by Native Americans—a crop estimated by Evans (1988) to be 1-2 million pounds of nuts per year.

Due to cultural and tribal differences, woodland project proposals requiring BIA funding must contain a signed tribal resolution to ensure tribal support and involvement. Proposals springing from the tribes have a much greater chance of success and allow diversity in management approaches.

Value-added processes or those that provide tribal employment are also looked at favorably when determining which projects should receive funding. The Zuni Furniture Enterprise is a perfect example of a tribal business that utilizes woodland resources and produces beautiful, value-added products while providing tribal income and employment. The considerable artistic talents of the Zunis play a major part in making the furniture enterprise a success.

Four examples of diverse tribal approaches to woodland management and use from within the jurisdiction of the BIA's Phoenix Area Office follow.

Hopi Reservation - Arizona Integrated Woodland Management Plan

The Bureau of Indian Affairs is currently working with the Hopi Tribe to develop a comprehensive, integrated woodland management plan for the tribe's 197,028 acres of piñon-juniper woodland. One of the first steps in the planning process involved a two-page questionnaire designed to poll tribal members about their priorities for tribal woodland areas. The questionnaire was hand-carried to all of the Hopi villages by tribal members to encourage maximum participation. Responses from 226 households were gathered. Tribal members were asked about their personal uses of the woodland areas, and what they thought the Tribe's management objectives for different woodland areas should be. Respondents indicated that the top three management priorities for woodland areas should be for fuelwood production, cultural/religious needs, and water production. There is a strong desire to protect the woodland resource, but an equally strong desire not to infringe on tribal members' rights to utilize the woodland resources for ceremonial and subsistence purposes. "Religion cannot be regulated" was often heard during scoping sessions. The management plan will try to synthesize necessary human use requirements into an integrated management scheme that fully considers wildlife, watershed and soil protection, aesthetics, recreation, and range concerns.

Uintah and Ouray (U&O) Ute Reservation - Utah
Woodland Demonstration Blocks

Six 2.5-acre woodland demonstration blocks were set up this year within a *Pinus edulis/Artemisia tridentata* (PIED/ARTR) habitat type on the U&O Ute Reservation. Tree species present in the blocks are Colorado piñon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*). The blocks demonstrate different silvicultural prescriptions such as shelterwood, group selection, a piñon nut orchard and a control block. Two other blocks show individual tree selection prescriptions with residual basal areas of 40 and 70 square feet per acre, respectively. Fuelwood and fenceposts generated by the project will be transported to the tribal wood yard, processed, and sold. Slash will be lopped and scattered to control erosion and to provide favorably microsite conditions for grass, forbs and seedling regeneration.

The entire area is to be fenced and signed after harvest. Plans also call for two additional blocks to be surveyed outside the fence. One of the blocks outside the fence will be a second control block to monitor any changes the fence itself causes, and one block will be installed in an adjacent area that burned in 1989. Installation of range and wildlife transects is included in the monitoring efforts. The blocks will provide a visual demonstration to the Tribal Council and tribal members and allow for local monitoring of changes resulting from silvicultural manipulation of the stands. Local site data gathered on this project will be useful in future decisions guiding proper management of the woodland resource.

Washoe Pine Nut Allotments - Nevada
Piñon Nut Production

The Pine Nut Allotments in western Nevada's Pine Nut Mountains were reserved specifically for the Washoe people under the authority of the 1887 Dawes Act. Currently, there are over 66,000 acres in individual 160-acre parcels that belong to specific Indian owners rather than to a tribal entity. The allotments contain stands of singleleaf piñon (*Pinus monophylla*) with a smaller component of Utah juniper (*Juniperus osteosperma*). Problems associated with the stands include trespass cutting of live trees, a minor outbreak of *Ips* bark beetles (*Ips confusus*) and some dwarf mistletoe (*Aeuthobium dwaricatum*). This area provides a perfect opportunity to use good silviculture to protect the health and vigor of a resource that is culturally important. Treatments are planned which are designed to increase nut production and the vigor of the residual stand while reducing the incidence of dwarf mistletoe. Harvesting must be timed in late fall or early winter so as not to increase the potential for a large *Ips* outbreak. Allottees provide the specific goals and objectives or desired future condition for their allotment, while resource professionals help them achieve those goals through sound forest practices.

Colorado River Indian Reservation - Arizona and California
Woodland Inventory to Guarantee Sustainability of Cultural Resource

The Colorado River Indian Reservation encompasses 269,921 acres in Arizona and California bisected by the Colorado River. Tribal membership includes 3,057 people. This reservation is outside the range of piñon-juniper, but contains honey mesquite (*Prosopis glandulosa*) woodland.

Many of the original stands of mesquite on the Reservation became depleted due to overharvesting, changes in groundwater and flooding, and conversion of natural vegetation to farmland. The Colorado River Indian Tribe became concerned that the resource might not be able to meet traditional cultural needs and, therefore, placed a six month moratorium on mesquite wood cutting and land conversion. The cultural need, in this particular case, was for the use of mesquite logs and arrowweed (*Tessaria sericea*) in funeral pyres for traditional Mohave cremations. Log lengths, diameters, and volume requirements of the mesquite are specific depending on whether the deceased member was an adult or a child. Given guidelines laid out by the Tribe, the University of Arizona's Office of Arid Lands Studies conducted a woodland inventory and issued a final report (Nabhan et al. 1985). Researchers had to match tribal death rates by size of the individual with woodland volume, growth data, and size of the trees. Although the subject is not a pleasant one to contemplate, the study was essential to Mohave tribal members who justifiably maintain that they must be guaranteed sufficient, sustainable quantities of mesquite and arrowweed for their funeral rites. As a result of the study, two large areas containing sufficient mesquite to meet the Mohave's future needs have been reserved along the banks of the Colorado River.

CONCLUSION

Hopi's integrated woodland management plan, the Ute's woodland study blocks, stand improvements designed to increase the Washoe's piñon nut crop, and the study to ensure a sustainable supply of mesquite for the Mohaves provide examples of managing woodlands to meet tribal needs and desires.

The BIA's woodland program sprang directly from tribal concern and involvement. Tribes requested that woodlands be fully considered and properly managed rather than ignored or eradicated as often happened in the past. Tribes prefer a holistic approach to woodland management, taking into account the human element and cultural and spiritual requirements. However, tribes are also unique, with their own histories, languages, cultures, and religious beliefs. The BIA does not try to standardize woodland programs. Instead, diversity and unique tribal approaches within the guidelines of sound forestry practices are encouraged.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the people of the Pueblo of Zuni. Living and working for four years with the Tribe was instrumental in shaping my own appreciation for the piñon-juniper woodlands of the Southwest. Special thanks to the folks who spent time giving me personal insights into their tribal culture and beliefs.

Appreciation is also extended to Lucille Watahomigie of Hualapai who sent me two of her beautifully done books: *Ethnobotany of the Hualapai* and *Ko* (piñon).

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The Capulin Piñon-Juniper Ecosystem Management Project
The Archaeological and Ecological Components

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Abstract.—The 1993 Capulin Piñon-Juniper Ecosystem Management Project is the culmination of a truly interdisciplinary planning process involving all resource disciplines and local community interests. Site selection incorporated range condition and management, vegetation composition and structure, soil and hydrologic conditions, and accessibility by the public. The stabilization of significant prehistoric Gallina archaeological sites was incorporated into the management prescription. The primary objectives were to improve watershed condition, improve the biological and structural diversity of the Piñon-Juniper Woodland, provide a sustainable nut crop and fuelwood for the local community, and to stabilize Heritage Resource sites.

The Piñon-Juniper ecosystems of the Southwest are now, and have been in the past a major source of agricultural land, food crops, fuelwood, forage for livestock, and building materials. This unique blend of natural resources and climate has favored human settlement. Many of the dwellings constructed by Native Americans prior to European influences were located in these ecosystems; present-day villages and pueblos in Northern New Mexico often occupy the same areas. As a result some, if not most, of these areas have a long history of use spanning thousands of years (Cartledge and Proper 1993). Historic sites include homesteads, agricultural fields, and mine sites. Prehistoric sites can include pit house, lithic and sherd scatters, and agricultural garden systems.

The demands for water, forage, and other resources continued into this century with an emphasis on livestock grazing and fuelwood production. At the turn of the century Pinion-Juniper was heavily harvested in the Jemez Mountains to provide fuelwood for the railroads used to transport timber. In the 1950's and 1960's, hundreds of thousands of acres of Piñon-Juniper were converted to grassland via chaining or dozer pushes. The grazing pressure in the first half of this century (Burkhardt and Tisdale 1976), combined with subtle climate shifts and drought (Betancourt et. al. 1993), and the lack of natural fires (Miller and Wigand 1994) have altered the conditions of these ecosystems. Many of the landforms that now support Piñon-Juniper ecosystems have higher than normal tree densities, closed canopies, and oppressed understories. The soil erosion exceeds long term rates (Pitlick, Wilcox and Allen 1994). Today, accelerated erosion over large areas exceeds rates that threaten site productivity (TES 1991). In some cases, well advanced gully and sheet erosion is causing increased mortality of long-lived species through exposure of root systems. The stability of archaeological sites associated with these ecosystems is often threatened. Today some of these areas continue to experience unauthorized fuelwood harvest, and uncontrolled livestock grazing which frequently exacerbates these existing conditions.

The need to improve the management and conditions of these ecosystems is often obvious, but it is very complex. Managing these resources for sustainability, biological diversity, watershed in-

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tegrity, and wildlife habitat while preserving the values and heritage of Native Americans and others who use these resources is a very difficult task.

The Capulin Piñon-Juniper Ecosystem Management Project is a significantly new approach to managing the Piñon-Juniper resources for the Coyote Ranger District on the Santa Fe National Forest. The project is unique in several ways. The planning process and management initiatives were developed using the concepts found within the Piñon-Juniper Initiative (USDA Forest Service Region 3), encompassing the needs of the public and traditional ways of life, while restoring sustainable ecosystem function. An ecological approach was employed to develop the desired future conditions of the area. Biological, ecological, edaphic, and archaeological information from the project area were used. This information indicated the conditions of the stand prior to the turn of the century. The age class and structural diversity of the overstory, understory composition and expression, soil productivity and conditions, and the past uses of the area were employed in order to determine the conditions of the stand prior to European effluences. The desired future conditions were generated from this information and were utilized to develop management strategies for the stand. The Heritage Resources of the area were viewed as a component of the ecosystem. Instead of identifying and avoiding the Heritage Resources, their conditions were incorporated into the planning. Management objectives were to provide fuelwood to the communities of Gallina, Coyote, and Regina, New Mexico while improving biological diversity, providing for improved soil stability, long term productivity, and overstory structural and species diversity.

SITE SELECTION

The potential natural vegetation, present vegetation composition, soils, climate, accessibility by the public, fuelwood volume, livestock management, and site conditions were used when selecting the project area. The Piñon-Juniper on the Santa Fe National Forest ranges in species dominance and understory composition along a climate gradient. At the cooler moister end of the climate gradient, at higher elevations, Piñon-Juniper is often co-dominant with Ponderosa Pine. Juniper Savannas, with little or no piñon in composition, occur on the warmer and drier areas at lower elevations. We sought to maximize the potential vegetative response by locating the project in an area on the cooler, moister end of the climate gradient. The moister end of the climate gradient is more likely to have annual rainfall patterns and precipitation which will support a positive vegetative response and seedling establishment when compared to the more xeric conditions at the lower elevations.

The Santa Fe National Forest contains Piñon-Juniper which is in relatively good condition, as well as areas which have been severely affected by past use and the subsequent erosion and/or higher than normal tree densities. Areas in good condition often have multiple-aged overstories with uneven distribution across the landscape. The canopy of the overstory often contains large masted Piñon and Juniper trees with canopy closures of less than 15 percent. The Piñon-Juniper stands in the best conditions have standing dead and fallen trees with an abundant herbaceous understory composed of native perennial grasses and forbs. In these conditions, it may only require the reintroduction of fire to maintain these systems. On the other hand we have Piñon-Juniper ecosystems that are severely eroded. In these areas the soils have often been truncated by sheet or gully erosion that has resulted in increased mortality of the overstory due to exposed root systems and a loss of the herbaceous understory. A third condition exists: areas with good vegetative composition and site productivity which are experiencing tree encroachment and accelerated soil erosion. These ecosystems have yet to cross the "threshold" of stability and sustainability where the system will quickly unravel. It was these systems "at risk" that we sought for the project area.

One of the primary objectives of the project was to provide fuelwood to the residents of Coyote, Gallina, Regina, and Youngsville, New Mexico. This necessitated choosing an area of sufficient volume of cord wood for a public fuelwood harvest, where public access could be controlled with existing fencing. It was also critical that the selected area had controlled livestock grazing with good compliance from the permittees. This was necessary if we were to achieve a favorable and sustained improvement in the herbaceous understory.

The area selected had to contain a mix of perennial warm and cool season grasses and forbs which would respond favorably to the treatment and an overstory with a multiple age class distribution which had canopy closures sufficient to suppress the expression of the understory. We wanted a site which was experiencing accelerated erosion (gully and sheet/rill erosion). The erosion patterns had to be treatable and not sufficiently advanced to have totally truncated the soils (having a total loss of the surface horizons), or gullies which had reached the top of the drainage basins or had down-cut to bedrock.

In short, we sought to treat an area that was at risk of loosing its soil productivity to erosion, was sufficiently productive to have a positive response to the treatment, and contained all the necessary pieces (biotic and abiotic) necessary for establishing the desired future conditions. It was also critical that slash treatment provided for improved effective ground cover, and a suitable micro-environment conducive for release and establishment of the herbaceous understory.

PROJECT AREA

The project location is in a Piñon-Juniper woodland adjacent to the village of Gallina, New Mexico. The area is approximately 7400 feet in elevation on a hill side slope with very shallow to moderately steep slopes. The area is located adjacent to the Capulin Creek which is a perennial tributary to the Gallina River. The area is composed of a mature multi-aged Piñon-Juniper woodland with an understory of Gamble Oak, Big Sagebrush, and native perennial grasses. The *Terrestrial Ecosystem Survey (TES) for the Santa Fe National Forest* describes the soils of the area as Typic Haplustalfs, fine loamy, mixed, mesic; moderately deep and deep sandy loams. These soils support a potential natural vegetation of *Pinus edulis, Juniperus monosperma, Quercus gambelii, and Artemisia tridentata spp. tridentata* (TES LSC4+1). The area is on the cooler moister end of the climate gradient that supports Piñon-Juniper ecosystems. Understory species present in composition included *Agropyron smithii, Muhlenburgia montana, Koeleria macrantha, Sporobolus contractus, Schizachyrium scoparius, Bouteloua gracilis, Oryzopsis hymenoides, Sitanion hystrix,* and *Blepharoneuron tricholpis.* Trace amounts of *Bromus tectorum* are present on the more disturbed sites within the planning area. Big sagebrush is present throughout and varies in expression depending on the canopy closure of the overstory. The overstory is composed predominantly of *Pinus edulis* and *Juniperus monosperma* with lesser components of *Juniperus scopulorum* and *Juniperus osteosperma.* Trace amounts of *Pinus ponderosa,* and *Pseudotsuga menziesii* are present in topographic positions on the landform.

The geology of the area is composed of the upper shale member of the Chinle Formation and localized terrace and pediment deposits. The dominant erosion processes are sheet and rill erosion which have resulted in pedistalled plants and debris dams. Well developed shallow gully networks were often associated with archaeological sites. Many of the gullies were threatening the stability of pithouses and other heritage resources. Many had reached the top of the basins in which they were migrating. Secondary headcut development was observed in existing gully networks. The overstory varied in canopy closure from between 60 and 85 percent. Small areas of even-aged mature Piñon-Juniper with canopy closures of 50 to 70 percent were present. The understory expression was severely limited by the closed canopies or erosion processes. Herbaceous canopy cover ranged from 4 to 16 percent. Bare soil was less than 25 percent within the closed canopy areas due to the heavy needle cast; however, where the canopy was less dense due to unauthorized fuelwood harvest, the presence of archaeological sites, and/or roading, bare soil was as high as 60 percent.

In the past, areas with high densities of heritage resource sites were avoided for fuelwood sales. On the Coyote Ranger District, high densities of prehistoric sites are very common and are almost always present within the Piñon-Juniper ecosystems. Although for this project we did not seek an area of high site density, we did recognize that wherever we planned treatments in the Piñon-Juniper ecosystem, Heritage Resources will be present. By bringing archaeological sites into the management prescription, we were able to treat the area on a landform basis, and provide for long term protection of the Heritage Resource sites.

THE HERITAGE RESOURCE COMPONENT

The Capulin Piñon-Juniper ecosystem management project is located in a region dense with Gallina culture settlements dating from 1059 A.D. to 1300 A.D. Much of what has been variously called the Gallina Phase (Hibben 1938), Largo Phase (Mera 1935), or Largo-Gallina Phase culture is located in the Coyote Ranger District of the Santa Fe National Forest. The Rosa Phase (ca. 700 to 850 A.D.) of the Gobernador Canyon and Navajo Reservoir area (San Juan River) appears to be the most likely ancestor to the Gallina settlements, although the temporal hiatus between 850 A.D. and the beginning of the Gallina phase (1059 A.D.) has not yet been explained.

The settlements of the Gallina make up the majority of the Heritage Resource sites located within the Capulin Piñon-Juniper Ecosystem Project Area. Six centuries have passed since these people abandoned their villages, yet their pithouses remain, as well as significant amounts of cultural materials. Ceramics, lithics, remnants of wooden stockades and stone towers, storage bins, hatch covers, clay elbow pipes, pointed-bottom pots (unique to the southwest), tri-notched axes, worked antler, and comb arrow polishers are some of the structures and materials which remain.

The Heritage Resource survey which was completed in July of 1993 located twenty-one archaeological sites within the 160-acre project area (Yates 1993). Eight sites are Gallina pithouse clusters, twelve are sherd and lithic scatters, and one site included both a lithic scatter and the remnants of the USFS Capulin Ranger Station (ca. 1912-1932). Gallina pithouses are subterranean dwellings, measuring between 7.5 meters and 13.5 meters in diameter and approximately four meters deep. Two of the twelve pithouses in the area have a surface storage structure attached. The cultural materials located during the survey included ceramics (Gallina black/white and grey ware), lithics (projectile points; primary, secondary, tertiary flakes; cores; and BR/M flakes), hatch covers used for Gallina storage bins, flagstone, and sandstone and basalt grinding stones.

Their agricultural systems could be quite well developed and are, culturally, very significant. Within the Coyote Ranger District, there are a number of Gallina agricultural features: terraced gardens, grid gardens, and reservoirs. In the Rincon Colorado area along the mesas of the Gallina River, each dwelling structure is associated with an area of terraced gardens. On Mesa Golondrina, high above the junction of the Chama and Gallina Rivers, a Gallina settlement called "Castles" includes pithouses, a pueblo-like structure, surface houses, and a possible tower. On the lower mesa of Golondrina, there are terraced gardens and an ancient reservoir (Douglas 1917 and Dick 1976). At Rattlesnake Ridge in the Cuba District of the Santa Fe National Forest (both Rattlesnake and Castles are listed on the National Register), an ancient Gallina Reservoir (at Bg 20/2) is estimated by Turney (1985) to have held more than 29,000 gallons of water, enough water to supply 1.75 gallons/day to 150 people for 45 days without replenishment (see also, Perret 1976).

Yet, despite the significance of the Gallina culture, only a small number of Gallina agricultural features have been studied. Few of their dwellings have been excavated. Of those which have been excavated, many were found to have been burned (Mackey and Green 1979). Charred remains of individuals were present within the structures. At Rattlesnake Ridge during a pithouse excavation, ten adult skeletons were found in a pile and each skull had pre-mortem fractures. Four of the skeletons had projectile points embedded, and there was some evidence of cut marks in the bone. This kind of evidence suggests some form of internal or external strife.

Much about the Gallina people remains a mystery, making the preservation of all Gallina Heritage Resource sites extremely important. The origin of the culture is not completely understood, nor is its demise. We do not know where they disappeared to or if they were, indeed, overrun by an incoming people. No one knows with what modern-day peoples they are culturally affiliated. None of the modern pueblos along the Rio Grande claim the Gallina as their ancestors. Nor do we know the specific ways in which an agricultural technology (probably brought from Mesa Verde or the San Juan River) was adapted to the higher elevations and differing climatic conditions of this region west of the Chama River and north of the San Pedro Mountains.

The Coyote Ranger District has the immense task of managing and protecting the remnants of a culture which has not yet been adequately researched or understood. Yet, some of the earliest archaeological research on the Gallina culture was based on excavation and survey work conducted within what is now the Coyote District's Capulin Piñon-Juniper Ecosystem Management project. Much of the research for H. P. Mera's article in *American Antiquity* called "Some Aspects of the Largo-Gallina Phase, Northern New Mexico" was compiled during the 1934-35 season when his team excavated a pithouse (LA 641) located in one of the three pithouse clusters within the Capulin project area (Mera 1938). The excavated pithouse with its subterranean hearth, deflector, ventilator shaft and storage bins dates to 1106 A.D. From the Mera excavation we know that over nine hundred years ago, ancient people established villages in the Piñon-Juniper woodland along the Rio Capulin and were utilizing its resources.

For over 10,000 years, human beings have been part of the Piñon-Juniper story. These woodlands contain the highest densities of Heritage Resources found anywhere in the Southwest (Cartledge and Propper 1993). Coprolite analysis has shown that the piñon nut was second only to corn as a food source (Aasen 1984). The Piñon-Juniper woodland contains a tremendous variety of foods: yucca, oak, rice grass, prickly pear, and juniper are some of these. Within the piñon-juniper woodlands of Black Mesa (Arizona), thirty-four useful plant species occur: twelve are food sources, four are medicinal, and eleven are used as raw materials (from Cartledge and Propper 1993, based on Gumerman 1984).

Within the Capulin ecosystem management project, thirteen of the Heritage Resource sites are tool maintenance and reduction areas, containing thousands of flaked artifacts, the remnants of the stone toolmaking process which in the upper Chama River region and eastern Jemez Mountains dates to the Paleo-Indian period (pre-5000 B.C.). During the project Heritage Resource survey, an Archaic component to the Capulin Piñon-Juniper woodland was documented when an En Medio-Parallel projectile point (1000 B.C. to 200 A.D.) was located (Yates 1993).

Today, the southeastern corner of the Capulin Ecosystem Management Project area is only a few hundred yards from the Hispanic village of Gallina and its elementary and high schools. For decades the present-day local communities have been using the area for fuelwood cutting and piñon nut gathering, much as the Gallina people almost ten centuries ago, utilized and eventually, possibly, depleted its resources. By considering the ancient human dimension, we can understand how these woodlands have come to be as they are. They are "not pristine and unmodified" (see Cartledge and Propper 1993). Archaeological research which includes paleoenvironmental, faunal and floral research can tell us much about the effects past cultures have had on the health of the Piñon-Juniper woodland. This, in turn, can help us make choices when managing the Piñon-Juniper woodland for the benefit of present-day communities.

The high use of the Piñon-Juniper woodland in the distant past and its usefulness now makes the management of these areas a challenging, if not an immensely complex task. The 160 acres of Piñon-Juniper woodland along the Rio Capulin selected for this ecosystem project exhibits the elements which make Piñon-Juniper management difficult if not daunting (high density heritage site distribution in an area which supplies local communities fuelwood and grazing land). Continuous use over many thousands of years has promoted erosional patterns which threaten both the heritage resources and the production of important natural resources upon which local people depend. At the onset of this project, soils in the area were disappearing, piñon root structures had been exposed, in some areas grass production was non-existent, and gully washes one and a half meters deep existed within eight meters of Gallina pithouse settlements.

The routine avoidance of the twenty-one heritage resource sites within the Capulin project area would not have helped preserve them. In fact, without the mitigating treatments used in the Coyote ecosystem Piñon-Juniper project, two of the pithouses and several of the lithic scatters in the area eventually would have been lost. Roads which traverse pithouses, used for years for piñon cutting, had caused continuous damage. As part of the Capulin project, the use of all roads through the area has now been controlled. The Heritage Resource sites have been seeded, grass production has been improved, and gully washes within sites have been stabilized.

The primary objectives of the Capulin ecosystem management project were to improve the size and age class diversity of the stand, improve soil and watershed conditions, and to protect and stabilize Heritage Resource sites from further degradation due to erosion. A fuelwood sale was administered during which the public was not allowed to cut within the heritage sites. However, the New Mexico State Historic Preservation Officer approved the stabilization plan with a provision which allowed Forest Service personnel to cut within the sites and spread the slash.

The stipulations detailed in the Heritage Resource clearance report were stringent and, in some cases, unique to different sites (Yates 1993). The slash cut from trees within the sites would be distributed in such a way as to stop or, at least, slow sheet and gully erosion and to encourage seedling development. All slash would be lifted and not dragged into place. Cordwood would be carried outside the boundaries of the sites. The sites would be cordoned off with bright yellow flagging; no vehicular traffic was allowed, public or Forest Service. The archaeological sites would be broadcast seeded by hand.

RESULTS

The desired future conditions of the areas were to move the vegetative structure and composition back to a more open uneven-aged Piñon-Juniper Woodland favoring the masted healthy crowned nut producing trees. The spacing on the leave trees was determined by intensive field reconnaissance. Initially the spacing was to be between 80 and 100 feet on the mature masted trees with smaller diameter trees interspersed between. During field reconnaissance it was determined that the favored leave trees (the healthiest and largest as evidenced by their size and canopy condition) were on a spacing of between 40 and 60 feet. Intermediate size trees greater than four inches in diameter were marked as leave trees to provide for an uneven-aged stand.

The vegetative treatments were performed via a tightly administered public fuelwood harvest. The area was cruised to establish "woodlots" with a volume of two cords. Fifty (two cord) fuelwood permits were offered to local residents on a first come, first serve basis. Woodlots were allocated by a lottery. Permit requirements involved felling trees except for those marked as leave trees, utilization of coarse woody material down to a two inch diameter, lopping slash to a height of eighteen inches, and scattering slash to achieve an even distribution. Treatment of the Heritage Sites was performed by all of the District resource areas through a District Work day. Soil protection was achieved by prohibiting fuelwood harvest when soils were wet (soil moisture greater than 25 percent of field capacity), locating vehicle access routes on the contour, and restricting vehicle access to slopes less than twenty percent. The project was implemented in September, 1993.

Monitoring the changes in ground cover (vegetation, bare soil, litter) and vegetative responses was performed by a stratified random sampling of the ground cover components by pace transect, by permanent photo points with a known azimuth, and by qualitative ocular estimates. Approximately 25 acres were treated including 6 to 7 acres of Heritage Resource sites. The immediate result was a decrease in bare soil from 21 percent to 11 percent for those areas with canopy closures greater than 60 percent prior to treatment. In the more open canopy areas bare soil was reduced from approximately 60 percent to less than 30 percent. Overstory canopy cover was reduced to less than 15 percent. Defined gullies within the treated area were stabilized using brush and debris dams and scattered slash. Sediment catchment was observed behind debris dams and behind slash.

Several days after treatment, a rainfall of light intensity and moderate duration occurred, followed by several days of warm weather. Visual observations of the existing vegetation and moisture content of the soils were made several days after the precipitation. Individual plants protected by the slash showed a growth response, where as plants not protected by slash showed no observable response. In addition, soil moisture was higher within and under the slash when compared to the moisture content of the soils not protected.

The following summer (1994), during seed set of the cool season grasses, those plants protected by slash were physiologically superior to plants not protected by slash. Vegetation growth was more vigorous, plants were taller with more leaf area, and had larger and more numerous seed heads. The canopies of the plants protected by slash were greater than those not protected. Seedling establishment was observed occasionally under slash, but more frequently within the sediment catchment behind debris dams.

Approximately one third of the area treated by the public had slash densities restrictive to plant growth or seedling establishment. Although this condition restricted plant growth and establishment, it did provide for improved ground cover and soil stability. Public compliance with the lop and scatter criteria was good. No leave trees were taken and the use of smaller diameter trees was fair. Lopping was performed most of the time; while scattering of the slash was performed less completely. Comments by local community members indicated a more relaxed atmosphere, knowing they had their own woodlot to harvest their fuelwood from.

CONCLUSIONS

The Capulin Piñon-Juniper Ecosystem Management Project was able to be implemented because its primary objective was the preservation of *all* resources: the Heritage Resources left behind by ancient people and the woodland resources upon which present-day local communities depend. It involved all the resource areas of the District—timber, range, heritage resources, soils, recreation, and fire—as well as local community interests. All shops within the Coyote Ranger District, as well as the Elder Americans, participated in this Heritage Resource stabilization and soil and watershed improvement project, and all resource areas benefited from the project. The goals of the different disciplines were the same: improve the quality of soils and herbaceous understory, retard erosion, and improve the age class distribution of the Piñon-Juniper stand. These methods and conditions help slow erosional processes that threaten Heritage Resource sites.

This was the first time the New Mexico Stage Historic Preservation Officer (SHPO) had approved such a plan. It was the first time on the Santa Fe National Forest that fuelwood had been cut from within the boundaries of archaeological sites and site stabilization had been incorporated into a fuelwood sale. To our knowledge, it was the first time in the Southwest Region (USFS) a plan of this sort—in which all District resource areas worked together to preserve Heritage Resource sites—had been implemented.

Consideration of the human dimension was one of the primary goals of this ecosystem management project, both the ancient human dimensions (archaeological site stabilization) and the modern-day one, providing fuelwood sales while ensuring sustainable ecosystem function. During this project, Heritage Resources and Watershed Management moved from their old function of project support to a new one, as full partners in ecosystem management.

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Community Based Piñon-Juniper Woodland Resource Management Planning for the Nahat'a' Dziil Chapter

Usha Little and Denver Hospodarsky[1]

Abstract.—The Navajo Nation's New Lands Nahat'a' Dziil chapter located near Sanders Arizona covers 350,000 acres of piñon-juniper woodland and is divided into 17 Range Management Units. The Office of Navajo and Hopi Indian Relocation currently manages these as functionally independent units emphasizing clustered residential development, livestock grazing, wildlife habitat improvement, and management of woodland resources for sustainable economic growth. Research in other counties suggests that community based resource management planning based on community forestry principles is a feasible option for the long-term sustainability of natural resources in the rural communities. The purpose of this on-going study is to evaluate the applicability of community forestry programs for the management of New Lands' woodland resources. The fundamental concepts of community forestry are to allow residents' needs and desires to define future conditions, and to incorporate community residents' rights and responsibilities of woodland resources stewardship into a management plan. The study has attempted to evaluate: (1) residents' recommendations regarding uses and allocations of woodland resources, (2) their willingness in assuming responsibility of developing community based plans and projects, and (3) feasibility of achieving mutual goals between resource managers and residents through community forestry approach. Informational efforts were initiated to promote awareness of the community forestry concepts through presentations, small group discussions, and a small-scale community vegetation restoration project. Community input was satisfied through interviews of small planning groups of grazing permitees and residents from each Range Unit. A series of meetings and communications were maintained to achieve coordination among residents, elected officials, community planners, and the resource managers. Some results and conclusion are discussed.

INTRODUCTION

In recent years a community based approach to addressing forest management issues has gained momentum in the United States. Long established abroad, the community based approach has been slow to gain acceptance domestically, however. As a result, the forestry profession in this country has only begun to realize the benefits of forest resource decision making conducted at the community level with the goal to improve environmental and economic conditions for rural people.

Recent expressions of concern for rural community stability and rural resource development by federal land management agencies may be interpreted to suggest maturing appreciation for the community approach, at least among public land managers. Such recent developments seemingly contradict long standing statutory expressions of concern for resource dependent communities in

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the United States beginning as early as 1944 under the Sustained Yield Act and continuing with the National Forest Management Act of 1976. Despite some recent developments in this country in support of community based forest management, community forestry as it is formally practiced abroad has remained largely a conceptual exercise with few applied examples to draw from.

As a result of the paucity of examples, any proposals to apply community forestry principles to North American land management must necessarily draw from conceptual origins within the foreign experience, while incorporating the unique traits of the domestic community under study. As the practice of community forestry develops in the United States, each new attempt to implement the community approach will require an initial assessment of its appropriateness for the specific population and resources in question. The need for empirically based community forestry principles are especially acute in our culturally diverse society whose individual communities reflect a multitude of needs, problems, and aspirations regarding the forest resource. This paper reports on one attempt to determine the applicability of community forestry principles and methods, in this case piñon-juniper woodland management planning in New Lands communities of the Navajo Nation, Arizona.

COMMUNITY FORESTRY

Community forestry has been defined by Fisher et al.(1989) as a forest management practice that includes protection, utilization, and distribution of forest products, and the institutional and organizational arrangements by which the management prescriptions are carried out. In community forestry the concern with institutional and organizational arrangements involves a shift from the technical-driven classical top-down approach with its focus on forest productivity to a people-centered, bottom-up approach that emphasizes helping communities to manage the forest upon which traditional livelihood and culture may depend.

Both the classical and community approaches to forest management share the same universal questions of production, protection, distribution, and management control. The community forestry approach, however, offers the opportunity to integrate local peoples' desires and knowledge, which has been largely constrained in the practice of traditional forestry (Burch 1988). Contemporary definitions of community forestry focus on the control and management of forest resources by local people who use forest resources for domestic purposes, as an integral part of traditional living (Fisher and Gilmour 1990). Community forestry projects address issues beyond lumber and fuelwood including the management of forest related products important to the community, such as fabric dyes, herbs, medicines, honey, fodder, nuts, and wildlife hunting. Community forestry incorporates an indigenous system of management, which allows the incorporation of traditional values into the formulation and approval of resource management policies that formally empower community groups.

Under the community forestry model, woodland management plans must consider technical forestry data in conjunction with knowledge of community social structure and cultural values as they relate to the woodland resource uses. The community forestry approach allows incorporation of local residents' knowledge, needs, and desires in defining future conditions, by incorporating residents' rights and responsibilities for woodland resources stewardship into a management plan providing empowerment to local people.

PLANNING AREA

Historical Background of the New Lands

In 1983, the Navajo Nation acquired 352,000 acres of Tribal Trust land, known as the New Lands, for the purpose of providing settlement to the families affected by the Navajo Hopi Settlement Act (Public Law 93-531) of 1974. The New Lands provides a settlement option to any certified relocatee and their extended families who do not wish to be relocated off reservation and who do not qualify or wish to acquire a homesite lease in the main reservation, but wish to maintain the traditional Navajo lifestyle based on livestock grazing and large extended families. The Office of the Navajo and Hopi Indian Relocation (ONHIR) has responsibility for managing the land and resources, while it continues additional development and relocation activities on the New Lands.

The New Lands is located 40 miles east of Holbrook along Interstate 40 near Sanders in Northeast Arizona. The topography of the New Lands includes flat grassy plains, gently sloping benches and steep broken ground with the elevation varying from 5,500 to 6,900 feet. About 30 percent of the New Lands is considered wooded area covered with piñon-juniper woodlands. The entire New Lands is divided into 17 range management units, 11 of which have already been developed with clustered homesites and grazing management cells for livestock. The clustered homesites are provided for the families with livestock grazing permits and permitees immediate relatives. Families without grazing permits are offered one acre lot homesite leases within the rural community sub-divisions of New Lands (ONHIR Plan Update 1990). All Navajo families relocated either into the range units or into the rural community sub-division have equal access to the woodland resources of the New Lands including firewood, piñon nuts, medicinal plants, scenic views, wildlife, and access to the religious sites.

COMMUNITY FORESTRY ON THE NEW LANDS

There are five reasons for selecting New Lands for community based woodland resource planning. First, New Lands currently does not have a sustainable management plan acceptable to community resource users. Second, New Lands' communities are recently established and community residents are fairly receptive to new ideas regarding resource management that are outside the classical forest management model practiced elsewhere on the Navajo Nation. Third, the residents of the New Lands communities include Navajo people who use adjacent piñon-juniper woodlands as an integral part of traditional living. Fourth, many New Lands residents desire innovative, but culturally appropriate, options for employment and income opportunities from woodland resources, in addition to more traditional uses. And finally, New Lands people express substantial concerns for the welfare of the land, resources, and people after the ONHIR support discontinues in completion of the relocation activities. The above situation presented an opportunity to study the applicability of the community forestry approach on New Lands.

DEFINING COMMUNITIES

A primary step toward a community based woodland management planning approach is defining and delineating the community as the operational unit of social organization within which to undertake community forestry activities. There are three general approaches in defining community. One approach may be to define community as locality, a human settlement with fixed and bounded territory. This definition is a favorite of economists who analyze locational areas based on where people live and work. Another approach defines community as a local social system involving interrelationship among people living in the same geographic area. This definition does not define clear geographic areas and lacks definitions of content and quality of social interactions and interrelationships. A third approach defines community as a type of relationship, especially a sense of shared identity without any geographic boundary, such as the environmental community (Lee et al. 1990).

With the purposes of this study to assess the viability of communities for the community based woodland resource management planning approach, community is defined for our purposes here by integrating some elements from all the above three definitions. In this study community refers to a human settlement delineated by geographical boundary and represented by locally organized political and social groups, which maintain formal social interactions, while engaged in activities to fulfill the needs and desires of the people holding common shared cultural values towards the land and piñon-juniper woodland resources.

OBJECTIVES

The purpose of this study is to determine the applicability of community forestry principles in the management of piñon-juniper woodlands in the New Lands communities. To evaluate the applicability of the community forestry approach, three research elements were identified as fundamental to community based woodland planning. These elements were 1) delineation of operational communities within the New Lands, to serve as the unit of analysis in resource planning research and plan implementation and analysis of existing institutional structure and capability of communities to accommodate the community approach, 2) identification of local peoples' needs for , attitudes toward, and determination to manage woodland resources. This paper describes how each of these elements may be integrated into a community based approach to piñon-juniper management planning for the New Lands.

SUPPORTING RESEARCH FOR COMMUNITY BASED PLANNING

With the main objective of the study to determine the applicability of the community forestry approach to piñon-juniper management planning for New Lands, three different kinds of research methods were used to meet planning information needs:

1. Formal interviews of community residents designed to determine a) types, quantities and frequencies of woodland resources use by the residents, b) community attitudes, opinions, and preferences towards present and future woodland management planning goals and activities, and c) who or which community group should involved in woodland resource management planning.
2. Direct observation of community activities and interactions obtained during personal visits. Direct observation methods were used to determine a) willingness of the management agency and chapter officials to coordinate woodland resource related community activities, b) both residents and chapter officials' willingness to take active participation in vegetation restoration activities.
3. Secondary data including community demographics, existing livestock grazing activities, and woodland inventory information pertinent to multiresource woodland resource management objectives.

Successful application of the community forestry approach requires adequate knowledge of the affected population and their relationship to woodland resources. Prior to conducting interviews of New Lands residents, careful consideration was given to the population's relationship with piñon-juniper woodlands, according to various ethnohistories commencing both before and following the arrival of anglo-Europeans. In addition, the sensitive nature of relocation activities was carefully considered in developing survey questionnaires and in identifying effective methods for approaching residents for interviews.

It is vital for the community forestry researcher or planner to understand and respect community social norms, religion, and traditional values before embarking upon planning for woodland resource issues. Besides knowing about the Navajo people, participating in community social activities, and interacting with the people as a friendly help instead of authoritative figure is essential. It is necessary to create a spirit of mutual trust and respect for the success of this study or any other successful community forestry enterprise. The community based process of managing piñon-juniper woodlands described in this paper is built upon a profound appreciation for evaluating Navajo culture and traditional values, as these values were used in identifying pertinent community forestry variables and interpreting study results.

RESULTS AND CONCLUSIONS

Personal interviews of New Lands residents indicate that the woodland resource is subject to both traditional and non-traditional demands. Traditional demands condoned by most residents include harvesting fuelwood and postwood for the personal uses, collecting juniper seeds and leaves for ceremonies, piñon nuts, and medicinal plants. Non-traditional demands include residents' desires for economic development activities through retailing fuelwood, postwood, and other marketable woodland resources. When asked whether New Lands juniper should be harvested as fuelwood to create jobs and income for the New Lands residents, 59 percent responded affirmatively and 39 percent said no.

The survey data indicated a community based forestry approach is desired by the majority of the New Lands residents and elected officials. More than 50 percent of the interviewed residents expressed willingness to work with a management agency in developing plans that incorporate their opinions into the planning process. Among interview respondents, 28 percent mentioned that final decisions about woodland resources should be made only by community people; while 22 percent said that Navajo Forestry Department should work with local planners, chapter officials, and community people in the planning process.

The survey results indicated, woodland resources are important to the New Lands people in their everyday life and that both New Lands elected officials and the residents prefer residents' opinions and needs be honored in the decision making process. The majority of those interviewed responded favorably to a locally developed plan that empowers local people. When asked if they were willing to organize a community group to work on developing woodland management planning, 60 percent of those community residents interviewed responded favorably, while 20 percent were not willing and 14 percent responded that they are too busy to organize such group.

Community forestry in practice must be based on clear delineation of what and where the subject community is, in order that forestry program comprehensively address the resource needs and desires of community residents, while considering the abundance and sustainability of woodlands within the community resource area. What practice requires is an operational definition of community that insures the community forestry program will proceed efficiently towards the mutually agreed upon goals of community residents and resource management agencies with stewardship responsibility for community resources.

Four levels of existing social organization offer promise as the basis for delineating operational communities in the New Lands. In descending order of organizational complexity these are: the Nahat'a' Dziil Chapter, Planning Board, range units, and grazing committees. The Nahat'a' Dziil Chapter and Planning Board are recognized as political organizations whose representatives are elected by Chapter residents. Chapter officials consist of a President, Vice President, and Secretary Treasurer. A monthly chapter meeting is held in which New Lands residents are encouraged to participate. The Planning Board includes two representatives from each range unit. Representatives are approved the residents of the respective range units to represent range unit issues to Chapter officials. The Planning Board's operational organization is unique to the New Lands; other Chapters of the Navajo Nation may not include such an organizational structure. Range units are characterized by groups of families living within the geographic boundary of prescribed range units. Grazing committees comprised of members from within individual range units, are recognized as a traditional social organization of Navajo culture. Grazing committees are comprised of families who have inherited livestock grazing rights to the land. There are various advantages and disadvantages associated in recognizing each of these social units as a basis for delineating operational communities within which to initiate community based woodland management planning approach. These advantages and disadvantages can be summarized as follows:

Chapter Government as Community Basis

The operational community organized around the Chapter can provide advantages such as the unity and strength displayed within the Chapter as whole, political authority for implementation of projects, monitoring, and widespread distribution of benefits. However, there are several disadvantages of using the Chapter level of organization as a basis for delineating community, such as residents' mistrust of Chapter authority, since the Chapter may hold political motives as a result of its direct ties to Tribal government. Chapter officials change every four year and priorities given by Chapter officials in defining community needs may changed depending on the personalities of the elected officials. Chapter officials have many responsibilities and may not find enough time to talk with people and subsequently address woodland issues relevant to the people. Chapter government may also experience conflicts of interest in resolving problems regarding woodland issues among range units of which they are and are not a part.

The Planning Committee as Community Basis

The 'Nahat'a' Dziil Planning Board', which consists of two elected representatives from each range unit, and they meet with Chapter officials once a month to discuss issues and concerns from their constituent range units. Currently the planning board's activities are subsidized by the ONHIR which retains an influential role in the chapter level decision making process. The planners invest their time on community affairs because they receive financial compensation. Some planners may not wish to assume additional responsibilities for developing a woodland management plan. The Planning Board members may be capable of coordinating activities with resource managers in developing woodland policies but implementing and monitoring a project is difficult for planners to under-take alone. Some planners also have indicated difficulties in communicating and working with local residents.

Range Units as Community Basis

A major concern with using range unit residents as a basis for community delineation is the unequal number of homes, population, and amount of woodland resource distributed among the residents of the 13 developed range units. A range unit with excess resources for community needs may wish to market surplus woodland products for income, while an adjoining range unit may not contain sufficient resources for subsistence activities. The uneven distribution of resources among range units may lead to conflict among range unit residents in the future. To mitigate this problem, management agencies need to define the amount of resources that could be harvested for either personal or commercial purposes based on biophysical condition of the each range unit. The present livestock grazing program that is organized according to range units is a positive example of cooperation to carry out woodland projects. An extension forester working with range unit residents on woodland issues, could facilitate other planning activities as well.

Livestock Grazing Permit Holders as Community Basis

The grazing committee made up of grazing permitees is a traditional unit of social organization recognized by the Tribal and Federal rangeland management agencies. Families with grazing permits play an important role in maintaining Navajo tradition, family ties, and legal rights to land and resources. The livelihoods of permitees are directly affected by range management decisions. Consequently, grazing committee members actively participate in meetings. Since the condition of the range resource is directly affected by any woodland management prescription, the active role of the grazing committees in resource stewardship suggests permitees as a viable community focus in taking a community based approach to woodland management. However, the community forestry literature is clear in its tenets that community based forestry programs are to improve the lives of all rural people, especially the poor. Authorizing grazing committee for woodland management may add more influence to the permitees and not enough to the other residents. Non-permitee residents should receive equal opportunity to use woodland resources and their desires and needs should be equally considered in the planning process.

Evaluation of the four levels of social organization to serve as a basis for community forestry programs suggests range units are viable community group with which to work with towards community based woodland management planning. Some of the reasons for this conclusion includes: set geographic boundaries of the range units, social and family ties facilitated by the clustered homes and neighborhood structure, existing range management program and established grazing committees for the range units, and most importantly, range units include planners, permitees, Chapter officials, — all community people.

Using range units as a community basis from which to initiate a community based management planning approach will necessarily include management concerns expressed by the existing organizations, while allowing community residents' input regardless of their affiliation with existing organization. However, this effort to be successful will require an extension forester to live in the New Lands and work closely with the each range units' residents in establishing a woodland resource committee. Formulation of a range unit level committee will improve the residents' communication abilities and will also enhance the planners' relationships with residents. This exemplifies an ideal grass-roots, bottom-up management planning approach.

Information needed to evaluate the management agency's capability in restructuring institutional and organizational arrangements to initiate a community based approach was observed on the New Lands based on the support and cooperation provided by the ONHIR, Navajo Tribe Forestry Department, and Chapter Officials.

The present management agency, the ONHIR, is willing and capable of implementing community based woodland projects. The Office of Navajo and Hopi Indian Relocation were active participants during meetings and interviews with the residents. New Lands is a part of the Navajo Nation and it is important for ONHIR to coordinate with the Navajo Forestry Department's woodland policies to assure compatibility. Several attempts were initiated as part of this research to establish cooperation between residents and the Navajo Forestry Department staff. Lack of familiarity with the procedures required for a community based approach among traditional foresters and policy makers possibly resulted in some hesitation in consulting with residents management recommendations.

RECOMMENDATIONS

The community based woodland management approach requires time, money, and a devoted extension forester willing to learn about community residents and their interaction with woodland resources. Classically trained forestry professionals, especially those working for rural indigenous communities, must understand and embrace the philosophy behind community based approach. The extension forester's management agency needs to mandate a policy and develop an administrative structure by which the extension forester can acknowledge community resident's unique relationship with the environment and bridge the gap between management agency and the community. The extension forester's task should include not only providing technical support regarding biophysical concerns, but also include activities to increase community empowerment such as moral building, participation, cooperation, and basic education in woodland ecosystems. The community based approach requires foresters and land managers to assume a community supporting role, which may be a new experience for many field foresters. Working directly with local leaders and woodland users can be stressful because the field staff must give up their technocratic, authoritarian roles in the community in favor of a role as advisor and facilitator. Agencies need to establish programs to train field foresters in dealing with local people according to ecologically and culturally appropriate modes of behavior.

The effectiveness of care for land and woodland resources by users is proportional to their sense of ownership and dependency on the resource. For a community based management approach to be successful, the people must be secure in the belief they will benefit from their investment as resource decision makers. The community based approach described in this paper is a benefit based approach where community people are helped to visualized the results of their efforts, thereby providing incentives for their involvement and effort. The management agency needs to evaluate the biophysical data and explain to the community prospective benefits associated with various management alternatives. Communities that use piñon-juniper woodland resources as an integral part of their traditional living can provide significant assistance to the sustainable management planning and monitoring activities conducted of the technical management organization. In this mutual arrangement between community and agency, both should agree how management task and benefits are to be shared by participants in the planning process.

This study attempts to describe some of the principles and methods of community forestry applicable to communities in the United States. The community based approach to managing the New Lands piñon-juniper woodlands of the Navajo Nation appears desirable to the people living there and appears feasible to implement as well. The key to the success of community based woodland management approach, however remains in the hands of management agencies currently with oversight responsibility for New Lands resources. The management agencies working with New Lands communities would be well served to recognize the significance of the community based approach for the long-term sustainability of the piñon-juniper woodlands of the Southwest.

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An Overview of Woodland Projects Incorporated at Four Pueblos in New Mexico

Buff Jebsen-Ross and Richard Schwab[1]

Abstract.—For centuries Indians throughout the Southwest have traditionally utilized and managed their Piñon-Juniper woodland resources for economic, social, cultural, and religious purposes. Basically, up to this point these uses have satisfied personal and family needs, and except for a few circumstances have not entailed intensive formal planning initiatives.

However, within the past few years tribes have become increasingly aware of the development potential of their woodland resources to supplement tribal revenue, personal incomes, and employment opportunities. Accordingly, the expanded management intensity and scale has made it necessary for Indian tribes to recognize the importance of implementing comprehensive woodland management planning.

There are several unique characteristics to this planning process uncommon to other land management agency practices. Differences in tribal governmental structures, social and cultural uses of the resource, land ownerships within tribal reservations, and traditional uses and perceptions to management all make planning a challenging experience.

The intent of this paper is to discuss several planning initiatives coordinated by the Bureau of Indian Affairs on behalf of Indian tribes that have incorporated comprehensive project planning processes. These planning efforts have transcended into successful woodland resource development endeavors devoting special concern to sustaining the woodland resources, while supporting the traditional cultural integrity of the Indian people.

INTRODUCTION

The Bureau of Indian Affairs', Southern Pueblos Agency (SPA) is located in Albuquerque, New Mexico. SPA serves ten separate and distinct sovereign Indian Nations with an overall land base of 1,063,761 acres. Of these lands, 200,000 acres are considered to be commercial woodlands and an additional 150,000 woodland acres are considered to be non-commercial. The remaining reservation acreage consists of range and timberlands. All of these lands are deeded to the tribes but are placed in Federal Trust status. The scattered locations of the tribes and the large amount of forested acres complicates the management of this unique trust responsibility. Furthermore, the "multi-tribal" agency situation at SPA produces challenges and situations not found at single tribal agencies.

Until recently this situation has largely ignored. Then in 1989, the Bureau of Indian Affairs (BIA) received money to initiate economic development of the woodlands resource through grant monies to the tribes. The Branch of Forestry at SPA has supported four Pueblos in applying for and receiving the grant monies from the BIA Woodlands Management Program. The purpose of these grant monies are as follows:

1. Explore the feasibility of tribal economic development through management and utilization of woodland resources, and
2. Study the potential for resource enhancement through woodland management (Schwab, 1993).

This paper will discuss the planning process of these projects and grants and their application on

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the ground. The planning process consists of four steps:

1. Inventorying the resource.
2. Consultation with the tribal leadership.
3. Tribal approval.
4. Project implementation.

INVENTORYING THE RESOURCE

The BIA provides forest inventory services to the tribes as part of its trust responsibilities. One of the elements of these inventories is determining the amount and location of commercial acreages. This in turn helps the tribes to determine the overall feasibility of economic development projects. The BIA uses a land classification scheme to determine commercial and noncommercial acreages.

Land Classification Scheme

For management purposes, the Albuquerque Area Office (AAO), Branch of Forestry has developed a forest classification system which divides the total forest into elements according to species composition, productive potential, accessibility, and other factors. This classification system is illustrated in Figure 1 and in the following discussion.

WOODLAND

Commercial woodland as defined by the BIA is land qualifying as forest, and containing less than 5% commercial timber crown cover and, diameters of at least 3.0″ at diameter root crown (DRC) of woodland species or 5.0″ at diameter breast height

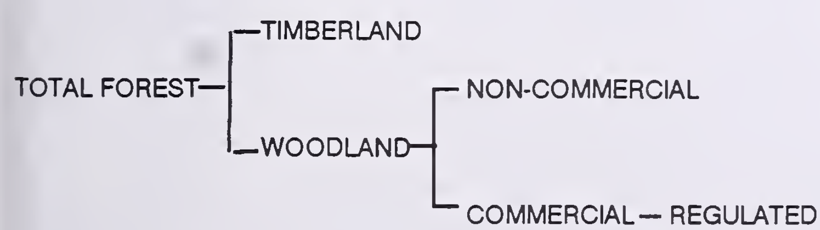

Figure 1.—Forest Type Classifications.

(DBH) for timber species, and considered a high woodland site. Commercial woodland is a term coined to describe that portion of the woodlands producing marketable woody products which is currently or prospectively accessible, is not withdrawn from such use, and not already accounted for within commercial or non-commercial timberland (BIA 1988). The commercial forests are then divided into regulated and unregulated lands.

Regulated

This class includes commercial woodland which produces or has the potential to produce at least five cubic feet per acre per year of commercial volume. These areas must be accessible, not reserved, and located on slopes less that twenty percent.

Non-Commercial Forest

This class includes:

1. Areas administratively withdrawn from woodland use.
2. Areas that are so steep, unstable, or rocky that they cannot be used for woodland production without causing serious environmental impacts.
3. Productive areas where there is low probability during the next ten years to use the woodland because of excessive development costs.
4. Non-productive areas that lack the capacity to grow at least fifteen cubic feet of woodland per acre per year.

The acreage of the Pueblo woodlands is provided in the following table (Albuquerque Area Office, Branch of Forestry, 1991):

PUEBLO	WOODLANDS	
	COMMERCIAL	NON-COMMERCIAL
Acoma	108,027	66,000
Cochiti	0	16,069
Isleta	22,817	2,600
Jeme	29,646	17,982
San Felipe	2,000	15,552
Sandia	0	2,525
Santa Ana	0	2,772
Santo Domingo	5,000	25,015
Zia	50,238	7,317
SPA TOTAL	217,728	155,832

TRIBAL USE AND NEEDS OF THEIR WOODLAND FORESTS

From these woodland areas, the tribal uses and needs has to be considered by the manager when planning development projects.

Cultural Significance

The woodland forests are a very significant part of the culture and ceremonies that are part of the Pueblo way of life. For example the fresh pitch of the Piñon pine (*Pinus edulis*) is used by "Medicine Men" for ceremonial purposes. Many of the feathers used in ceremonial dances come from birds directly associated with the Piñon-Juniper woodlands.

It is a belief of the Acoma people that the spirits of deceased relatives reside in living trees within the woodland forest. This greatly complicates the management of the forest (Stanley 1992).

Many of the historic sites of the early Anazazi people are found in the P/J woodlands and are held sacred. For example there are the Kow-ina ruins in Cebollita Canyon and the Sand Canyon ruins near Acoma.

A Bounty of Natural Harvest

The nut of the Piñon pine has been a staple of the Pueblos and many of the other Native Americans of the Southwest for many centuries. The woodlands are also an important habitat for a wide range of wildlife that has provided a historic nutritional substance for the people of the Pueblos. Hafner (1991) listed the following species that are found within the woodland forest: mule and whitetail deer, antelope, elk, and rabbit. Dr. Schemnitz in his presentation in 1991 stated that quail and turkey are game birds also known to utilize the woodland habitat.

Today the woodlands also provide habitat for domestic livestock.

A Fuel Source and Building Materials

Tribal members have historically favored the juniper species of the woodland component over the piñon pine. This stems from the other more important uses of the piñon, nutrients and ceremonial. The One Seed Juniper (*Juniperous monosperma*) is the favored fuel source of the Jemez tribe due to its burning characteristics.

With the introduction of domestic livestock and the fencing of open ranges, the need for a handy and inexpensive building material has come into play. The Rocky Mountain Juniper (*Juniperous scopulorum*) is favored for fence post material which is followed by the One Seed Juniper.

Historically piñon was used for vigas and uprights but have been replaced with the Ponderosa pine (*Pinus ponderosa*).

Future Demands of the Woodland Forest

The Pueblos recognize the need to better manage their natural resources and thereby control their own destiny. They see a need to provide jobs and income on the reservations and see their woodland forest as a source of revenue.

The tribal elders can remember open woodland forests with plenty of forage. Now these stands have closed canopies with little or no undergrowth of grasses and forbs. This is a hinderance to domestic livestock and an empty kitchen for wildlife.

Through the implementation of Tribal woodland enterprises the attempt to properly manage their woodland resources is being undertaken. Sound silvicultural practices are turning overgrown stands into a productive ecosystem where man and beast can prosper. These cuts also provide employment opportunities for tribal members and a new source of revenue.

DEVELOPMENT OF THE WOODLAND PROJECTS

Tribal Input, the Basis For Each Project

As with every other federal agency that conducts projects on the ground, the BIA must conform to NEPA standards and regulations. It is also open to outside criticism and citizen lawsuits. Unlike other federal agencies however, the BIA has a more finite and unique constituency, which is the Tribe who has sovereign rights to the land. Consequently it is the Tribe that has the final say concerning a project. Therefore, the BIA's, Branch of Forestry acts as a consultant and trustee to each of the Pueblos.

At SPA, the planning for each project must be fully explained to the Tribal Council. The presentation must take into account the biology of the management alternatives as well as cultural and traditional values. To facilitate this process, the Forestry Management Plan consolidates the proposed projects into one document.

Some benefits of planning are as follows:

1. The Tribe takes charge of its future.
2. Gives direction to the BIA's work.
3. Increases accomplishments.
4. Makes it easier to raise money.
5. Involves and educates people.
6. The plan is a basis for monitoring management activities.
7. Allows Tribe to enter in cooperative management agreements.
8. Protects precious or sensitive resources.

The Southern Pueblos Agency Forest Operating Plan provides detailed descriptions about how to manage the forest resources in order to accomplish the goals of the individual Tribes. This is in accordance with the Bureau of Indian Affairs Manual (53 BIAM Supplement 2, Section 2.4) which states the following:

"Forest Management Plans are required for all Indian Reservations having forest resources. The harvest of timber from any Indian forest lands will not be authorized until there have been prescribed methods of cutting based on sound silvicultural principles. The plan is a guide to ongoing forest activities and reflects the extent of the management knowledge available on the forest. Preparation of reservation forest management plans and their revisions are a responsibility of the Agency Superintendents. Tribal consultation and legally required consent will be an integral part of forest management planning. Management plans will be approved by the Area Director."

The Planning Process

Planning is simply the process of envisioning a desired future and developing the methods to achieve it. The process used for planning at SPA is adapted by a method developed by Dr. James Hardy (1981) for nonprofit organizations. That process uses a planning triangle seen in Figure 2.

Figure 2.—Planning Triangle.

This triangle consists of four components. Each component must be followed in order. Too often, organizations decided what they want to accomplish before deciding which direction they want to follow. Hardy's process helps organizations develop that direction. A description of each component is as follows:

1. The Mission Statement - This is an abstract statement of the values and purpose of the Tribe and their philosophy for the use of their natural resources. It is the focal point of the plan.
2. Long Range Goals - These are defined as a description of a desired future for the use and management of resources within a specific time frame.
3. Objectives - Every goal has one or more objectives which describes *what* has to happen one year from now to ensure that the goals are being achieved.
4. Action Steps - These are specific, accountable procedures which state who is responsible for accomplishing the objective and how it is going to be done. This is the only component that specifies how something is going to be accomplished rather than what is to be achieved.

The successful development and implementation of a reservation resource plan involves teamwork between the Pueblo and the Bureau of Indian Affairs (BIA). In order to facilitate this, two working groups are usually formed. These are the Pueblo's Natural Resource Planning Committee and the Bureau's Interdisciplinary (ID) Team. The ID Team meets with each Pueblos' committee at the onset of the management planning projects. A summary of the planning meetings are as follows:

1. Objectives of the meetings were explained to all Committee and Team members. The objectives were two fold, to learn about planning and to develop the components of the plan.
2. The benefits of planning were explained as were the planning process and planning definitions.
3. A Mission Statement was developed. This statement was usually written before the meetings by the Pueblo Governor and the facilitator and then reviewed by the committee.
4. Outside factors and the current status of all resources were reviewed.
5. Long range goals for the management of the reservation were developed by the Pueblo committee. These goals are approved by the Tribal Council.
6. Measurable and attainable objectives were developed for each goal.
7. Once the Pueblo had determined what kind of future they wanted for the use and management of their resources, action steps were written for the achievement of each goals and its objectives.
8. The Implementation Plan was written and presented at the meetings. The plan included the Mission Statement, goals and objectives, action steps, and resource summaries. The resource summaries included maps and resource descriptions.
9. The Plan was made available for review and comment and then approved by the Tribal council.
10. The plan was implemented.
11. One year from the implementation of the plan, it will again be reviewed by the ID team and the Council. The purpose of the review is to evaluate the plan's implementation, update the one year action steps, and make any necessary revisions.

Organization of the Plan

The Forest Operating Plan consists of three documents, as follows:

1. Forest Inventory Analysis - This report (one for each pueblo) is designed to document forest inventory field procedures, determine the current forest condition, and to calculate an Allowable Annual Cut (AAC) for the forest. This report is a basic step in the forest management planning process.
2. Policies and Procedures - This document contains the general course of action that will be followed by the Branch of Forestry in order to run its program. It includes guidelines on forest management activities such as reforestation, fire management, timber sales, etc. It is divided into five sections:
   a. Introduction
   b. Goals and Objectives
   c. Timber Management Program
   d. Forest Protection
   e. Branch Organization

Because forest policies and procedures are generally the same for each pueblo, one "generic" document was prepared which applies to all four pueblos.

3. Executive Summary and Action Plan - This document consists of a brief summary of the status of the resource and the specific projects and Action Steps which are planned for each Pueblo. The Action Steps are updated annually at the end of each fiscal year and the implementation of each Action Step implementation is tied to individual performance elements. In planning for each Pueblo, the manager must remember that each Pueblo is unique unto itself and that no two Pueblos will see things in the same light. Therefore nothing can be taken for granted.

Once the tribe has settled on what it desires to accomplish, it can seek available funding to achieve its goals. For woodlands projects, they can apply for funds from the BIA's Woodlands Management program.

Funding For Projects

The BIA at the Agency level does not have annual budgeting set aside for woodland management. Instead monies are allocated from the Area office to fund projects as proposed by the individual tribes. Four Pueblos within the jurisdiction of SPA have been awarded six grants from this source. Those tribes and their projects are as follows:

1990	ISLETA PUEBLO COMMERCIAL FUELWOOD PROJECT
1991	ACOMA PUEBLO COMMERCIAL WOODLAND ENTERPRISE
1992	ACOMA PUEBLO SPECIALTY PRODUCT GRANT
1993	SANTA ANA PUEBLO LIVE NURSERY PROJECT
1994	SANTA ANA PUEBLO NURSERY RETAIL CENTER
1994	JEMEZ PUEBLO COMMERCIAL FUELWOOD AND MULTI-PRODUCT ENTERPRISE

These grants are intended to begin an ongoing enterprise that will hopefully reach self sufficiency. This is merely pilot project front money to carry the enterprise through the first year and to pay for the accumulation of inventory that is marketable revenue. This program income can then sustain the enterprise.

The entity that controls the funding can either be the Tribal Administration with the support of the Tribal Council or a separate entity defined by a charter such as is found in the Pacific North West or, for example, the Mescalero Apache Timber Company.

The BIA through the Agency Branch of Forestry has control of approving projects based on Tribal proposals and then holding the Tribes to the agreements of that contract. The BIA is available to advise the best means of utilizing this money to achieve the best results. Accountability of deliverables as stated in the grant contract is the responsibility of the tribal enterprise.

Project Layout and Harvest

It is the responsibility of the BIA to make recommendations of areas to be treated. The Tribe being the land owner must designate which area they want treated and then get the approval of the Tribal Council through a resolution. Once a Tribal resolution is in hand, the Agency Forester begins work with the Tribal Administration to ascertain that preliminary work and layout meets the needs of the Tribe.

An interdisciplinary team from the BIA and Tribe then meets at the proposed site to discuss concerns and any issues need to be mitigated before harvesting occurs. The SPA Branch of Forestry prefers a leave tree mark on all but their Forest Pest Management treatments. With a leave tree mark you are managing the residual and the rest of the trees are excess to the crop tree needs of the stand. Thus promoting better silviculture.

Once all the comments have been noted and mitigated the treatment area is turned over to the enterprise for implementation.

The method of harvesting is the Tribes decision. This can be accomplished through different schemes and hiring tactics.

1. Pay individual tribal members to harvest, split, and haul materials on a load basis.
2. Hire a tribal crew to do all the work.
3. Pay individual to harvest and haul and a small crew to split sell.
4. Utilize individuals being funded through other programs to do all or part of the work.
5. Subcontract the operation to tribal concerns or individuals.
6. Subcontract to outside businesses for stumpage.
7. Use a combination of any of the above. As the old saying goes, "there's more than one way to skin a cat".

Problems Encountered

The number one problem encountered in all but two of the Pueblos is continuity in the program. Yearly changes in the many tribal governments bring shifts in priorities. In many instances a manager is hired for only part of the year with no one to carry the "ball" into the next season or year.

Some of the Pueblos have tried to run the entire program from a branch already overloaded with work and problems. This a sure way to failure as experienced at Isleta Pueblo.

Another major problem is the trespass of the very resources designated for the project. This trespass has been conducted by tribal members and from non-members from outside the Pueblo. Once some activity is observed in the forest you can assured that someone is going to help themselves to the "easy pickings".

In many cases available funding has run out before an area can be completely treated. Many acres that have been prepared for harvesting are still waiting for some sort of treatment.

In one instance money obtained through the sale of fuelwood products was misplaced, closing down the entire enterprise.

Accomplishments and Success Stories

The development of the woodland grants at SPA has enabled its staff to successfully prepare over 270 acres of commercial woodlands. An additional 210 acres have been prepared for Pest management treatment to suppress and deter the spread of two species of Dwarf mistletoe: *Arceuthbium divaricatum* in the Pinyon (*Pinus edulis*)

For fiscal year 1993, the Branch of Forestry helped to obtain 30% of woodland grant monies from the Albuquerque Area Office. This was over 8% of the entire national Woodland Management budget (BIA 1994).

Accomplishments by Pueblo

ACOMA

1. Applied for and awarded a $ 30,000 Woodland Management grant.
2. Opened contracts with tribal members to harvest and haul 145 loads of piñon-juniper.
3. Constructed a 69,000 square foot woodyard.
4. Purchased a Supersplit log splitter from GFX Manufacturing corporation.
5. Purchased a work shed to shelter the enterprise's equipment.
6. Hired three additional tribal members to split and stack the firewood.
7. Produced 100 commercial fuelwood cords.
8. Ninety five cords sold commercially with the rest going to tribal members in need.
9. Produced $6,509 in clear profit.
10. Distributed over $26,000 in payroll to tribal members.
11. Split and stacked over 60 cords from this year's Timber Stand Improvement projects.
12. Applied for and awarded a $20,000 Specialty Woodland Product grant.
13. Purchased a Vermeer Brush chipper, model 1220.
14. Produced 450 cubic yards of chipped material.

ISLETA

1. Applied for and awarded a $54,000 Woodland Grant.
2. Contracted 12 Tribal members to haul over 400 truck loads of green piñon-juniper.
3. Purchased a Duerr 20 ton and 25 ton woodsplitter.
4. Purchased a four wheeled drive pick up truck and radio equipment.
5. Provided additional salary for staff at the Tribal Cinder and Gravel Enterprise yard for scaling and book keeping services.
6. Produced over 300 cords of commercial fuelwood and sold them at $100/cord.

SANTA ANA

1. Applied for and awarded a $26,400 Woodland Grant.
2. Provided $10,870 in salaries to extend the employment of the existing work force of 3 laborers.
3. Purchased one chainsaw and a hydraulic truck hoist.
4. Transplanted 294 wildlings to nursery.
5. Containerized trees were sold for a $2,000 profit.

The best example of woodland management is found at Santa Ana Pueblo where they have expanded their Tribal Nursery and Greenhouse enterprise to include the harvest of wildlings in their Bosque woodlands or natural tree nursery. This harvesting is being conducted to help open dense stands of Russian olive (*eleagnus angustifolia*) and to reduce competition. One hundred and thirty trees have been retrieved and containerized for public sale. They plan to double that number this coming fall. Not only are they succeeding in managing their own lands, they are doing it at a profit. That profit goes to keep their employees working year round instead of seasonal.

JEMEZ

The project has just begun this spring and has been held up due to extreme fire danger. Even though hindered by fire restrictions the enterprise has been able to haul over 30 cords of firewood.

The Enterprise is proposing to cut and haul over 400 cords this year.

At this time the Pueblo of Jemez is developing their Forest Enterprise that will employ 6 to 10 people year round while producing a variety of products from their forests. These will include vigas, latillas, fuelwood, fence posts, and Christmas trees. They are also planning to contract thinning and other services from other land owners.

RECOMMENDATIONS AND OBSERVATIONS

Another commodity of the woodland grants is the knowledge and experience gained from administering them. Some of the lessons learned are as follows:

1. The history of the area is better understood. We learn past uses as well as the environmental history.
2. The Tribe's needs and expectations are better solicited for the area. It is their land and the projects are more successful when it is something they want done.
3. The tribal constituency is educated on the biology of the prescribed management and its alternatives, either silviculturally or otherwise. Knowledge is a very powerful thing when used right.
4. Its preferred to have the Tribes plan in hand. Don't let available funding run the program.
5. The most important element is to have a positive, enthusiastic Tribal member running the operation. This person must not have other duties within the Tribal Administration. The person in this position must be dedicated to the Tribe and the resources. They must also have a great deal of initiative, be creative, and have the ability to anticipate the unexpected.

BASIC SUPPORT NEEDS FOR A SUCCESSFUL OPERATION

1. WOODYARD
   - A. FENCED AND SECURED.
   - B. CENTRALLY LOCATED.
   - C. EASILY ACCESSIBLE - LOADING & UNLOADING.
   - D. LARGE ENOUGH TO HOLD STOCK WITH EXTRA ROOM TO MANEUVER EQUIPMENT AND TRUCKS.
2. WOODYARD FOREMAN
3. COMMERCIAL SPLITTER

   LARGE ENOUGH TO HANDLE 20" DIAMETER LOGS.
4. DELIVERY VEHICLE
   - A. 1 TON DUALLY.
   - B. TRAILER.

OPERATIONS

1. HARVESTING
   - A. FELLING
   - B. LIMB AND SCATTER
   - C. BUCKING INTO LENGTH
   - D. LOADING

In summary, given a large enough resource and a cooperative Tribal Council, there is no limits on how far an enterprise can go within the southwest. The only limits are those produced or recognized by the people within it.

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The Effects of Fire on Cultural Resources Mesa Verde National Park, Colorado

Kathleen Fiero[1]

Abstract.—In 1989 the Long Mesa fire burned approximately 3000 acres in Mesa Verde National Park, Colorado. The fire spread along the top of Long Mesa and the adjacent canyons covering an area containing approximately 200 known archeological sites. Because of the concern for cultural resources, all fire lines and similar earth moving tasks were done by hand with an archeologist on each crew. No heavy equipment was used. The archeological sites in the burn area varied from prehistoric to historic, isolated hearths to surface pueblos and cliff dwellings. A resurvey of the burn area was undertaken to evaluate the extent of fire damage. The direct effects of the fire varied from very minimal impact on buried sites to complete loss for historic wood structures. Two rooms in cliff dwellings burned. During this resurvey, 23 previously unidentified sites were recorded. A project to stabilize cliff dwellings in the burn area was undertaken as was a study of the effects of fire retardant on pottery sherds. Three natural resource studies were also funded: a vegetation map, a fire history study, and a vegetation and fuels inventory.

INTRODUCTION

Mesa Verde National Park is located in southwestern Colorado on the northeast edge of the Colorado Plateau. The park was established in 1906, ten years before the National Park Service, to preserve and protect the cultural resources located within its boundaries. The park contains 52,000 acres and the vast majority of this area has been surveyed by an archeologist. Approximately 4,000 sites have been recorded. These sites vary from large cliff dwellings to one and two room storage units, from masonry pueblos to dirt walled pithouses. There are also wood sweat lodges, fence posts and cabins. The great majority of the sites are a manifestation of the Northern San Juan Basin Anasazi tradition and date from AD 600-1300 but there are a few earlier Archaic sites and a few that date to the historic period, AD 1860s to the present.

Mesa Verde was well named by some unknown Spaniard. The flat cuesta that slopes gradually to the south is indeed green. There are three main vegetation communities in the park: piñon-juniper woodland which is dominant at the south end of the mesa, mountain shrub at the north end of the mesa, and Douglas fir on the north facing escarpment.

Fires have been suppressed in the park since its establishment in 1906. Consequently high fuel loads have developed in many areas of the park. There have been several major fires in the park: 1934, 1959, 1972. The last major fire, the Long Mesa fire, was in 1989.

THE LONG MESA FIRE

The Long Mesa fire burned approximately 3000 acres. The fire started in a dense stand of piñon-juniper (fig. 1) and spread north moving into the mountain shrub community and finally burned itself out descending the north escarpment in a Douglas fir community. The fire started on a hot, dry, windy day in early July and burned for two weeks. The effects of this fire on the park's cultural resources will be discussed in terms of the direct effects of the fire, and the effects of fire suppression activities.

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Fire Suppression

Two key management decisions had a big impact on the effects of the fire on cultural resources. One decision was to fight the fire by hand—no heavy equipment was used. This decision was based on previous fire experience in Mesa Verde and in other park service areas with high densities of cultural resources, a common attribute of piñon-juniper woodlands in the Southwest. The second important decision was to assign an archeologist to each fire crew. Each archeologist was given a copy of the cultural resource base map for the area where they were working. Initially the archeologists were sent out with each crew to flag fire lines but as the fire was being fought, this changed to flagging areas to be avoided by line work, i.e. flagging the sites. Also all fire fighters were told of the significance of the cultural resources and the importance of avoiding damage to these resources. Because all work was done by hand and because there was an archeologist on each crew, there was virtually no damage to the cultural resources by fire suppression activities. Only two sites were damaged and in both cases the damage was very minor, one upright slab was chipped and one stone was displaced from a wall. There was no vandalism and no artifact piles. The only graffiti noted was minor and was not in the vicinity of a site. It is worth noting that the archeologists found that keeping ahead of the fire crews, flagging sites, was easier during the fire than during mop-up when people were spread much thinner over the landscape.

Figure 1.—This photograph shows the typical condition of the piñon-juniper woodland after the Long Mesa fire. Note the burned piñon pine and serviceberry and the heavily spalled sandstone boulder.

Figure 2.—The condition of a mesa top pueblo after the fire. The pueblo is located in the mountain shrub community.

Post-Fire Survey

Immediately after the fire was officially out, an archeological survey of the burn area was initiated. By overlaying a map of the burn area on the cultural resource base map, it was known that 194 recorded archeological sites were in the burn area. These sites varied from hearths to large pueblos, from surface sites to cliff dwellings, from prehistoric to historic structures. Of the 194 sites, 165 were relocated. Two of the 29 sites that were not relocated were probably consumed by the fire (wood structures). The others may have been missed because after the fire it was not easy to locate metal site stakes amongst all the ash and burned trees and bushes. Also some of these sites may have been misplotted originally or damaged by road maintenance between the time of the original survey and this resurvey. Twenty-three previously unrecorded sites were located and recorded during this survey. Most of these sites were located in areas that had been covered by a dense growth of shrub (better known as *Quercus goddamnus* to archeologists) and after the fire the sites in these areas were much easier to see.

Of the 188 sites evaluated for fire damage in the burn area (Eininger 1990:32), 49 (26%) were missed by the fire, 71 (38%) suffered low damage, 32 (17%) moderate damage, and 36 (19%) high damage. The 29 sites that were not relocated were not evaluated and so are not included in these totals. If any of these were totally consumed by the fire, as two may have been since they were wood structures, this would increase the percentage of sites in the high category. Of these 36 located sites suffering high damage, four were totally destroyed, and one room in two different cliff dwellings burned. The four totally destroyed sites were wood sweat lodges. Pack rat debris in the two cliff dwellings caught fire and resulted in incredibly hot fires burning in those rooms. Factors involved in defining low, moderate and high damage included fire intensity, vegetation loss, impact to artifacts, damage to rubble and amount of site area affected by the fire (ibid:11). The high category (fig. 2) covered such observations as vegetation on the site totally burned, soil and rock oxidized, spalling of exposed stone, scorched artifacts (ibid:32). Low was used to refer to sites that were partially or wholly burned over but with little visible impact because of low fire intensity. Moderate was somewhere between these extremes.

On the basis of this survey, sites were recommended for rehabilitation work: erosion control, water diversion, stabilization. Eighteen cliff dwellings in the burn area were stabilized in 1989 and 1990 and water diversion measures were taken as needed at these sites (Fiero 1991). Two talus slope sites were seeded. This was the only intervention in the burn area. No other seeding, planting or other erosion control measures were undertaken. Their was above average moisture in the fall, winter and spring of 1989/90 and vegetation returned to the burn area very rapidly.

Studies Undertaken as a Result of the Fire

Oppelt and Oliverius (1993) studied the effects of fire retardant on sherds and concluded that it was minimal. The amount of duff around the sherd was the critical variable in determining how smoke blackened the particular sherd became. Floyd-Hanna, Romme, and Hanna (1994) completed a vegetation and fuels inventory of the park, Romme and Hanna developed a vegetation map, and Floyd-Hanna and Romme (1993) studied the park's fire history by dating oak. There has been no research into the effect of slurry on stone, wood, ceramics. Duncan (1990) compiled an annotated bibliography on the effect of fire on cultural resources.

Actions Taken by the Park

The park now has a fire management officer who is responsible for fire suppression activities in the park. The park policy is still to put out all fires as soon as is practical and every summer there is a helicopter and helitac crew in the park for this purpose. There is also a fuel reduction crew in the park in the summer. They reduce fuel loads around park buildings by cutting trees and shrubs and removing the wood by hand. Park buildings have been prioritized as to their importance (Research Center which houses the archeological collections first, Museum second, etc.) and fuels are reduced around buildings based on this schedule.

CONCLUSIONS

Those archeological sites which are the most vulnerable to damage from a wildfire (see also Romme, Floyd-Hanna, Conner 1993) are wood structures such as hogans, cabins, fence lines. Also very vulnerable to fire damage are rock art panels because of rock spalling, and cliff dwellings which contain combustible material. Less vulnerable to damage in a fire are lithic scatters and water control devices such as check dams. Those sites with the least vulnerability to fire are buried unexcavated pueblos and pithouses. As important as site type in surviving a fire, is the type of fire suppression activities which take place during a fire. On the basis of the Long Mesa fire, there is no question that the lack of bulldozers and other heavy equipment and the use of archeologists on the fire lines reduced the amount of damage to the cultural resources.

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Western Juniper: An Evolving Case Study in Commercialization, Ecosystem Management, and Community Development

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Abstract.—The talk upon which this article is based was intended to stimulate exploration and marketing of juniper and piñon products. Ultimately, the objectives are to better utilize fiber harvested for ecosystem management purposes, and improve local community and tribal economies. The evolving case history of western juniper (*Juniperus occidentalis*) commercialization efforts, from an unofficial coordinator's perspective, is offered as an example of what could be done in the Southwestern United States.

INTRODUCTION

There are many parallels between the cultures, economies, and geography where western juniper exists (primarily Eastern Oregon, Northeastern California, and Southwestern Idaho) and the Southwestern United States. And similar to western juniper, there appear to be opportunities to increase the value of fiber removed for other management activities.

For example, it appears that markets for piñon-juniper novelties and high-end rustic furniture are wide-open. It is remarkable that *none* of the stores at Sky Harbor Airport, Phoenix, and few in Sedona, stock items made from Southwestern piñon-juniper species. Based on informal discussions with store owners, the absence of piñon-juniper items is more a problem of supply, than demand or price. In addition, there is infrastructure already in place for the piñon-juniper fuelwood industry, and only minor adjustments would be necessary to sort the type of high-quality logs desired by wood products manufacturers from lower quality material.

It is not unreasonable to assume that proceeds from the sale of piñon-juniper could be doubled, based on the market niches identified above. Realistically, however, more work is needed before this can happen: Basic marketing research should be undertaken to confirm market niches and buyers, and products should be tested in conditions replicating customer home or office environments.

Following is a brief description of the process and efforts made during the last four years to commercialize western juniper. The experiences discussed should be instructive to those contemplating ways to improve utilization and the value of fiber removed for other ecosystem management activities.

WESTERN JUNIPER COMMERCIALIZATION PROJECT BACKGROUND

Federal timber sales have declined drastically over the last five years in much of the Western United States. The decline in Federal timber availability, as well as changing markets and improved manufacturing techniques, have contributed to economic hardship and social dislocation, especially in small, timber-dependent communities.

The Winema National Forest, located in South-central Oregon, about four years ago organized a "focus group" of small, medium, and large wood product manufacturers, to identify critical issues, potential areas of cooperation, and who would consider working together with the Forest Service, and other government and non-profit economic development organizations. Further impetus to discussions was provided by the shutdown of

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several local mills: Over the course of just 18 months, 1,200 manufacturing jobs were lost out of a total regional manufacturing employment base of less than 4,000.

The "focus group" met informally three times and, as might be suspected, identified "supply" as the major issue facing the industry. Follow-up interviews with manufacturers were conducted by Forest Service personnel from the Forest Products Lab (Madison), Conservation and Recycling group, and Winema National Forest, using relationships established through the "focus group". Interviews were designed to define problem areas and refine what might be possible given resources available and manufacturer interests. An updated inventory of wood products manufacturers in the region was completed at the same time (Kent 1992).

Interviews yielded several partners, as well as some "doable" research projects or field manufacturing trials. High interest was also expressed about better utilization of and markets for western juniper (*Juniperus occidentalis*).

WESTERN JUNIPER WOODLANDS AND EXISTING INDUSTRY

Western juniper woodlands occupy approximately four million acres, primarily in Eastern Oregon, Northeastern California, and a small portion of Southwestern Idaho. It is the least-utilized wood fiber resource in this region, with an estimated volume of over 700 million cubic feet. About 40% of the volume is on private lands and 60% on lands managed by the Federal government (Bolsinger 1989; Gedney 1994, personal communication).

Historically, a small volume of western juniper has been harvested for fence posts and firewood. There are also small existing markets for juniper rustic furniture and novelties, and at least a thousand acres of juniper woodlands in Northeastern California have been harvested over the last couple of years for power generation biomass (Ward 1994, personal communication).

WESTERN JUNIPER REMOVAL

Landowners and resource managers east of the Cascade Crest are accustomed to hearing western juniper characterized as a "water sucking weed". Many have heard accounts of how old springs flowed once all the juniper was cut down. Dissenting voices about western juniper removal and eradication throughout its present-day range are few.

Juniper removal is usually undertaken by private landowners on their own or on a cost-share basis through governmental programs, such as the "Agricultural Conservation Program" (ACP), administered by the Agricultural Soil and Conservation Service (ASCS), and "Forest Service Stewardship Incentive Program" (SIP), administered by state forestry agencies. Due to lack of demand and markets, juniper removed by landowners and public land managers is often piled and burnt, or simply left to decompose after being knocked down or cut.

WESTERN JUNIPER COMMERCIALIZATION PROJECT

A fundamental premise of the "Western Juniper Commercialization Project" is that interested manufacturers will identify and explore their own markets, if well-prepared raw material (e.g. dried and surfaced) and assistance with technical problems are available.

The first effort to put raw material into the hands of manufacturers consisted of slicing and drying veneer. It was thought that sliced veneer would maximize value and yield from an inherently difficult tree to mill with traditional methods and in traditional lengths. Partners were recruited and samples distributed at several industry meetings.

Interest stimulated by the sliced veneer samples, and a local mill's willingness to experiment, led to a production run of juniper fencing material. A portion of the production run was dried in a dehumidification kiln, surfaced, and distributed to 14 different Oregon wood products manufacturers for prototype and market development. Another mill run was soon put together to test market landscape timbers and decking. A portion of this run was dried in a steam kiln and distributed to more interested manufacturers.

Early market exploration confirmed potential markets for: 1) Fencing (if material is partially dried before shipping); 2) Decking (especially higher-end radius-edge decking); and 3) Landscape timbers. There was also strong interest in higher-graded lumber for flooring, cabinets, furniture, interior paneling, novelties, as well as straight substitution for species which were becoming difficult and expensive to acquire. Additionally, markets were explored and confirmed for milling residual (composites), especially if the residual was in the form of "clean" chips (less than 6% bark content).

STEERING COMMITTEE AND PARTNERSHIPS

A "Juniper Forum" was held in 1993 to publicize western juniper commercial potential, biological concerns, and project accomplishments. Another goal of the "forum" was to increase networking and identify more potential partners. Over 150 people attended and there are now more than 300 listings on a western juniper mailing list maintained by an industry partner.

Membership on the "Steering Committee" is about equally divided between industry, government/non-profit, and landowners. Membership mix was designed to reflect the wide range of interests potentially involved in commercializing a new species. The "Steering Committee" gets together about four times per year at locations around the state, and meetings are open to all interested parties. Committee members recently toured the eastern red cedar industry in Missouri to learn about and compare techniques and markets for a species closely-related to juniper: Eastern red cedar (*Juniperus virginiana*).

The committee has helped the unofficial Forest Service coordinator define and prioritize proposed projects, and find partners and funding to make them happen. Projects are based on problems identified by industry, scientists, and other cooperators, and range from improving inventory information (to include more explicit ecosystem-related data categories) to solid wood drying trials.

Partnerships are necessary to make things happen, and they change according to project requirements and organizational or business interest. A common thread though, is that there is reliance on government, industry, and non-profit organizations and sources, rather than just one or another.

Over 40 different businesses, institutions, organizations, and agencies have actively participated in western juniper projects. This includes at least 25 different private firms, five research institutions (Oregon State University, University of Montana, Forest Products Lab, and Pacific NW and Intermountain Forest and Range Experiment Stations), three state forestry agencies (Oregon, California, and Missouri), Oregon Economic Development Department, three local county economic development and two Resource Development and Conservation (RC&D) organizations, as well as 10 Bureau of Land Management, Extension, and National Forest System offices in Oregon and California. Critical logistic and financial support has been provided through the Community and Rural Development programs, Forest Service Pacific Northwest Region, State and Private branch.

JUNIPER WOODLAND ECOLOGY AND RESEARCH

The ecological side of the "commercialization process" is not being ignored. Over a year ago, a position paper was put together for the "Eastside EIS" Team, mandated by President Clinton in 1993 as part of the President's "Forest Plan" (Pacific Northwest Region) (Swan 1994). Prominent field scientists from different institutions helped with this effort and, in part due to Steering Committee efforts and field scientist input, western juniper woodlands will be specifically addressed in this major policy document.

Contacts between the Forest Service coordinator and field scientists active in western juniper woodland research continue: A field demonstration area is being developed on private land to showcase the latest in harvest techniques and juniper management research, training sessions for key personnel who will have to administer increased juniper harvests on private lands are planned, and a work plan and budget are being investigated to better inventory key juniper woodland ecological attributes and commercial potential.

PRODUCTION AND FIELD TRIALS, AND MARKETING PROJECTS

Production and field trials involving juniper have lead to preliminary reports and descriptions for a variety of topics, as well as better definition of potential products and markets:

1. Slicing and drying;
2. Scaling methods comparisons;
3. Composites;
4. Interior stains and finishes;
5. Bending properties;
6. Pallets;
7. Fencing lumber recovery;
8. Harvest machinery comparisons;
9. Pellets and BTU;
10. Fasteners;
11. Bark as cement aggregate;

12. Shrink/swell properties of solid-wood panels.

Production and field trials in progress include:

1. Drying schedules;
2. Edge-glued panel working environment comparisons;
3. Moisture meter correction factors;
4. Furniture and cabinet parts;
5. Flooring;
6. Exterior stains and finishes;
7. Peeling characteristics and veneer markets.

Planned production and field trials, and marketing projects include:

1. Debarking;
2. Harvest equipment and techniques;
3. Log storage;
4. Production-level kiln schedules;
5. Another juniper forum;
6. Rustic furniture market niche ID and design;
7. Shavings;
8. Buyers/sellers data base;
9. Harvest and management demo area;
10. Newsletter;
11. Mulch;
12. Further bending product/market exploration.

OBSERVATIONS OF AN UNOFFICIAL COORDINATOR

Markets for western juniper are confirmed and industry interest is increasing. Interest will no doubt grow even faster as technical and economic problems are addressed. Following are observations from the perspective of an unofficial coordinator about what has worked and not worked, which may be valuable to others contemplating commercializing "under-appreciated" fiber resources:

1. **Stimulating Market Dynamics** - Well-prepared (e.g. dried and surfaced), raw material has to be available to manufacturers for product and market identification and exploration. New markets and niches are constantly being identified through this process.
2. **Ecology** - Ecological issues, such as watersheds and social systems, are directly affected by commercialization and should be addressed at the same time. Efforts can be coordinated and sometimes combined. For example, a better inventory of western juniper woodlands is needed for both ecological and commercial purposes. Based on discussions with scientists and industry, some data categories are similar and can be combined.
3. **Identification of Unique Characteristics** - It is important to identify a species' unique characteristics to assist marketing efforts, as well as dispel stereotypes. This may take research assistance, both in the lab and in field trials with manufacturers.
4. **"Eggs in One Basket"** - It is advisable to divide efforts between cottage-level manufacturers and larger commercial producers. Different markets and products will be identified.
5. **Problem/Project Definition** - A critical aspect of private, non-profit, and government cooperative projects is "problem and project definition". Government entities and industry need to do their homework about local resources before deciding there really is a problem and a need to involve additional outside organizations. A "team" approach improves problem and project definition. Team members should include representatives from entities with direct interest in a project's outcome, such as industry, local economic development organizations, research, government, and private landowners.
6. **"Doable" Projects** - Ensure that when projects are defined with industry and other affected interests, at least some are "doable" in the short-term, and have clear economic benefit and a reasonable chance of success. "Nothing begets success like success."
7. **Multiple Primary Producers** - More than one primary producer is needed before most manufacturers will commit to products and markets. Reliability is a bigger issue than size and volume. Sole sourcing is risky at this stage of the industry.
8. **Project Coordinator** - *Someone* needs to organize and coordinate. In the early stages,

government can contribute by helping to identify and combine different resources in the public and private sector.

9. **Communication** - Some form of regular communication is necessary to help things along and recruit more partners - newsletters, open forums, field trips, and meetings all help.

10. **Steering Committee Formation and Composition** - An informal "Steering Committee" or similar body is important to identify problems, prioritize projects, network, gain funding support, and look into the future. A conscious decision was made to integrate membership of the "Western Juniper Steering Committee" to reflect various interests, ranging from landowners to public land managers, and manufacturers to economic development organizations.

11. **Commitment and Time Line** - Commercialization of a new fiber resource is not a one-year, one-grant process. It takes consistent leadership, intense communication and networking, and constant refinement of which problems will receive highest priority.

12. **Federal or State Agency Support** - If government agencies want to have influence in how or what occurs, they have to find ways to assist and where assistance will be accepted. In the case of western juniper, the Forest Service has played a key role because of current legislation and funding programs, as well as the unique multi-faceted nature of its mission (which includes Research, State and Private, and National Forest system). Other organizations may play a similar role in other situations.

13. **Funding and Partnerships** - In addition to a "coordinator", funding is necessary for operations. As little as a couple of hundred dollars is often the difference between making something happen or a project falling apart. "In-kind" services or supplies are also necessary, but not feasible for everything. Partnership projects can become so logistically complex that minor problems cause major repercussions.

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Tres Piedras Piñon-Juniper Silviculture: A Partnership Project Between the USDA Forest Service and New Mexico State University

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Abstract.—In 1993, a Partnership Agreement was made between the Carson National Forest and New Mexico State University to examine the effects of thinning intensity on piñon-juniper woodland ecology on the Tres Piedras Ranger District. The goal of the project is to evaluate fuelwood harvesting effects on the regeneration of overstory species, wood production, and herbaceous ground cover. The project area had been harvested in large blocks, 60 to 90 ha, from 1979 through 1990. Preliminary surveys of the area indicate that these blocks were relatively uniform in initial basal area and edaphic conditions. This area provides an ideal laboratory for evaluating the effects of thinning intensity on the ecological processes on piñon-juniper ecosystems.

INTRODUCTION

The piñon-juniper woodlands of the southwestern United States have, and continue to satisfy many of man's needs. This utilization occurred well before written records existed, with estimates of up to 20,000 years before present (Buckman and Wolters 1987). Use of the piñon-juniper woodlands includes the harvesting of tangible products as well as satisfying religious, spiritual and cultural needs (Miller and Albert 1993). Commonly harvested products include; products from the trees themselves such as fuelwood, fence posts, piñon nuts and juniper berries. Other products harvested from the piñon-juniper woodlands include; wildlife, forage for livestock and water via the watersheds encompassed by the woodlands. Nonmaterial uses of the piñon-juniper woodlands include recreation, including wildlife watching and hiking, and the spiritual and cultural associations many Native American groups have with these woodlands.

The piñon-juniper woodlands of the southwest are fast becoming recognized as one of the regions more valuable natural assets. The pressure on these woodlands for the products and uses stated above is increasing with the increasing population of the southwest. As this pressure escalates, the likelihood of a long-term disruption in the administration of the woodlands also escalates. This is especially true for the piñon-juniper woodlands administered by public land agencies who need to address the needs of many, sometimes divergent, user groups. The U.S.D.A. Forest Service has been developing sustainable, multi-resource management strategies for piñon-juniper woodlands to address these changing needs (Buckman and Wolters 1987, Tidwell 1987).

Administration of these woodlands can be perplexing. The relatively slow and poorly understood ecosystem dynamics of the piñon-juniper woodlands increase the difficulty of evaluating an administrative decision with regard to the ecosystem health of these woodlands. This point necessitates that the administration of piñon-juniper woodlands be based on an understanding of the biological and ecological processes of the woodlands. However, studying an ecosystem and

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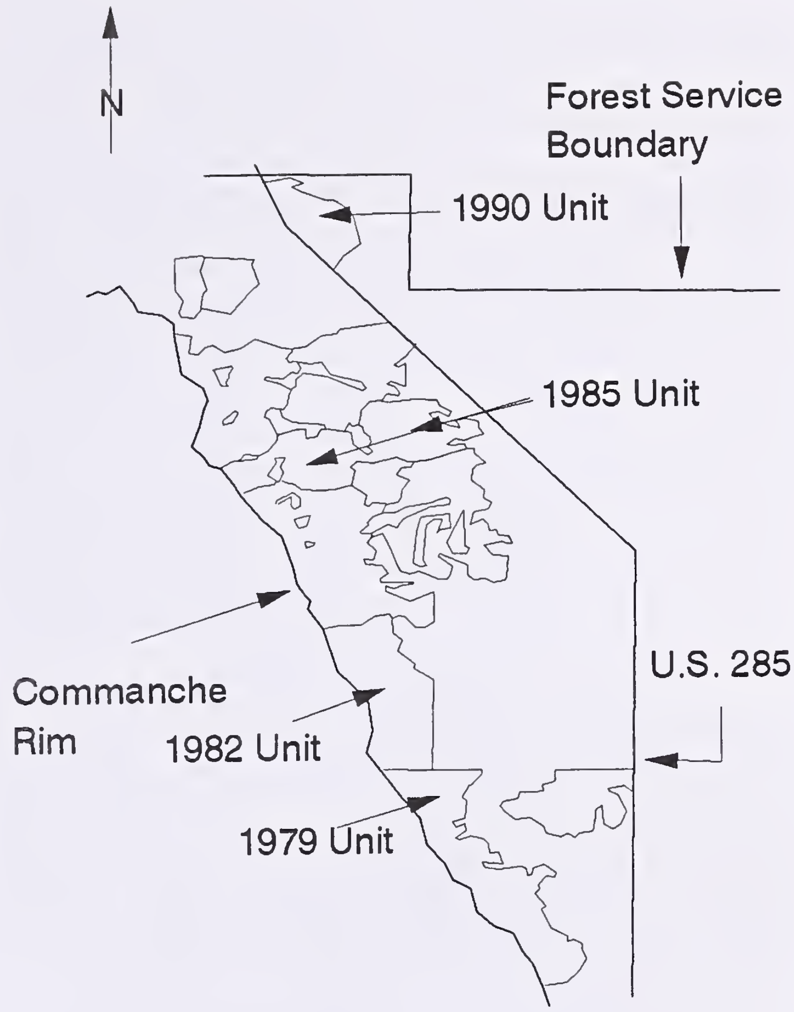
generating meaningful information to assist land managers can be quite costly. Buckman and Wolters (1987) noted that direct Federal funding for such studies is somewhat restricted. Understanding such restrictions and recognizing the need for such information on the piñon-juniper woodlands, the Carson National Forest and New Mexico State University entered into a Partnership Agreement in 1993. The Partnership Agreement provided a mechanism for the two organizations to collaborate without the exchange of funds.



THE PARTNERSHIP AGREEMENT

Project Location

The project site is located on the Tres Piedras Ranger District of the Carson National Forest in northern New Mexico. Specifically, the project area is south of the town of Tres Piedras, NM (Figure 1). The Comanche Rim is the western border of the project area and U.S. Highway 285 is the eastern boundary with the exception of the 1990 thinning unit which is immediately east of the highway (Figure 2).

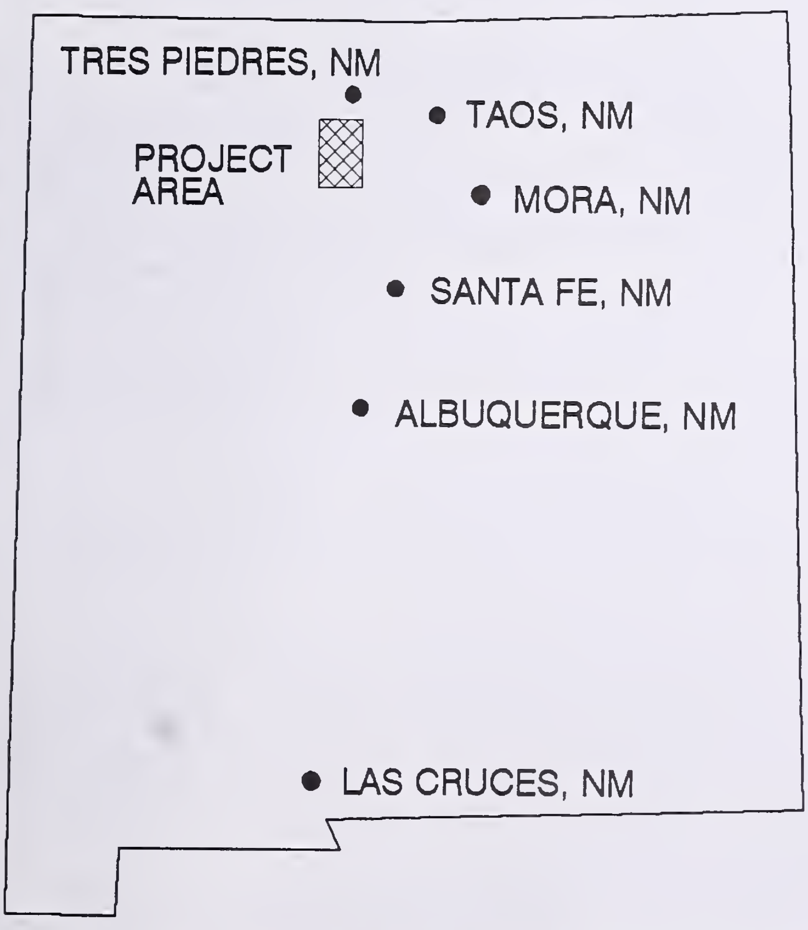


Figure 1.—Location map of the Tres Piedras piñon-juniper project area.

Site History

There are approximately 4,035,340 ha of piñon-juniper woodlands in New Mexico (Fowler et al. 1984). The Carson National Forest administers approximately 135,970 ha of piñon-juniper woodlands (CNF Plan Amend 7, 1990). Approximately 16% of the piñon-juniper woodlands administered by the Carson National Forest are within the Tres Piedras Ranger District.

There is extensive evidence of man's presence in the project area. Archeological surveys of the area indicate that hunter-gathers initially used the area during the Archaic Period (5,000 - 0 B.C.) with lithic scatters being the predominate form of archeological site (Elder 1994). European man's arrival in the area appears to be associated with the arrival of the southern spur of the Denver & Rio Grande Railroad in the 1880's (Carpenter 1994). A good review of this period can be found in *Logging on the Denver and Rio Grande* by Chappell. There is also evidence of wood cutting activity in the past as indicated by old, large stumps from trees felled by axes. Using Budy and Meeuwig's (1987) classification, these stands would be classified as old-growth, high-graded stands.

In 1979, the Tres Piedras Ranger District and the Carson National Forest initiated a program of thinnings in the project area. The initial prescription was to thin the stands to a residual spacing ranging from 6 x 6 m to 12 x 12 m (20′ x 20′ to 40′ x 40′). Leave trees were chosen primarily on the criteria of form. The intent to generate an uneven-aged or even-aged condition is ambiguous, however, this approach closely resembles Bassett's (1987) classification of a 2-step shelterwood system.

The thinnings which were imposed were not initially designed as a research study, but rather as a management prescription. The trees were marked for removal by several different Forest Service personnel over the time of the thinnings. The trees were felled and removed by the general public, predominately in the form of fuelwood. Many of the marked trees however, were not removed. This combination of different marking personnel and variable tree removal resulted in a wide variation of thinning intensities imposed on the project area. Also, the high frequency of archeological sites in the project area left many areas undisturbed by the thinning activity. These undisturbed areas, of variable sizes, could possibly satisfy the needs of control plots depending on their size.

The project area was also under an active grazing program prior to beginning the thinnings and throughout the thinning treatments. The project area continues to be grazed by livestock today.

Project History

In the Spring of 1992, the Carson National Forest Silviculturist, Jim Fitch and myself (John Harrington) visited the project area to discuss piñon-juniper silviculture alternatives for the Carson National Forest. Following several additional visits to the project area, we concluded that post-treatment measurements of the thinning treatments were needed in order to assess the effects of the treatments. There was enough variability in thinning intensity during each year's treatment that we felt useful information could be generated regarding thinning intensity effects on the woodlands.

In mid-summer of 1992 we met with the Tres Piedras District Ranger and staff to discuss alternatives to evaluate the thinning treatments. It was concluded during these meetings that the likelihood of independent funding for the project would be limited. However, by combining the two organizations resources we could achieve the mutual objectives of both organizations. Over the next nine months a Partnership Agreement was drafted and submitted for approval by New Mexico State University and the Carson National Forest. On October 20, 1993, with the signature of the Carson National Forest Supervisor, the Tres Piedras Piñon-Juniper Partnership Agreement was approved.

Project Goals and Objectives

The Partnership Agreement set four broad goals to be achieved. These goals were:

1. To develop a database on the piñon-juniper woodlands in the project area.
2. To examine the impacts of thinning intensity on ecological processes in the piñon-juniper woodlands.
3. To develop an efficient, and thorough plot inventory procedure that can supply information to assist in administrative land management planning; to help create a database of ecological and biological information to be used in continuing research endeavors.
4. The establishment of permanent plots in the piñon-juniper woodlands on the Carson National Forest, Tres Piedras Ranger District.

The situation on the project area lent itself well to a replicated treatment study over time. However, to ensure there is in fact replication of treatments over time, several assumptions needed to be made and validated. These assumptions were:

1. The different thinning years were on similar sites with similar initial site and stand conditions. These similarities include similar edaphic and climatic properties as well as similar stand structures prior to thinning treatments; (i.e. the treatments were imposed on one initial population).
2. Each thinning year had similar variability in thinning intensity; (i.e. replication of treatments over time).
3. There was sufficient magnitude in thinning intensity whereas replicate plots of each thinning intensity could be located in each thinning year; (i.e. sufficient within year replication of treatments).

Project Structure

The project is divided into two phases. The first phase involves the validation of the assumptions, obtaining preliminary wood fiber production effects of the thinning and obtaining the information necessary to design the second phase of the project. The second phase involves the bulk of the work towards the attainment of the main goals of the project.

Phase 1

Objectives

The specific objectives of the first phase of the project are:

1. To determine the magnitude and range of thinning intensity (based on ground line basal area) on the project area.
2. To provide variability information necessary to design the second phase of the project area.
3. To locate plots for use in the second phase of the project.
4. To generate preliminary data on the diameter growth response of residual trees.

Materials and Methods

Thinning Unit Determination—The project area had annual thinning tracts from 1979 through 1990. Each tract was cut during the late summer and fall (mid August through September). An exception to this was part of the 1988 thinning tract which was re-entered in 1989. Thinning years 1979, 1982, 1985, 1990 and the portion of the 1988 thinning tract not re-entered in 1989 were selected for initial inclusion in the project. A minimum of 25 plots were to be established in each of the five selected thinning years.

Thinning area boundaries were determined using aerial photograph interpretation from the 1990 air survey of the area and from records located at the Tres Piedras Ranger District office. Thinning unit boundaries were delineated on acetate overlays of the aerial photographs (scale = 1:12,000) and areas calculated using a Summagraphics digitizing table.

Following area size determination, plot locations were determined by randomly dropping a dot grid over the 1990 aerial photographs of each thinning unit. The distance between each dot was 5 chains. To sufficiently cover each thinning unit and satisfy the minimum number of plots for each thinning unit, a distance of 10 chains was used within and between plot transects.

Plot Procedure—At each plot center a 202 m^2 (1/20th acre) fixed radius plot was established. Plot center was marked initially with a wooden stake. (During subsequent visits to the plots, plot center was reestablished with 0.7 m steel marker and a plot tree was tagged using a 5 cm aluminum tag). The fixed radius plot had a radius of 8.02 m (26.3 feet).

Species and ground line diameter was recorded for all standing trees and stumps greater than 2.5 cm (1″) within the plot boundary. Ground line diameters were measured using tree calipers. Also, all advanced regeneration (possessing secondary needles but less than 5 cm ground line diameter) was recorded for the plot. Estimation of the number of seedlings not considered as advanced regeneration was also recorded.

Wood cores were taken from two overstory piñon trees at each plot. Cores were taken at a height of 1.37 m (4.5 feet) from the ground. Cores were placed in plastic drinking straws labeled with the appropriate plot information. Trees for coring were selected using the following system. The first piñon encountered proceeding clockwise from the north radius and the first piñon encountered proceeding clockwise from the south radius.

Data Analysis—Ground line diameter data was used to determine current plot basal area and estimate the basal area removed in the thinning treatment. These two values were combined to estimate the initial basal area prior to the thinning treatments. Graphic analysis and non-parametric analysis procedures (Wilcoxon Rank Sums and Kruskal-Wallis Test) were used to compare the distributions from each thinning year of the initial basal areas and thinning treatment intensities. All analysis were performed using the SAS 6.03 statistical analysis software programs (SAS Institute, Cary, NC).

Tree cores were analyzed in the laboratory to determine tree age and annual increment from 1969 to the present (fall/winter 1993). Cores were extracted from the plastic straws and stained using a phloroglucinol staining procedure as outlined by Patterson (1959). Annual ring widths were measured for the previous 25 growing seasons (1969 through 1993) to provide reference contrasts from site to site with regard to diameter growth rates. Ring widths were measured under a binocular dissecting microscope using a 1.2 magnification setting with 10X ocular lenses. One standard ocular lens was replaced with a 10X calibrated ocular. The calibrated lens allowed for the determination of ring widths to the nearest 0.1mm.

PRELIMINARY RESULTS

The 202 m^2 acre plots of the first phase have been established. Analysis of the data from these plots is still being conducted. Initial evaluation of initial basal area indicate that the 1988 thinning unit was not similar with regards to basal area prior to the thinning treatment. Both non-parametric procedures used to

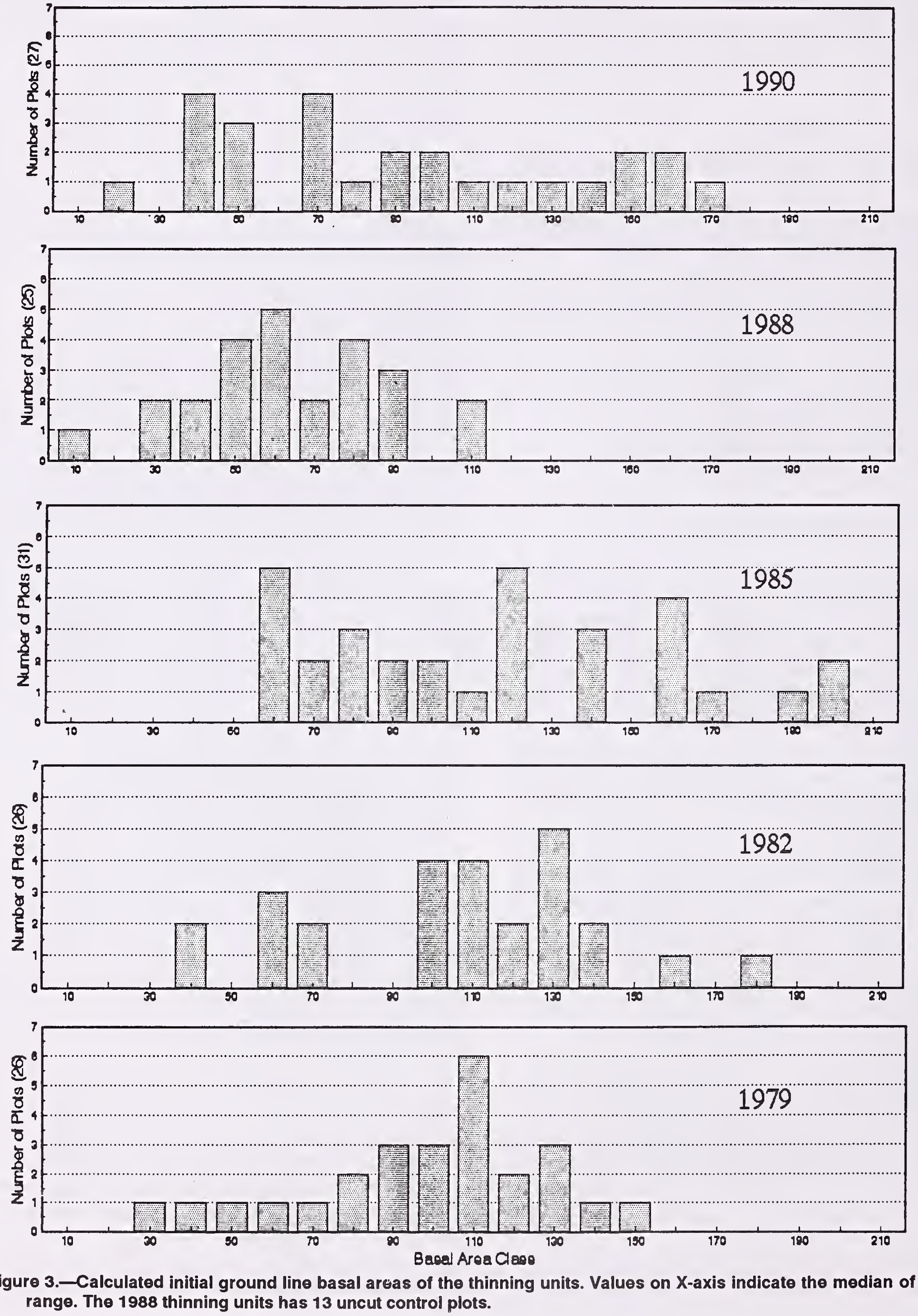


Figure 3.—Calculated initial ground line basal areas of the thinning units. Values on X-axis indicate the median of the bar range. The 1988 thinning units has 13 uncut control plots.

evaluate the initial basal area data indicated the 1988 thinning unit did not have the same distribution as the other four thinning units. The initial basal area of the 1988 thinning unit ranged from 10 ft^2/ac to 110 ft^2/ac (Figure 3). The initial basal area for the remaining four thinning years being evaluated, 1979, 1982, 1985, and 1990, ranged from 20 ft^2/ac to 200 ft^2/ac (Figure 3).

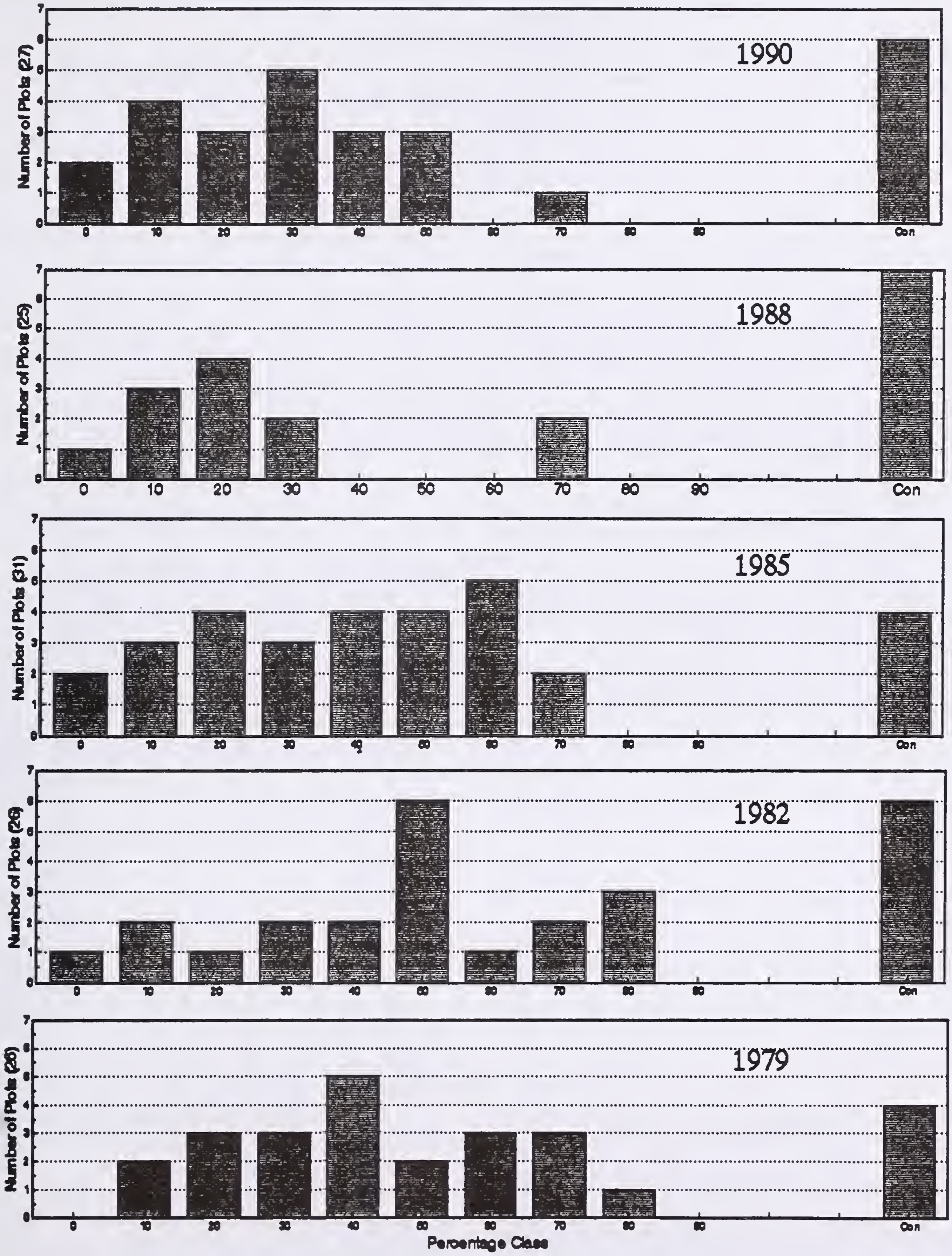


Figure 4.—Percent of initial basal area removed by plot frequency for the 1979, 1982, 1985, 1988, and 1990 thinning units.

The non-parametric analysis of the percent of initial basal area removed (thinning intensity) also indicated that the 1988 thinning year was not representative of the other 4 thinning years being examined. This discrepancy of the 1988 harvest can also be seen graphically. Only 2 of the 25 plots measured had greater than 30% of the initial basal area removed (Figure 4). The other 4 thinning years had a much greater frequency of heavier harvests (Figure 4).

Phase 2

Objectives

The objectives of the second phase of the project are less defined at this point. Specific objectives will not be developed until the analysis of the first phase data is complete. However, several areas which will be addressed have been defined. These areas include:

1. Examination and evaluation of spatial and temporal trends in regeneration conditions involving overstory species.
2. Examination and evaluation of edaphic and microsite factors impacting regeneration of overstory species.
3. Examination and evaluation of the diversity and abundance of herbaceous ground cover.
4. Examination and evaluation of the wood fiber response in residual overstory species.
5. To provide a thorough inventory (database) of species present and their distribution on the sites for the establishment of long-term studies.

Materials and Methods

Exact plot procedures have not yet been determined for this phase of the project. However, it will involve a combination of fixed size plot and variable size plot techniques to satisfy the objectives of this phase.

SUMMARY

The work thus far indicates that the 1988 thinning year will not be part of the replication study. Further evaluation of the age and diameter growth data will provide further information on whether the four remaining thinnings units can be considered as originating from a single population. Also, the analysis of the tree ring data will provide some preliminary information as to the effects of the first entry removals on residual trees.

Completion of the first phase should be done by November 1994. Field work should begin on the second phase early in the Spring of 1995.

ACKNOWLEDGMENTS

The authors of this manuscript would like thank several individuals for their assistance in this project. These people include Dan Rael, District Forester on the Tres Piedras Ranger District; Jack Carpenter, Forester on the Tres Piedras Ranger District; Henry Sandoval, Forestry Technician on the Tres Piedras Ranger District; Brett Coleman, Range Conservationist on the Tres Piedras Ranger District; and, Andy Lindquist, former Carson National Forest Supervisor and extremely helpful volunteer on this project. Thanks.

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Piñon Pine Seed Production, Collection, and Storage

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Abstract.—Key phases in the seed production cycle of piñon are summarized. Seed production is cyclic and good crops occur at 2-7 year intervals. During the 58-year period, 1936 to 1994, good seed crops were produced on the average every 4.1 years. Seed usually becomes mature and collectible in mid-September, which is about 26 months after the start of the seed production process. Seed yields on individual trees may exceed 20 pounds. Good seed stands produce an average of about 250 pounds of seed per acre in good seed years. Seed yields per acre can be increased through careful selection and retention of the best and most consistent seed producers, and elimination of poor seed producers by thinning in selected high yielding stands. Seed production can be further increased by transplanting good seed producers into high yielding stands and/or establishment of seed orchards. Seed orchards can be established by transplanting seed bearing trees selected on the basis of heavy and consistent seed production (transplant orchards), or with seedlings produced from seed collected from selected heavy seed producers (seedling seed orchards). Currently, most piñon seed is collected by manually picking seed from the ground. Collection of seed from individual trees in enhanced seed stands could be mechanized. In seed orchards seed collection can be highly mechanized through use of a net retrieval system such as used in southeastern pine seed orchards. Good quality piñon seed can be stored for 5-10 years or more when stored in sealed containers, at 5-10 percent moisture content, and at 0-20 degrees F. A recommendation is made for the establishment of a complete piñon seed enterprise which would include seed production, collection, treatment, storage and marketing.

INTRODUCTION

Probably the most important cash crop produced by piñon (*Pinus edulis* Engelm.) is the high quality, edible seed (nut) crop. There is a very high demand for piñon nuts because of their excellent taste and high nutritional value. Piñon seeds are sold as edible nuts and are used in candies, cookies, and other home and restaurant foods. In addition, piñon seed is also used for production of seedlings for landscaping purposes in the Southwest.

While piñon nuts have been a food staple by the American Indian in the Southwest for many centuries, and a significant portion of the nut crops remain in the Southwest, the majority of piñon nuts are shipped to large eastern cities, especially New York City (Lanner 1981).

The annual demand for pine nuts of all species (shelled and unshelled) exceeds 6 million pounds. In 1991 and 1992 it was estimated that as much as 7 million pounds of piñon nuts (unshelled) were harvested and an additional 5.3 million pounds of shelled pine nuts were imported (Delco et al. 1993) for a total of 12.3 million pounds of nuts for both years for an average of 6.16 million pounds per year. Annual imports of pine nuts into the U.S. appear to be inversely related to the availability of piñon nuts. Delco et al. (1993) reported that shelled pine nut imports declined from 4.0 million pounds in 1989, a poor piñon seed year, to 2.6 million pounds in 1992, which was a good piñon seed year. During this same period the import price per pound of shelled pine nuts increased from $2.19 in 1989 to $4.69 in 1992. And, it appears

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that piñon nuts are not currently being offered to the food industry at prices that are competitive with these import prices.

It seems logical then, that any increase in the annual supply of piñon nuts would be of substantial benefit to the piñon nut industry and, in turn, would provide added income to the people of the Southwest.

Increases in the annual supply of piñon nuts, at more competitive prices, can be achieved relatively easily by: 1) harvesting more seed during good seed years, 2) increasing seed yields per tree by selection of consistent high seed yielders, 3) increasing seed yields per acre by increasing the number of high seed yielders per acre, 4) using cultural techniques to increase seed yields per tree, 5) improving seed collection efficiency through mechanization, 6) use of long-term (up to 10 years) seed storage, and 7) development and utilization of a piñon nut marketing strategy.

Basic information on piñon seed production, collection and storage is provided in this paper that can be used in the development of a strategy for the establishment of a piñon seed enterprise, which would include all phases of a seed business including seed production, collection, storage, packaging, and marketing.

SEED PRODUCTION

Seed Production Cycle

For most north temperate coniferous species, the seed production cycle (the entire time period between initiation of reproductive initials and mature seed is produced) takes place over two consecutive growing seasons (2-year cycle) for species such as Douglas-fir, the spruces, and true firs, or three growing seasons (3-year cycle) for most pine species, including all of the piñon species (fig. 1).

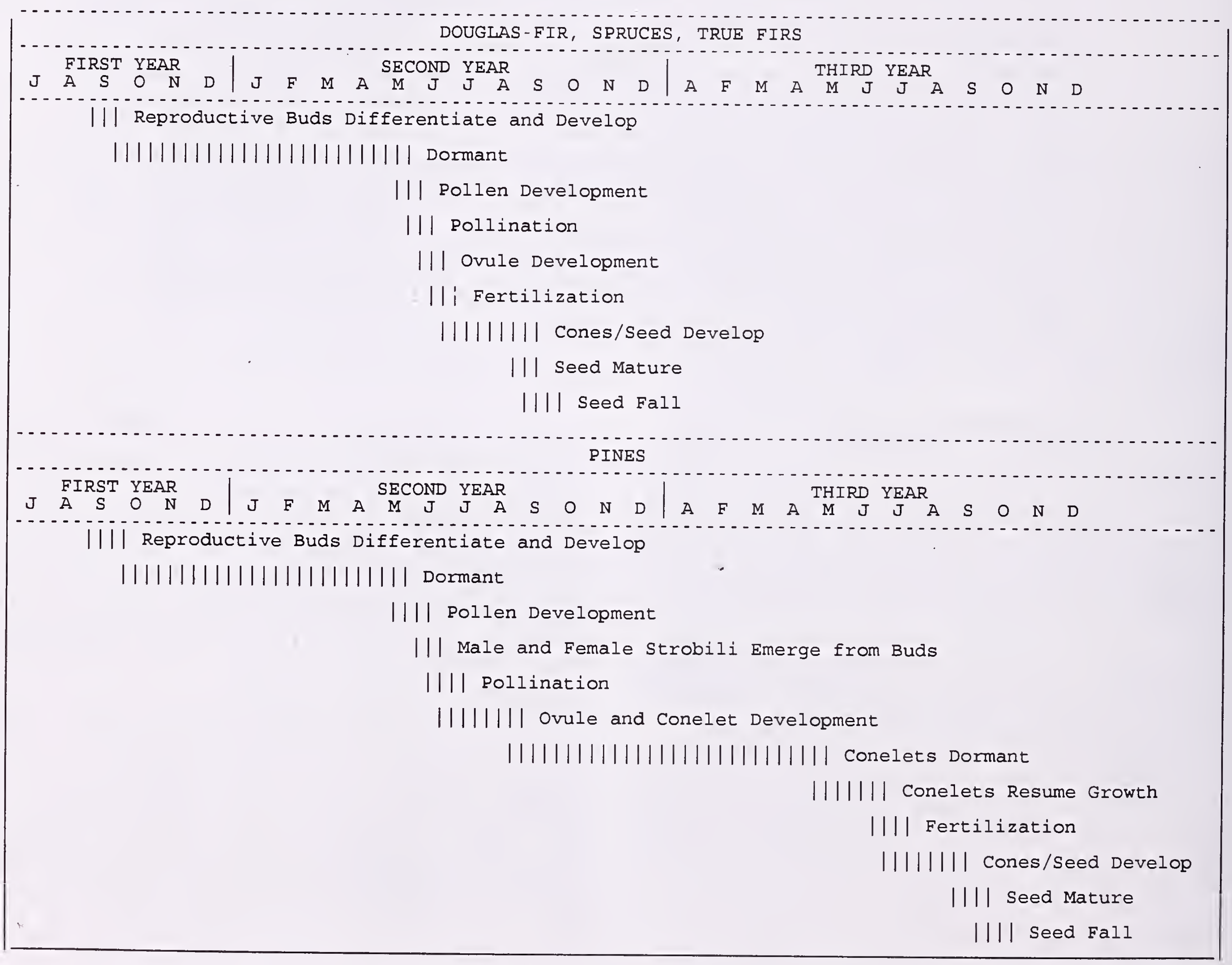

Figure 1.—Cone and seed production cycles of Southwest conifers.

In the Southwest, male and female reproductive structures in the conifers are initiated in late summer and mature male and female reproductive structures (strobili) emerge from reproductive buds the following spring. In the 2-year cycle species, the remainder of the seed production cycle from pollination to seed maturity, occurs between May and September of the second growing season. In contrast to the 2-year cycle species, most of the pine species, including piñon, require another full year for mature seed production to occur. In Southwestern pines, male and female reproductive structures are initiated in late August and September, after height growth has been completed, of the first growing season. Growth of these initials is completed by October. These structures remain essentially dormant until they emerge from the reproductive buds in late May to early June of the second growing season. This stage is followed shortly thereafter by pollination. At this stage, mature pollen grains are shed and disseminated by wind to females, usually on adjacent trees. After reaching the females the pollen grains germinate and form pollen tubes. The pollen tubes and ovules, which later develop into seed, then start to rapidly develop; but their growth is soon arrested and these structures remain essentially in a resting condition throughout the remainder of the second growing season and second winter. Growth of the dormant females resumes about one year after pollination in late May to June of the third growing season. Fertilization, the fusion of a single sperm cell (male) and an egg cell (female), then occurs in late June to early July of the third growing season. The fertilized egg then divides and differentiates to form the embryo. Soon after fertilization the cone and enclosed embryos rapidly develop and the cones and seed become mature in late August to September of the third growing season. These key phases in the seed production cycle of piñon, first described by Little (1938a and b), are summarized in Table 1.

Table 1.—Key phases in the seed production cycle of piñon [1].
Pinus edulis Engelm

First Year
1. August 15 - September 30
   Buds containing male and female primordia differentiate and develop.

Second Year
2. May 15 - June 15
   Male and female reproductive structures (strobili) emerge from buds.
3. June 15 - June 30
   Pollination occurs.
4. June 15 - August 31
   Rapid conelet and ovule (develop into seed) development.
5. August 15- December 31
   Conelets dormant.

Third Year
6. May 1 - May 15
   Conelets resume growth.
7. June 21 - July 7
   Fertilization occurs.
8. July 1 - August 31
   Rapid cone and seed development.
9. September 1 - September 15
   Seed mature.
10. September 7 - October 31
    Seed fall.

[1] *After Little 1938a,b and Ronco 1990*

Cone and Seed Crop Frequency

Cone and seed crops in the conifers do not occur on a regular annual basis; they occur periodically. This annual variation in cone crop production is related to and affected by the biological characteristics of individual species, internal nutrient supplies, and by external conditions such as weather, insects, diseases, and predation by birds and mammals (Eremko et al. 1989). Intervals between good cone crops may be as little as 2 years as in jack pine, lodgepole pine, and Scots pine; 3-4 years in the spruces and Douglas-fir; or every 4-5 years for other pines, such as the white pines, ponderosa pine, and piñon in the Southwest. Good seed crops in all southwestern pine species tend to be synchronous, occurring in the same year over large geographic areas; that is, when a good seed crop occurs in one pine species then there are usually good seed crops in the other pine species throughout the Southwest. In piñon, good seed crops usually occur every 4 to 7 years over the entire piñon area in New Mexico, eastern Arizona and southern Colorado (Barger and Ffolliott 1972). During the 58-year period, 1936 to 1994, reports in the literature (Little 1941, Barger and Ffolliott 1972, Betancourt et al. 1993) and seed collection records showed that good piñon nut crops occurred throughout the Southwest in 14 years, for an average of 4.1 years between commercially collectable crops. In local areas the interval between good nut crops may vary from as little as 2 to 5 years, or may be more than 10 years (Little 1941). Very rarely are good nut crops produced in consecutive years, such as occurred in 1991 and 1992 (Betancourt et al. 1993). It does appear that another good crop will occur in the fall of 1994, and if this occurs, then good crops will have been produced in 3 out of the past 4 years, a very rare occurrence.

Seed Yields

Cones often occur on trees 3 to 4 feet in height and 10 to 20 years in age, and significant numbers of cones may be produced on trees that are 5 to 10 feet tall and 20 to 30 years old. However, the largest crops are produced on mature trees which are usually 20 to 30 feet tall with wide, full crowns. Piñons of this size may be 75 to 100 years old, and individual trees may produce cones for centuries (Phillips 1909, Botkin and Shires 1948, Ronco 1990). It should be noted that while seed production is indirectly related to tree age, seed production usually begins after a tree reaches a minimum specified size and height; for piñon that height appears to be 3 to 4 feet.

Individual cones usually produce 10 to 20 seeds, but may produce up to 30 seed (Ronco 1990). During good seed years, good individual seed producers may produce up to 8 bushels of cones (Phillips 1909). At 3.3 pounds of seed per bushel and 1900 seed per pound (USDA Forest Service 1974), this translates to 26 pounds of seed or over 50,000 seed.

In good seed years piñon stands produce an average of about 250 pounds of seed, or 475,000 seed, per acre (Kline 1993), but the best stands may produce as much as 300 pounds of seed per acre (Phillips 1909). In any particular year, seed crops are either good or poor, but seldom intermediate (Ronco 1990). The total piñon nut crop harvested annually in New Mexico, eastern Arizona, and southern Colorado averages between 1 and 2 million pounds. Crops harvested during good seed years probably average about 4 million pounds, with a range of 3 to 6 million pounds. The largest piñon nut harvest, which occurred in 1936, totaled almost 8 million pounds (Little 1941).

The size of the nut crop harvested in good seed years is often regulated by the price that large seed dealers are willing to pay collectors; when seed supplies become plentiful, seed dealers lower the price paid to collectors. Increases in nut harvest during good seed years can be achieved simply by seed dealers providing modest increases in the average price paid to seed collectors from the current rates of $1-2 per pound to $2 or more per pound (Tanner and Grieser 1993).

SEED PRODUCTION IMPROVEMENT

Early seed production and seed yields per tree are under strong genetic control; consequently, seed production in stands can be increased substantially through individual tree selection. Seed production per acre can also be enhanced by concentrating seed production on the more productive piñon sites, increasing the number of good seed producers per acre, use of cultural treatments to increase seed production per tree, and by protecting the trees and stands from damaging insects and seed predators such as birds and rodents. By utilizing some or all of these methods and techniques, a relatively simple and cost efficient seed improvement program can be developed.

Stand and Individual Tree Selection

Currently, in the U.S., the piñon nut (primarily *Pinus edulis* Engelm.) is the only commercial nut crop collected entirely from "wild" trees (Little 1993). Some stands are inherently good and consistent seed producers and they are usually found on the more productive sites. These sites generally have deeper soils, with higher nutrient levels, and occur at higher elevations where annual precipitation is higher and better distributed throughout the growing season. A selection program can begin by conducting surveys on the more productive lands to locate the highest nut yielding stands. Identified stands should be marked and reserved for use as seed production stands.

Over 50 years ago Little (1940) recognized that some individual piñon trees are consistently good nut producers, and others, consistently poor. He also noted that some trees produce more cones than others and some trees produce larger cones with more nuts per cone.

The second phase of a selection program would be to identify individual high seed yielding trees within selected high seed yielding stands. The entire individual tree selection program could be accomplished within two to four years depending upon the number of individuals trees to be selected for inclusion in a seed production improvement program. Two types of individual tree selections can be made: Type 1 selections which are large, mature, high seed yielders that are to be left in place, and Type 2 selections which are relatively small (10-20 feet tall), young (15-20 years old), good seed producers, that can be transplanted into enhanced seed production stands or into orchards.

Enhanced seed production stands are those that have been selected as high seed yielders and enhanced by transplanting Type 2 selections among Type 1 selections, at fairly regular spacings to increase the number of high seed yielders per acre. Seed production could be further enhanced in these stands by using one of more of the following cultural treatments: cultivation to remove competing vegetation, irrigation, fertilization, and shaping of the crowns to increase the cone bearing surface.

SEED ORCHARDS

The most intensive, and therefore most costly, way to increase seed production would be to establish seed orchards on productive, agricultural type lands. Establishment and maintenance of piñon nut orchards would be similar to that of other nut orchards, such as the pecan and pistashio orchards in the Southwest.

Two types of orchards could be established: transplant orchards or seedling seed orchards. Transplant orchards can be established by transplanting Type 2 selections to an orchard site at regular spacings, such as 15 x 20 feet, after the site has been thoroughly prepared similar to an agricultural field.

Seed orchards can also be established with seedlings produced from seed collected from Type 1 selections. This type of orchard may appear to have little promise since piñon typically exhibits very slow growth under natural conditions. However, relatively fast growing seedlings can be produced as containerized stock that are intensively cultured in a greenhouse-shadehouse growing complex. When grown under these conditions 6-8 inch tall seedlings can be grown in 6 months and 3-4 foot tall trees in 3 to 4 years. If intensively cultured, container-grown trees, are then planted to fairly productive sites where they can cultivated, irrigated, and fertilized, they can be grown to moderate seed production size in less than half the time it takes under natural conditions and 8-10 foot tall trees can be grown in 10 years from seed.

During and after transplanting of Type 1 selections or planting of intensively cultured seedlings, the orchards should be periodically cultivated, irrigated, and fertilized to promote seed production. Established orchard trees can be shaped to increase the cone producing surface of individual trees. In addition, a pruning program, designed to remove basal branches up to 5 feet above the ground, should be used to increase seed yields per cone, increased seed size, and increase yield of full seed per cone (Montano et al. 1980).

The orchards should also be protected from cone and seed insects through maintenance of a intensively controlled pesticide application program and from seed predators, such as birds and rodents.

Potential Yields from Orchards

The following example of a small seed orchard illustrates potential seed production from a piñon transplant orchard. The type of orchard established, its size and age, and mix of cultural treatments used will determine actual amounts of seed that can be produced at any particular time after orchard establishment.

Orchard: Type—transplant orchard

Size —10 acres

Spacing—15 x 20 feet

Total trees—1450 (145/acre)

Assumptions: Time frame—10 years after establishment completed

Average seed yield—10 pounds per tree
Good seed year every 4 years

Seed Yields: 14,500 pounds of seed (1450 trees x 10 pounds/tree) every 4 years

3,600 pounds of seed per year

360 pounds of seed per acre per year

Plus any seed produced in intermittent years.

A seed orchard of this size is probably not an economically sound venture because of the initial high unit costs of establishment and maintenance; however, yields estimated here can be easily converted for any multiples of 10 acres. Prior to any orchard establishment a series of economical analyses would have to be made in order to determine the minimal orchard size needed to provide a modest economic return from the orchard.

SEED COLLECTION AND STORAGE

Collection

By far the vast majority of piñon nuts are picked by hand, one at a time, from the ground, after the majority of cones have opened. Perry (1922) estimated that 22 pounds of seed picked by hand is considered a fair day's gathering, although some especially dexterous persons can pick up to

40 pounds a day. More enterprising individuals spread sheets, blankets, tarps, plastic, etc. under individual trees, then shake the trees one or more times to dislodge seed from open cones. This method of collecting seed could be enhanced by mechanizing the collection process. This could be done by developing a harvester/shaker that would place a collecting surface around the base of the tree and thump or shake the tree to dislodge the seed. This method of collection would be most efficient if used in enhanced seed production stands or in seed orchards. In a seed orchard situation where the trees are all spaced at regular intervals, seed collection could be highly mechanized by use of a net retrieval system that is used in southeastern pine seed orchards (Edwards and McConnell 1982, McConnell and Edwards 1984). With this method of seed collection a net material, originally developed from carpet backing material, is laid in continuous strips under the trees prior to cone opening. When the majority of cones have opened naturally, individual trees can be shaken to dislodge seed. After essentially all of the seed has fallen onto the netting, the netting is retrieved by pulling individual netting strips from one end with a machine that collects the seed and places it into collection bins as it rolls the netting onto storage rolls.

Seed Storage

Routinely, unshelled pine seed can be stored successfully for up to 10 years, or more, when it is stored in sealed containers, at temperatures of 0 to 20 °F, with moisture contents between 5 and 10 percent. Unfortunately no published information is currently available listing the optimum, long-term storage conditions for piñon to maintain seed viability, and nutritional status and taste of the nuts. Piñon seed, however, can be stored under these conditions for a minimum of 10 years without appreciable loss in seed germination if the seed is of good quality when it is put into storage. Research and/or administrative studies are needed to determine the optimum long-term storage conditions necessary to maintain seed viability, and the high nutritional value and taste needed in the commercial nut industry.

RECOMMENDED PIÑON SEED ENTERPRISE

Currently, there are few commercial piñon seed dealers in the Southwest. Consequently, only relatively small amounts of piñon seed are available on a consistent annual basis, and very little shelled seed is available to U.S. markets. However, there continues to be a very high demand for piñon nuts as reflected by the volume of pine nuts imported annually into the U.S.. Delco et al. (1993) noted "that there may be a real window of opportunity to market the piñon nut throughout the U.S. at this time" and "An understanding of the market place and the potential for developing a economic and environmental policy for growing, harvesting, shelling, and marketing piñon nuts is key to competing in the U.S. and world markets with these nuts".

A group of individuals and/or an agency in the Southwest having extensive holdings of piñon lands could take advantage of this opportunity by establishing and operating a complete piñon seed enterprise which would include: 1) purchase of seed from local collectors, 2) establishment and maintenance of a seed improvement program to provide additional seed on a more regular basis, 3) long-term seed storage, 4) development and use of nut roasting and shelling equipment, 5) seed packaging, and 6) a seed marketing program. Development of this type of enterprise could result in a more stable supply of piñon seed at competitive prices for the food, landscaping, and reforestation industries in the Southwest.

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Carrizo Demonstration Area Restoration of a Southwest Forest Ecosystem

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Abstract.—The Carrizo Demonstration Area is located on the Smokey Bear Ranger District, Lincoln National Forest. It encompasses 55,000 acres of National Forest and private land, and is comprised mainly of piñon-juniper forest. The Carrizo Demonstration Area was established in 1989 as a pilot project designed to restore and sustain watersheds, increase natural food production for wildlife and livestock, and increase biological diversity by managing the area based on ecological principles. The Carrizo program is a demonstration of the Forest Service's ecologically based, multiple resource management. The primary purpose is to provide stewardship of the land to achieve and sustain desired conditions, cooperative partnerships to plan and implement projects, and utilize research and technology to provide quality on-the-ground resource management and protection. Over 4,000 acres of multi-resource improvements have been planned and implemented thus far to begin a transformation of the area toward desired future condition. The desired future condition will be achieved when active accelerated soil erosion is stopped, steep gully slopes are stabilized, and permanent riparian vegetation is restored. A mosaic of vegetative structural age classes and densities will exist within the different ecotypes, moving toward a balanced and stable ecosystem. Enduring partnerships with landowners and permittees will be permanently established to aid in sustaining the desired condition of the land.

INTRODUCTION

The Southwestern Region is gearing up to implement a program that emphasizes an ecological approach to multiple-use management of the piñon-juniper ecosystem. The Lincoln National Forest started on a project about four years ago, called the Carrizo Demonstration Area. Much of the Carrizo area now contains large expanses of continuous canopy piñon-juniper forest. Under these present conditions, natural openings are dominated by young piñon (*Pinus edulis*) and juniper (*Juniperus monosperma*, *Juniperus deppeana*, and *Juniperus scopulorum*) trees, and historically open woodlands have become dense thickets. Due to the increased competition from trees, these ecosystems are devoid of the grasses and other vegetation that hold the soil in place, contribute to plant diversity, and provide food or cover for various wildlife and livestock. Much of the productive soil beneath these dense woodland stands has eroded away, leaving behind an extensive gully system which continues to transport silt-laden water into streams and rivers, and serves to lower the water table. The need for this project was brought about through the urging of area private landowners and grazing permittees, who for years have had to contend with the deposition of millions of tons of sediment that originated on National Forest land, as well as a steady decline in livestock grazing capacity due to a decrease in forage.

The piñon-juniper woodlands have gone through many changes over the past 20,000 years. Due to gradual global warming, they have migrated from lower elevations to higher elevations and extended their range from southern latitudes to northern latitudes (Betancourt et al. 1986). By the middle of the 19th century, most of the

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piñon-juniper woodlands in south-central New Mexico were located on steeper, rockier slopes, although transition zones existed between piñon-juniper and the short-grass rangelands and piñon-juniper and ponderosa pine (*Pinus ponderosa*). Much of the woodland area, in particular the lower elevation zone, was very open in appearance. It had been maintained in that condition by periodic fire. Tree ring studies in New Mexico indicate that many forests burned, on the average, at 7 to 10 year intervals (Stoddart et al. 1975) prior to settlement of the area.

But one of the most remarkable changes occurred during the last 100 years. During the late 1800's and early 1900's, much of New Mexico received intense grazing pressure from domestic livestock. Lincoln National Forest records show that by 1902 on what is now the Smokey Bear Ranger District, 80,000 head of livestock were grazing on the Lincoln Forest Reserve (Hightower, 1902). To put this in perspective, today the permitted livestock - the grazing capacity is 5,000 head of livestock. Because of this heavy livestock grazing, the grasses were reduced to the point where they could no longer carry these periodic wildfires which kept the piñon and juniper trees in check. The reduction in available fuels in combination with fire suppression by public land management agencies, led to a proliferation of young piñon and juniper trees that throughout this century have increased, and are out-competing native grasses and forbs. As tree canopies became closed, grasses and plants that prevented erosion and provided forage for wildlife and livestock rapidly declined because they could not compete with the piñon and juniper trees (Evans, et al. 1988). Many of the perennial streams and springs, life-blood for the rich diversity of riparian and wetland ecosystems, were in part lost because of the excessive water requirements of these woodland trees (Ponce and Lindquist, 1990).

Livestock producers throughout the Southwest have for many years been concerned because of the long-term loss of forage productivity associated with this situation. Deer, elk, wild turkey, many songbirds, and other species of wildlife have been adversely affected by this change in habitat conditions. Private landowners adjacent to the National Forest have had to contend with the deposition of millions of tons of sediment that originated on the forest. Water, a scarce and precious commodity throughout the southwest, requires healthy forest watersheds. The quality, and potentially the quantity of water supplies for nearby communities, agricultural centers in Pecos River Valley and Tularosa Basin, and local wildlife and livestock are affected by the condition of the watershed.

MISSION

Our mission for the Carrizo area is to establish cooperative partnerships to aid in the development of sound land stewardship principles and to serve as examples in the implementation of land management activities to restore watersheds to satisfactory condition. Stewardship goals also include providing for a variety of wildlife habitats, increasing plant and animal diversity, restoring the natural beauty of the landscape, and improving overall ecosystem health. Management strategies focus on soil stabilization practices, vegetation management, water resource development, vehicular travel management, and sound range management practices, and are based on the best scientific and management information available.

The desired future condition will be achieved when active accelerated soil erosion is stopped, steep gully slopes are stabilized, and permanent riparian vegetation is restored. A mosaic of vegetative structural age classes and densities will exist within the different ecotypes, moving toward the balance and stability which occurred prior to European man's settlement of the area. Prescribed fire will be introduced to resemble the natural fire frequency that evolved with, and shaped the natural ecosystem. Enduring partnerships with adjacent landowners, traditional and non-traditional users, and nearby communities will be permanently established to aid in sustaining the desired condition of the land.

ECOLOGICAL APPROACH

The focus in the development of the Carrizo project was the recognition that all resources are interrelated and the integration of all resources into a management system is essential for long term success. Each aspect of the project was evaluated for it's effects on all resources, including the human environment. Our past custodial management philosophy for piñon-juniper ecosystems has led to a steady decrease of resource values (Doughty, 1987). The Carrizo area interdisciplinary planning team devised strategies to restore and sustain woodland watersheds. The major identified

CARRIZO DEMONSTRATION AREA TERRESTRIAL ECOSYSTEM SURVEY MAPPING UNIT PRESCRIPTIONS				
TES UNIT	TOTAL ACRES	SLOPE	DFC DESCRIPTION	MAX. OPENING SIZE
3	6,284	0 - 15%	Grassland/Savannah	10 - 200 Ac.
7	2,853	0 - 15%	Savannah/PJ Woodland	1 - 30 Ac.
8	3,908	15 - 40%	PJ Woodland/Oak Woodland	1 - 10 Ac.
11	1,404	0 - 15%	Grassland/Savannah	10 - 100 Ac.
265	1,449	0 - 15%	Savannah/PJ Woodland	1 - 30 Ac.
3014	1,499	+ 40%	Oak Woodland	0 - 4 Ac.
302	3,154	15 - 40%	Ponderosa/PJ Woodland	0 - 4 Ac.
3034	5,057	+ 40%	Ponderosa/PJ Woodland	0 - 4 Ac.
3054	2,212	+ 40%	Mixed Conifer	0 - 4 Ac.
3074	2,209	+ 40%	Mixed Conifer	0 - 4 Ac.
311	3,527	0 - 15%	Ponderosa/PJ Woodland	0 - 10 Ac.
336	2,516	15 - 40%	Savannah/PJ Woodland	1 - 20 Ac.
3404	1,276	+ 40%	Oak Woodland	0 - 5 Ac.
3484	2,094	+ 40%	Oak/Mt. Mahogany	Open
401	2,179	0 - 15%	Savannah/PJ Woodland	1 - 30 Ac.
402	5,781	15 - 40%	PJ Woodland/Oak Woodland	1 - 15 Ac.
404	1,345	0 - 15%	Ponderosa/PJ Woodland	0 - 10 Ac.
405	2,475	15 - 40%	Ponderosa/PJ Woodland	0 - 10 Ac.

elements of this program are watershed, wildlife, vegetation, ecology, and range management. Through the use of the Southwestern Region's Terrestrial Ecosystem Survey the team identified high priority potential treatment areas as those with unsatisfactory watershed condition and high soil productivity. The Terrestrial Ecosystem Survey is also used as the basic ecological unit to display objectives and prescriptions for desired future condition. The planning team compared the existing condition with the desired condition to develop a list of possible management practices and prescriptions for each Terrestrial Ecosystem Survey mapping units.

The following table displays the major Terrestrial Ecosystem Survey mapping units and their desired condition descriptions:

With the help of cooperative partnerships, treatments to produce desired conditions have included rehabilitating gullies by constructing small dams and reshaping gullies; establishing native vegetation to stabilize the soil by thinning trees for fuelwood, removing unwanted trees excess trees through mechanical means, prescribed fire, and by reseeding disturbed areas; providing dependable water supplies for wildlife by restoring and protecting riparian areas, installing inverted umbrella trick tanks, and developing existing springs; increasing overall forest health through thinning or harvesting trees in diseased or overstocked timber stands and through prescribed fire; and establishing travel access in line with resource needs by closing or obliterating unnecessary roads, relocating roads to more stable or suitable areas, and maintaining necessary roads and trails.

STEWARDSHIP

The restoration of watersheds is designed to stop excessive downstream sedimentation, preserve soil productivity and increase the duration of channel flows. In addition to stabilizing watersheds, benefits of the ecosystem approach being implemented include increased wildlife habitat capability, improved rangeland condition, increased visual diversity, and an increase in supply of forest products such as fuelwood, fence posts, vigas and poles. Once ecological restoration is established, the emphasis will be on sustaining a healthy ecosystem. Sound range management practices, such as deferred rotation grazing, fuelwood harvest, and the use of prescribed fire to maintain diversity, will be used to achieve a sustainable ecosystem. Where treatments have been implemented, watershed conditions have improved dramatically. Cool season native species of grass and forbs which were once thought to be lost have returned in abundance. In several drainages, springs have begun to flow again, creating many opportunities to establish or enhance riparian vegetation. As a result of these changes, many species of wildlife which were declining in numbers have returned to the area. A more diverse setting across the landscape has increased the scenic quality of the area, and will allow future resource management to more easily maintain a natural appearance.

Positive changes have even begun to occur on adjacent private land following treatments accomplished on National Forest. In one area, a pond located on private land had filled with sediment from past gully and sheet erosion transported by overland flow from the National Forest. The landowner removed 4,800 cubic yards of topsoil from this pond at the same time watershed restoration treatments were being implemented above the pond on the National Forest at the same time watershed restoration and vegetation treatments were being implemented above the pond on the National Forest. During Spring season, a spring which had not run in at least 35 years began to flow. The large spring, as well as many other new, but smaller springs in adjacent drainages, continued to flow throughout the summer, filling the pond with clean, clear water. In addition to baseflow increases, sediment coming from the National Forest was minimal. The landowner was able to stock the pond with trout and catfish, and is now the permanent summer residence for many waterfowl.

Opportunities to improve economies within the surrounding rural communities have been enhanced due to increased production of forest products such as fuelwood and poles for vigas, and an increase in big game wildlife. Partnerships with adjacent landowners and others have opened up new lines of communication and have substantially increased the level of trust with our public.

PARTNERSHIPS WITH PEOPLE

Partnerships are an integral part of this effort. Thirteen grazing permittees, three adjacent private landowners, New Mexico Department of Game and Fish, New Mexico Division of Forestry and Resource Conservation, New Mexico State University (NMSU), New Mexico Range Improvement Task Force, and NMSU Cooperative Extension Service participated in long range project development. Numerous field trips involving diverse groups of constituents have been hosted to inform the public of the need for a stewardship approach to management of the piñon-juniper ecosystem. Congressional representatives have been closely involved throughout both the planning and initial implementation phases of the project.

Grazing permittees and private landowners have been the primary partners with the Forest Service for site specific watershed restoration and vegetation management projects. Project implementation partnerships are designed to meet multi-resource objectives by achieving complete treatments. For example, commercial fuelwood cutters have historically harvested only those trees which can be sold for firewood, leaving hundreds of excess trees per acre. Commercial fuelwood cutters

within the Carrizo area now cut all trees not designated to be left. In fact, some partners can harvest a fuelwood area by written prescription, no longer needing the Forest Service to designated leave trees, creating additional savings to the government. Private landowners have purchased fuelwood sales on the national forest, and perform the same treatment on their adjacent private land. One landowner even entered into a cooperative agreement where vegetation on both National Forest and private land was managed with a prescribed burn.

In Fiscal Year 1993, a partnership involving South Central Mountains Rural conservation and Development, the Administrative Council of the Western Region's Sustainable Agriculture Research and Education Programs at the University of California at Berkeley, New Mexico State University and the Forest Service was formed to produce and distribute a high quality video portraying ecosystem management with the Carrizo Demonstration Area. The primary objective of the video is to educate a wide range of publics and develop support for an ecological approach to multiple-use management in the piñon-juniper woodlands. Participants in the video include agencies and environmental groups such as Soil Conservation Service, Forest Service, New Mexico State University, Nature Conservancy, American Wildlands, as well as many private individuals.

COLLABORATION WITH RESEARCH

An ongoing focus of the Carrizo project has been to attract interest from researchers to explore the many questions associated with managing piñon-juniper woodlands on a landscape scale. Many institutions, organizations and individuals are involved in ongoing piñon-juniper research. The Rocky Mountain Forest and Range Experiment Station is currently researching on-site soil productivity and modeling soil erosion in the Carrizo area. Other efforts include Southwestern Region's New Mexico piñon-Juniper management initiative, U.S. Department of Agriculture's cooperative Pecos River Basin Study, NMSU Cooperative Extension Service's rangeland watershed program, and New Mexico Department of Game and Fish - Habitat Improvement Stamp (Sikes Act) program.

PROJECT REVIEW

Since the inception of the Carrizo Demonstration Area in 1989, a number of projects have been implemented which are moving the area closer to the desired condition. With the help of cooperative partnerships, approximately 2,500 acres of unsatisfactory condition watershed have been treated through vegetation management to increase herbaceous ground cover, four miles of gullies have been treated through installation of structural improvements or gully sideslope stabilization, and five miles of roads have been obliterated to reduce another source of downstream sedimentation. Specific improvements for wildlife habitat have been implemented on almost 1,100 acres through prescribed fire or creation of wildlife openings. In addition, two wildlife water developments were installed, and 15 acres of existing riparian have been fenced to manage livestock grazing. Forest products sold as a result of vegetation treatments include 2,850 cords of fuelwood, 4,000 board feet of timber, and 500 small and medium poles.

Implementation of another project is underway to improve habitat for big game wildlife, as well as northern goshawk, using prescribed fire. Except under extreme conditions, use of prescribed fire to create openings within most areas of piñon-juniper is very difficult to accomplish successfully. This project was designed to thin seedlings and saplings prior to burning to create the necessary ground fuels to carry the fire. The fire will then result in a natural appearing mosaic of different habitat structural stages across the landscape. The natural food supply for big game wildlife as well as goshawk will be increased, and watershed conditions will be improved through increased ground cover.

CONCLUSION

The management situation in northern New Mexico is different than in south-central New Mexico, primarily from the cultural value standpoint and usage of piñon-juniper woodlands. But the ecological condition is essentially the same. Watersheds are being severely degraded to the point where site productivity is being lost. We cannot afford to lose much more topsoil from our woodland watersheds without seriously endangering production of commodities such as the piñon nut crop and fuelwood. As pointed out earlier, we have already experienced the loss of understory vegetation critical to wildlife and livestock. And possibly worst of all, damage to riparian areas has been extensive.

The ecological approach to multiple use management is a win-win proposition. Take piñon nut production for instance. Years of research and implementation have shown that if you thin selected piñon-juniper sites, larger piñon trees can be grown, and thereby increase the production of piñon nuts. By lopping and scattering slash from the thinning, ground cover would be increased, reducing erosion. And as shown by projects implemented within the Carrizo area, diversity for all resources would be increased.

For Carrizo, one of our basic objectives is to test different treatments for managing woodland watersheds. Some of the treatments will not respond the way they are designed. But the point is, we have already learned a great deal from past mistakes and successes, and we will continue to monitor our projects to learn and make the necessary adjustments to achieve the desired future condition. The Southwestern Region of the Forest Service has already taken a major step forward in recognizing the values and complexities of the piñon-juniper ecosystem.

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Silvicultural Systems for Piñon-Juniper

James R. Ellenwood[1]

Abstract.—Silvicultural systems and cutting methods can be applied to piñon-juniper stands. Several silvicultural systems are available depending upon the objectives of the landowner. Even-aged, uneven-aged, and irregular-aged silvicultural systems are described and compared for managing piñon-juniper stands. Each system involves the application of treatments to individual stands to achieve a desired condition. Silvicultural treatment an be maintained. A proposed density management regime is presented.

INTRODUCTION

The piñon-juniper woodland is the largest cover type in the southwestern United States covering 47 million acres of land, however, despite this superlative, it has often been considered the least managed. Low demand and product value for piñon-juniper motivated past management to emphasize forage values, however, the suppression of wildfire and periods of over-grazing has consequently reduced forage production. Over the last two decades, demand for fuelwood has increased dramatically, which has resulted in an increase in demand for fiber products from the piñon-juniper ecosystem. In more recent years there has been a paradigm shift towards ecosystem management, as a result, two major initiatives have been adopted by the USFS, the Piñon-juniper Initiative and the Forest Health Initiative. The intent of these initiatives is to restore the health of the piñon-juniper ecosystem. Silvicultural practices are some of the tools that can be used to accomplish this objective. The intent of this paper is to present some of these available tools and to present them within the perspective of ecosystem management.

SILVICULTURE AND ECOSYSTEM MANAGEMENT

Silviculture is the most ancient conscious application of the science of ecology; the association arose before the word "ecology" was coined (Smith 1986). Silviculture relies upon ecological knowledge out of necessity. While ecosystem management is perceived to be a philosophical shift in management emphasis, the fundamentals of silviculture remain profoundly rooted in ecological principles. In other words, silviculture uses an ecological approach to accomplish management objectives.

The basic management unit for silviculture is referred to as a stand or site. A site is essentially the forest community from which tree life forms have a consistency of age, density, species, and structural composition. Silvicultural systems are applied on a site basis. The aggregate of many sites over a large area (10,000 to 100,000 acres) is considered a landscape. Depending upon landscape objectives, several silvicultural systems can be applied to various sites throughout a given landscape.

Ecosystem management emphasizes the bigger picture by looking at units of land over varying scales of time and space. An ecosystem management approach develops objectives for the landscape, from which the site objectives are derived to accomplish these landscape objectives. A specific site objective is not necessarily the "best" one for a given site, but can be one that contributes to the overall landscape objectives. The aggregate of many site objectives will meet the landscape objectives. For example, at any given time, there is a portion of the landscape providing forage, another portion providing old growth characteristics, and another portion providing wildlife cover.

Thus, silvicultural practices are used to maintain or establish forest ecosystems comprised of a

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changing mosaic of successional stages and vegetative patterns. Variations in individual sites can range from highly diverse forest stands of multiple species and structures to areas of relatively uniform vegetation and from areas of openings to areas of unfragmented continuous tree canopies (Bergsvik 1994).

ECOLOGICAL POTENTIAL, TES, AND THE APPLICATION OF SILVICULTURE

While the piñon-juniper woodland is often viewed as a single cover type, there is great diversity in its classification. Plant associations are used to describe the potential natural community. The potential natural community is often described in ecological surveys to determine site potential. Plant associations are used to determine what species composition and productivity can be managed on a site. By characterizing the potential of a site, comparisons can be made between various management strategies, for example, a site that has a strong woody vegetation potential may be too costly to maintain in a grassy condition.

The Terrestrial Ecosystem Survey uses the plant association and considers climate and soils. It is estimated that approximately 280 map units will eventually be described for the piñon-juniper cover type in the Southwestern Region. The Terrestrial Ecosystem Survey has been used to segregate landscapes into areas of common potential. From this, site specific data is collected and an existing condition is determined.

A site specific application of silviculture is documented as a silvicultural prescription. Silvicultural prescriptions are developed for a given site based upon the existing condition, the ecological potential of a site, the silvical characteristics of the desired species, and the management objectives as defined by the desired condition.

DESIRED CONDITION

Desired conditions are selected based upon management objectives. The desired condition needs to be cognizant of the ecological requirements of each of the desired species. Potential natural community is not necessarily the desired condition, but one of the bounds from which one is derived. For example, it may be desirable for a preferred wildlife species to maintain a seral successional stage by maintaining cool season grasses in a climax piñon-juniper plant association—the plant species desired need to be ones that are capable of growing on the site. The existing vegetation condition may also not be desired, for example, a site in which grasses are absent in the interspaces of piñon-juniper groups, the desired condition would be to have grasses in the interspaces.

There are three generalized management objectives which are often applied to piñon-juniper management:

Sustaining grassland - on areas which have historically been grasslands that have slowly reverted to piñon-juniper. This objective has been the subject of much debate. Since the principle objective is to maintain grassland species, the treatments applied are not considered part of a silvicultural system. However, some of the silvicultural treatments can be used to achieve this objective.

Sustaining woodland - on areas which have historically been piñon-juniper. This objective relies on the application of traditional silvicultural systems. Sustaining woodland does not preclude the production of forage, since this creates a mosaic of stand structures throughout the landscape and each site and portions of sites periodically provides forage.

Sustaining woodland savannah - on areas where the historic density of piñon-juniper was relatively low and the grasses dominate the understory. This objective uses a modified application of silviculture since the principle objective is not purely managing the woodland, but managing the matrix of grassland and woodland upon the same site. One needs to account for the regeneration of the savannah woodlands the same as one needs to for the woodland objective.

Maximizing a single resource such as fiber or forage over a landscape may no longer be the desired condition under ecosystem management. A healthy ecosystem can provide some of those products and sustain the many parts that comprise it. Implementing a silvicultural prescription does not mean to maximize fiber production. Based upon landscape objectives, a desired condition is selected for each site. It is through the desired condition that site objectives are set. The practice of silviculture offers a means to manipulate vegetation to meet a variety of management objectives. These practices are not the vehicle for the establishment of the objectives, they are simply the means of achieving them (Bergsvik 1994).

SILVICULTURAL SYSTEMS

Silvicultural systems for piñon-juniper woodlands have been previously described by Bassett (1987), Ronco (1987), and Holland (1989). However, given the new directions of ecosystem management, a fresh look needs to be presented.

As in most sciences, terminology is often confusing. There is a distinction between silvicultural systems, methods, and treatments, which are often misapplied. A silvicultural system consists of a series of treatments that regenerate and control the stocking of a site through time. A regeneration method consists of one or more treatments used to establish a new forest on a site. A silvicultural treatment is usually a single operation applied to site.

There are 2 broad classes of silvicultural systems, high-forest systems, which rely upon regeneration by seeds, and low-forest systems (coppice), which rely upon regeneration by vegetative propagation such as sprouting.

The low-forest system is dependent upon the ability of a desired species to vegetatively propagate. In the piñon-juniper woodland, only one species, alligator juniper, is considered a prolific sprouter (Barger and Ffolliott 1972). This system is typically included under the clearcut method of the high-forest system, however, it is more correct to recognize the coppice method as its own distinct system based upon the regeneration source. If the desired condition is to maintain alligator juniper in a pure stand, then the coppice method is an option to consider.

In Region 3, the high-forest system is subdivided into three systems: even-aged, uneven-aged, and irregular-aged systems.

Even-aged Systems

Even-aged systems rely primarily on maintaining trees within a site at or near the same age with variations of no more than 20 percent of the site rotation. Even-aged systems utilize separate regeneration and tending treatments. Even-aged regeneration can be accomplished with three methods.

Clearcut Method - removes all trees from a given site in order to allow the stand to regenerate. Regeneration is achieved from seeding by adjacent areas, seed stored in the litter of the prior stand, or by planting. This treatment has the same appearance as a grassland restoration treatment, however the difference lies in the long term objective, which is to regenerate trees rather than to maintain grassland. The clearcut method is the simplest method to implement as well as the least expensive if planting can be avoided. This is the most effective method to temporarily increase forage and browse.

Woodland species produce large, wingless seeds which do not disperse very well by wind, however, bird species such as the corvids, have been well documented to disperse piñon and juniper seeds (Balda 1987). Typically, seeds are cached in areas that remain accessible during the winter, such as in tree cavities and the base of large trees. It is generally accepted that the clearcut method is less than reliable for establishing a properly stocked stand, however, the presence of cached seeds and presence of advanced reproduction lessens this problem. The clearcut method is also effective at controlling the larger dwarf-mistletoe infected areas.

Seed Tree Method - removes most of the trees from a given site leaving behind a few seed trees which provide the seed source for the next stand. This treatment has the same appearance as a woodland savannah treatment, however the difference lies in the long-term objective, which is to regenerate the site rather than to maintain the woodland savannah. This method is subject to the same dispersal limitations of the clearcut method.

Shelterwood Method - opens the crown canopy enough to encourage seed production and reduces competition for light and moisture to allow for the establishment of new seedlings, while leaving enough trees to protect the site from the drying effects of wind and too much light. This method is effective in controlling smaller dwarf-mistletoe infected areas. This method is usually implemented in several cuts or steps over a number of years.

The *prepatory cut* is used to develop windfirmness in leave trees, crown development for seed production, and accelerate the breakdown of a deep duff layer. None of these objectives appear to be necessary for most piñon-juniper stands (Bassett 1987).

The *shelterwood seed cut* leaves the best seed producing trees to establish seedlings. This treatment can coincide with the objective of providing piñon nut production since it requires the selection of good seed producing trees to provide for the next generation of trees.

The *removal cut* removes the sheltering seed trees to allow the newly established seedlings and saplings to grow freely. This treatment may be performed in one or more cuts. The period of time between the seed cut and removal cut may be as long as 40 years for a stand with a 200-year rotation age or twenty percent of the established rotation age of the stand (Bassett 1987). Under the final removal cut, one has the option of leaving reserve trees for continued production of piñon nuts or future snags.

When an adequately stocked understory of advanced reproduction exists, a simulated shelterwood method can be applied (Ronco 1987). The seed cut is not necessary and removal cuts are performed to release the established seedlings and saplings. Piñon seedlings and saplings are typically found underneath the canopy of the mature piñon. Caution should be taken in that the removal of the overstory cover may kill these seedlings. Mortality is reduced when seedlings are greater than one foot in height (Gotfried 1993).

Each regeneration treatment may include associated treatments. Prescribed burning is sometimes used to reduce slash and control competing vegetation as a preparation for the seedbed.

Intermediate Treatments - are applied to a site between regeneration events. Sanitation-salvage treatments are used to remove dead or dying trees, often to control an insect or disease outbreak. Precommercial thinning is used to control the stocking of young trees which are too small for commercial value. Commercial thinning is used to control the stocking of larger trees which have a commercial value. However, this is rarely practiced in the piñon-juniper woodland because low product value and high operating cost makes profitability highly marginal.

Uneven-aged Systems

Uneven-aged systems involve the manipulation of a site to simultaneously maintain continuous forest cover, regenerate desirable species, and to allow for growth and development of trees through a range of age classes. Within a given stand, the regeneration, tending, and harvesting treatments occur simultaneously. Uneven-aged systems require setting up a residual stocking level, a maximum diameter, a desired diameter distribution (usually described by a factor of q), and a cutting cycle. Because of the slow growth of woodland species, a cutting cycle of 50 to 100 years is recommended (Meeuwig 1983). A 40 year cutting cycle may be appropriate for woodlands stands which are capable of producing 10 or more cubic feet of wood per year (Bassett 1987). There are 2 methods of uneven-aged systems.

Single-tree selection method - selects individual trees in various diameter classes for removal. This method works well with shade tolerant species. While woodland species are considered shade intolerant, seedlings survive in moderate shade, often growing underneath the protection of mature trees and shrubs (Meeuwig 1983). This method is considered the best method to fit most natural piñon-juniper stand conditions. Regeneration is more reliable because the heavy seeds do not have to travel far to adequately occupy the smaller regeneration units, in addition, shading from the residual trees helps to protect the established seedlings (Bassett 1987). This method is effective for controlling dwarf-mistletoe infections which occur on a few isolated trees. Single-tree selection is a method to consider if its desired to re-establish the piñon-juniper and grass matrix where small interspaces between groups of trees are occupied by a grass component.

Group selection method - selects trees in groups throughout a stand for treatment. Regeneration openings are recommended to be no larger than twice the average height of the mature trees in the site (Bassett 1987). This method works well with shade intolerant species and can be used in piñon-juniper woodlands. This method is also limited by the previously stated dispersal limitations. This method is effective in controlling dwarf-mistletoe infections which occur in groups of trees. Group selection is another method to consider if its desired to re-establish the piñon-juniper and grass matrix where larger interspaces between groups of trees are occupied by a grass component.

Irregular-aged Systems

Irregular-aged systems are not recognized as standard silvicultural systems, but are a combination of the other two systems. This system relies upon maintaining trees in a multi-storied condition much like the uneven-aged system, however, not all ages are present. This system works well where regeneration is not a consistent periodic event and where the desired stand condition is not purely even-aged or uneven-aged. The group shelterwood method has been applied in the southwest to partially mimic the grouped distribution of ponderosa pine. This results in a stand that is multi-aged, but not all-aged. The application of this system to piñon-juniper woodlands has not been previously discussed and is being offered here as an additional tool for consideration.

Each of these practices can be applied at different levels of intensity to meet site specific objectives that address local conditions.

SILVICULTURAL PRACTICES AND RESEARCH

Piñon-juniper has been managed with many treatments applied throughout the last century. Many of the treatments have concentrated on restoring the grassland cover type. Given the vast amount of area, only a small portion of area has had a silvicultural system implemented. To illustrate the application of silvicultural practices three project areas are described.

Heber Ranger District Study Plots - a few silvicultural prescriptions are being studied by the RMFRES as part of an on going research project. Three treatment types are being studied, grassland conversion, simulated shelterwood removal cut, and individual tree selection. The single tree selection is based upon a Q of 1.2 (computed on a 1 inch diameter class), a maximum diameter of 15 inches with the upper limit being flexible depending upon the available trees, and a residual basal area of approximately 60 square feet (Gotfried, pers. com.). This study is currently on-going and the results will not be determined for several years. In general, the District sees this as an opportunity to implement more projects in the piñon-juniper.

Carrizo Ecosystem Management Project on the Lincoln National Forest has implemented several prescriptions for ecosystem management over the last 4 years. The primary objective for the project is for restoring the watershed condition. Several fuelwood treatments and pushes have been applied to restore what was previously a piñon-juniper savannah. Several thinning treatments have been applied to generate scattered slash in the interspaces. This provides shelter to protect the site and to establish grasses. Group shelterwood treatments were applied to sustain the piñon-juniper woodland (Edwards, pers. com.).

BIA-Albuquerque has set up several study areas on tribal lands throughout New Mexico to examine the effectiveness of several silvicultural treatments, such as single tree selection, group selection, shelterwood seed cuts, and piñon nut production thinnings. In addition to the study areas, the BIA actively manages the piñon-juniper woodland for fuelwood and piñon nut production. Many of the treatments are focused upon sanitation/salvage and clearcutting to control dwarf-mistletoe and Ips beetle outbreaks. Piñon nut enhancement is also important since it provides a source of income for various tribes (Woconda, pers. com.).

Table 1.—Single-tree Selection Diameter Distribution for Piñon-juniper.

Diameter class	TPA	BA	SDI
0.1 to 3.4"	130.8	3.0	9.7
3.5" to 6.4"	75.7	10.1	24.2
6.5" to 9.4"	43.8	15.0	30.0
9.5" to 12.4"	25.4	16.5	29.1
12.5" to 15.4"	14.7	15.5	24.9
Total	290.4	60.0	118.0

Throughout the Region the application of a silvicultural treatment is limited by the market conditions for the resultant commercial products. Commercial fuelwood purchasers need to be able to profit from their enterprise and many factors can influence this, such as the amount of the volume removed within a given area, the local species preference, average tree diameter, slash requirements, and access to markets. On the other side of the coin is whether on not you have quality contractors. The success of implementing a treatment hinges upon contractor performance. All of these are considered during project planning.

Desired Diameter Distribution

In today's political climate, there is a growing concern over the management of all National Forest lands. The negative appeal of even-aged management techniques has created the need for us to look at uneven-aged management techniques more seriously. The recommendations for the northern goshawk encourages group selection treatments to the ponderosa pine and mixed-conifer cover type. In the piñon-juniper type, there has been many applications of single-tree selection and group selection, however, few of these have closely followed a strict application to balance the desired diameter distribution. As a result, it is difficult to determine what is truly sustainable.

In light of this, the diameter distribution represented in table 1 is recommended from the Heber Study plots.

This distribution is based upon a Q of 1.2 (computed on a 1 inch diameter class), a top diameter of 15 inches with the upper limit being flexible depending upon the available trees and a corresponding adjustment to the trees per acre of the top diameter class, and a residual basal area target of approximately 60 square feet. For implementation, the residual trees per acre can be implemented on a three inch diameter class, making five classes.

It should be noted that this distribution is at a stand density index of 25 percent of maximum for piñon-juniper. This considered to be the onset of competition for trees. If the desired condition is to maintain a strong forage component, a lower residual density would need to be selected.

ADAPTIVE MANAGEMENT

The highest success in applying silvicultural practices in piñon-juniper has occurred on the more productive sites. On poorer sites, the application may not be as successful. On the Carrizo Project, the initial thinnings over a larger area are being applied at a very light intensity. The intent is to start the restoration of the interspaces. The subsequent treatments are intended to be progressively more intense. This approach allows managers to change direction as new information and ideas are developed.

In conclusion, management should be viewed as an adaptive process: we learn about the potentials of natural populations to sustain harvesting mainly through experience with management itself, rather than through basic research or the development of general ecological theory (Walters 1986). The challenge is to be creative, innovative, and willing to take acceptable degrees of risk in designing and testing new silvicultural practices (Bergsvik 1994).

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Trial Applications of Low-Impact Herbicides for Piñon-Juniper Control in the Southwest[1]

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Abstract.—A significant need exists to develop effective, efficient, safe, and environmentally sound approaches to control piñon-juniper trees, especially for small trees, those less than 6 feet in height. To meet this need, a new approach using a low-volume application of the herbicides Tordon 22K (picloram) and Spike 80W (tebuthiuron) in water was evaluated. Herbicides mixtures were applied to the base of selected trees just above the ground using a backpack sprayer. Tordon 22K was tested at 10, 20, 40, and 80 percent concentrations in water and Spike 80W was tested at 0.5 and 1.0 pounds of product in one gallon of water. This low-volume approach was selected to allow applicators to carry sufficient product and carrier into rough and remote areas. The goal was to only treat selected trees and avoid adversely affecting grasses and other nearby plants. The results of trial application done on the Gila and Lincoln National Forests show that satisfactory control of small trees can be achieved. The approach also may be useful for control of larger trees under selected circumstances.

INTRODUCTION

Piñon-juniper (P-J) woodlands occupy a vast acreage in the Southwest. Over the past 100 years, tree densities have increased many fold and trees have spread into adjacent ecosystems. This situation has and will continue to cause numerous adverse environmental and social effects. Although considerable controversy exists over the causes of the problem and past control measures, it appears there is general agreement that on-the-ground management actions are needed to restore deteriorating ecosystems and enhance protection of areas that will be in an unsatisfactory condition in the near future. An enormous opportunity exists to create and maintain healthy P-J ecosystems. The key will be to have effective, safe, economical, environmentally sound, and socially acceptable methods that can be used by those responsible for managing affected lands.

An excellent overview of the various management options and related recommendations is included in the publication entitled "Watershed Management Practices for Piñon-Juniper Ecosystems" (USDA Forest Service, 1993). Acceptable methods are available to some extent to treat larger trees, those above 6 feet in height, such as through fuelwood harvests. The control of small trees and sprouts, however, has proven to be a much more difficult problem. Hand methods (cutting, chopping, and grubbing) have and are being used, although the effectiveness, cost, and safety of these

[1]*All pesticides must be registered by appropriate State and/or Federal agencies before they can be used. Pesticides can be injurious to humans, domestic animals, desirable plants and other wildlife – if they are not handled properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.*

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techniques cause concern. Herbicides have been shown to be the most efficient, effective, and safe approach to control small trees, but they have not been widely used in recent years. A lawsuit in the 9th Circuit Court of Appeals and a subsequent temporary suspension of the use of herbicides on National Forest Systems lands in 1984 all but ended herbicide use on National Forests and other Federal lands in Arizona and New Mexico. This legal barrier no longer exists. In addition, certain herbicide formulations and application methods developed and used in the 1970's and 80's do not meet the needs of current resource managers. The high cost of compliance with the National Environmental Policy Act (NEPA) and the public controversy over the use of herbicides also contributed to the lack of herbicide use.

In 1993, we decided to take another look at the herbicide option for control of unwanted trees. A review of herbicide performance showed that picloram and tebuthiuron were the most promising products, since they were broadleaf and brush products, registered for range and pasture uses (Johnsen 1987; McDaniel and White-Trifaro 1987). A positive aspect for both of these herbicides is that they will have minimal effects on established grasses at application rates specified on their respective labels. It should be noted that both of these herbicides are considered "soil active" materials; however, we decided to test a new application approach of applying the herbicide directly to the base of target trees. A major objective of the herbicide evaluation was to attempt to develop a low-volume, selective application technique that could be effectively used to treat small trees, especially in rough and remote terrain, where other alternatives would not be appropriate. Broadcast applications and directed foliar sprays were excluded because of environmental concerns and operational constraints, especially the need for a large volume of water.

APPLICATION APPROACH

Low-volume, basal applications of Tordon 22K (picloram) and Spike 80W (tebuthiuron) mixed with water were evaluated. Tordon 22K is a liquid formulation and Spike 80W is a wettable powder. The herbicide mixtures were applied to the base of selected trees at ground level using a backpack sprayer with a diaphragm pump (fig. 1). A model 30 gunjet with a 0002 or DE-2 spray tip was used. This equipment is relatively inexpensive; the total cost being about $125. The major advantage of the backpack sprayer is that the pump is sealed at the factory and tested to 70 psi to prevent leaks. The herbicide mixtures were not applied to the soil; rather, they were applied to the base of trees and sprouts just above the ground. Tordon 22K was tested at 10, 20, 40, and 80 percent concentration in water and Spike 80W was tested at 0.5 and 1.0 pounds of product in one gallon of water. These different concentrations were tried to determine the lower limit of the product that might yield satisfactory control. Larger trees were also treated to determine if treatment success could be achieved. A band from 2-4 inches was sprayed on these trees. The widest band of herbicide mixture was applied to the largest trees and the band was reduced progressively as the diameter of the trunk decreased. Initially, the spray mixture was herbicide and water; however, a silicone wetting agent was added to the mixture beginning in March 1994 to increase the movement of the herbicide down the stem. The goal of the basal application technique was to only treat selected trees and not affect desirable trees and shrubs within two to three feet. The low-volume approach was selected to allow applicators to carry sufficient product and carrier into remote areas to optimize application efficiency.

Figure 1.—Backpack sprayer used to apply herbicides to the base of trees.

The tests were done on the Gila National Forest, North Star Mesa, and the Lincoln National Forest, Carrizo Demonstration Project site. Piñon pines (***Pinus edulis***) were treated at both sites; however, the juniper species were different. Alligator juniper, ***Juniperus deppeana***, a sprouting species, was the target on the Gila National Forest, and one-seed juniper, ***J. monosperma***, was the primary species treated on the Lincoln National Forest. Permanent rectangular-shaped plots were established and marked with stakes and flags to enable evaluation of treatment effects in the future. The applications were done by walking through each plot spraying selected trees. Treatments were applied in August and November, 1993, and March, 1994. Evaluations of effectiveness were made in November, 1993; March, 1994; and June, 1994. Additional evaluations are planned over the next six to nine months.

TREATMENT RESULTS

The results of the trial applications for both herbicides are very promising. After only three months, significant browning of foliage was observed in over half of the treated alligator juniper sprouts, seedlings and saplings of both juniper species, and piñon saplings. Larger trees showed some effects, although to an extent less than the smaller trees. Treatment effects were more apparent with the picloram mixtures, but tebuthiuron is a slower acting herbicide and the results are expected to improve over time. Treatment success continued to increase after six months, but few effects were observed on nearby untreated trees and shrubs. By nine months, foliage brown-out of trees on the Gila National Forest site exceeded 90 percent for the Tordon 20, 40, and 80 percent concentrations (Table 1). A 10 percent mixture of Tordon, which was applied six months previously, controlled about 70 percent of alligator juniper sprouts and seedlings. Since the levels of tree brown-out on the Lincoln National Forest are similar to that observed on the Gila National Forest, a separate table was not included. The mortality of piñon exceeded that of junipers on both treatment sites. On the Lincoln National Forest, exceedingly high treatment effects were observed on larger trees.

For trees less than 6 feet in height, the 20 percent Tordon mixtures produced control results as good as the 40 and 80 percent concentrations. More time is needed for to evaluate the 10 percent mixture, but it appears the lower limit that will yield satisfactory results could be below the 20 percent concentration level. Thus, the current cost for the herbicide will be somewhere in the range of $8-16 per acre. Also, the silicone wetting agent appeared to improve the movement of the spray mixture down the stem, which could be a critical factor when lower concentrations of herbicide might be used.

Although the Spike 80W treatments have not produced tree brown-out as high as that observed with Tordon 22K, the overall treatment success may be similar in a few more months. As shown in Table 1, the half pound per gallon of water mixture of Spike 80W yielded better initial foliage brown-out than the pound per gallon mixture. This was probably due to the higher volume of the spray mixture applied to each tree. The results on the Lincoln National Forest are similar, except no sprouting stumps were treated.

It will take more time before the final conclusions can be made about the effects of the various treatments, especially for the larger junipers.

Table 1.—Piñon-juniper herbicide trail results, Gila National Forest, North Star Mesa, Evaluated on June 1, 1994.

Plot No.	Date Treated	Herbicide	Foliage Brown-out (percent) Sprouts	Seedlings/Saplings	Larger Trees
1	8/23/93	Tordon 22K 20%	90+	90+	20
2	8/23/93	Tordon 22K 40%	90+	90+	20
3	8/23/93	Tordon 22K 80%	90+	90+	30
4	8/23/93	Spike 80W (1/2 lb./gal.)	60	60	10
5	8/23/93	Spike 80W (1 lb./gal.)	40	40	5
6	11/15/93	Tordon 22K 10%	70	70	10
7	11/15/93	TORDON 22K 20%	80	80	10
8	3/7/94	Tordon 22K 20%	80	80	10
9	3/7/94	Spike 80W 1/2 lb./gal.)	30	30	5

DISCUSSION

It appears that the spray mixtures flow down the stem following root profiles and the herbicide is absorbed by root hairs around the base of treated trees. Susceptible trees and shrubs within two to three feet of treated trees have shown little signs of herbicidal activity. Besides being selective, a major benefit of the basal application approach is that the herbicides are not applied to the soil.

The next step will be to focus attention on how to utilize this low-volume, selective application approach to achieve desired future conditions. A few possible circumstances where this new technique may be useful follow:

Create or Maintain Existing Openings. Treatment of undesirable or excess seedlings and saplings to create or maintain existing openings in P-J stands would be one of the most economical uses of this new application technique. It probably would cost less than mechanical grubbing, and a major advantage would be to avoid ground disturbing activities within protected areas.

Fuelwood Harvest Areas. Treatment of alligator juniper sprouts and excess seedlings and saplings would be another economical use following fuelwood harvest. This approach would be particularly desirable in areas where prescribed fire might not be an option.

Thinning. Thinning in P-J woodlands has been done to promote growth of remaining trees, release understory ground vegetation, and most recently, to create fuels to enable the use of prescribed fire. The low-volume, selective herbicide technique would be appropriate where trees are too small to be of commercial value or in rough and remote terrain. Removal of small trees that occur under larger trees would help to prevent fire from moving into the crown of the larger trees that are considered to be desirable.

Wildlife Openings. Large expanses of dense canopied P-J woodlands are common in the Southwest and offer little in terms of plant and animal diversity. A directed basal herbicide treatment could be used to create openings in selected areas across the landscape to increase diversity, release native plants, and reduce sheet erosion. Dense stands of smaller trees in inaccessible areas would be most suited for this approach.

Creation of Snags. Snags are important habitat for several birds and other wildlife. Creation of snags may be one of the few economical uses of herbicides to treat large trees. Areas that are inaccessible would be best suited because snags are usually harvested by the public in accessible areas.

Protection of Archaeological and Historic Sites. In some cases, these sites can be adversely affected by erosion and arroyo cutting and may need to be protected through watershed improvement efforts. Since mechanical treatments can damage these fragile resources, management options are often limited. Herbicides may offer an attractive option to restore P-J woodlands to a healthy condition to provide prolonged protection of these sites.

CONCLUSIONS

Ecosystem management is a concept that will guide vegetation management on public lands in the future. Ecosystem management involves using an ecological approach to achieve multiple-use objectives by blending the needs of people, environmental values, and scientifically based techniques. It must be realized that P-J ecosystems, which are threatened or are being damaged by an "over abundance of trees", can only be restored to a healthier state through the removal of trees. All available methods—fuelwood harvest, mechanical methods, prescribed fire and cultural practices, like limiting livestock grazing—will need to be used. Herbicides will be one of these tools to achieve management objectives, used individually or in combination with other methods, as part of an integrated vegetation management approach.

There has been a wealth of information to show that herbicide formulations used in modern resource management are "safe" when used properly. Herbicides are among the most rigorously tested consumer products on the market today. Before they are registered for use, herbicides must meet strict standards of human health protection and environmental safety. In addition, a major benefit of the herbicides evaluated in this study is that they provide selectively through both directed application and the inherent selective nature of the products. It will be particularly important to have thorough environmental analyses for projects on Federal lands, which incorporate available risk assessments, to respond to possible challenges to proposed herbicide projects. It is important to note that risk assessments developed in recent years, such as the Risk Assessment For Herbicide Use in the Forest Service Regions 1,2,3,4, and 10 and on Bonneville Power Administration Sites, which includes the Southwest, have withstood legal challenges.

As always, well trained applicators and specialists will be needed to ensure program success. Significantly, the public will demand that resource managers and applicators be knowledgeable about the methods and herbicides that are proposed for use. Comprehensive training and certification programs will need to be developed and implemented before this new herbicide approach can be used to help solve the enormous environmental and social problems that are occurring in P-J ecosystems in the Southwest.

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Piñon-Juniper Fuelwood Markets in the Southwest

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Abstract.—This study estimates the commercial harvest and sale of piñon-juniper (pj) fuelwood from state, private, and public forests in Arizona, Colorado, New Mexico, Nevada, and Utah. The demand for fuelwood peaked five or six years after the 1973 oil embargo. Reports and personal interviews suggest there is less fuelwood consumed today than there was during early 1970 and 1980. There is a strong public awareness for better air quality. Many cities and towns have "no-burn" days during winter temperature inversions. Persons residing in these communities cannot use the same amount of fuelwood they used in the past, before the restrictions were in effect. A surge of interest by the sagebrush rebellion groups has seemingly reduced availability of fuelwood from public and some state woodlands.

INTRODUCTION

Information contained in this paper came from Fiscal Year-92 and 93 annual reports prepared by federal, and state forest officers. Woodland and timber acreage are from the Rocky Mountain Inter-Mountain Research Station publications listed in the bibliography.

During the last ten years fuelwood harvests have varied from year to year (Table 1). One location may increase its harvest while another experiences a decrease. Looking at values for the Southwest, fuelwood use is less than it was twenty years ago.

People throughout the United States are concerned about air quality, and the Southwest is no exception. During winter months there are several days and sometime weeks of weather that produce temperature inversions. Communities with clean air ordinances prohibit the use of wood stoves and fireplaces without catalytic converters when there are temperature inversions. Typically radio and TV stations announce no burn days to keep the public informed.

The Colorado front range has strict regulations concerning the use of conventional wood stoves and fireplaces. A few cities will not allow contractors to build homes with fireplaces.

Table 1.—Estimated Timber and Woodlands (Millions of Acres) Southwestern U.S.

	State	Timber	Woodlands
Arizona	72.8	5.5	9.1
Colorado	66.6	15.0	6.0
New Mexico	77.0	6.2	9.0
Nevada	70.0	0.7	9.0
Utah	52.5	16.0	9.0
Total	338.9	43.4	42.1

When inversions occur residents burning fuelwood must switch to cleaner burning fuels such as natural gas or LP fuels. Approved wood burning appliances may include wood pellet stoves or stoves and fireplaces with catalytic converters.

Since the oil embargo, natural gas and liquid petroleum gas prices have fluctuated, although the cost of these fuels in normally less than fuelwood. Today most homeowners know that petroleum fuels are less expensive, cleaner burning and more readily available than fuelwood. People that have wood stoves and natural gas furnaces prefer wood heat. Wood has many desirable characteristics such as aroma, flame lengths, color and sound.

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TRIBAL WOODLAND ACREAGE

The Bureau of Indian Affairs (BIA) is the trustee for most Tribes in the Albuquerque, Navajo, and Phoenix Areas that have significant PJ acreage. The Albuquerque Area is responsible for tribes in New Mexico, and Southwestern Colorado namely Southern Ute, and Ute Mountain. Albuquerque Area has 1,400,926 woodland acres, and 879,641 acres are commercially accessible.

Navajo tribal forestry has a woodland forester that works on the Navajo Reservation and the new lands. New lands are part of the Navajo Reservation created by congress, to relocate Navajo people that previously lived on the Navajo and Hopi joint use area. The Navajo tribe oversees almost four million acres of woodlands, the largest woodland acreage of any tribe in the nation (Table 2).

There are fourteen reservations in the Phoenix Area that have 2,089,162 acres of woodland with 752,502 acres classified as commercially accessible. This does not include the arid, lower elevation desert reservations with significant stands of mesquite. This includes Tohono O'odham, Gila River, Fort McDowell, and Tribes along the lower Colorado River. Range Conservationists at Tohono O'odham estimate they have almost one million acres of mesquite. Most of this mesquite is too small for fuelwood.

Many tribes have annual resolutions and ordinances for fuelwood and small forest products. These documents set prices for miscellaneous forest products, and develop guidelines for harvest.

Tribal members have cut fuelwood for many years to supplement their income. Tribal members must pay for a paid permit, which allows them to sell on or off their reservation. Alligator juniper (*Juniperus deppeana)* is a preferred species. When dry it is lighter to work with, has a pleasant aroma, and except forks and large knots, it is easy to split.

Indian cutters try to sell all of their wood to tribal members or merchants and people in towns close by. Fuelwood prices range between $50 and $125. Factors that cause variability includes: the

Table 2.—Woodland Acres (millions) and Estimated Allowable Cut(mmbf) Includes tribal ownerships in Arizona, New Mexico, Colorado, Nevada, and Utah

Area	Acres	Allowable cut
Albuquerque	1.4	2.056
Navajo	4.0	1.500
Phoenix	2.1	4.033
Total	7.5	7.589

Table 3.—Average wholesale fuelwood prices delivered to broker.

State	Gambel Oak	Piñon	Mesquite	Alligator Juniper	Other Juniper
Arizona	--	$88	$165	$88	$85
New Mexico	--	$80	$105	$80	$70
Colorado	--	$65	$55	$55	$50
Nevada	$90	$60	--	--	$55
Utah	$85	$50	--	--	$45
So. Calif.	$170	$100	$175	$110	$95

season of the year, availability, road conditions, competition and the purchaser. Preferred clients include motels managers that are willing to pay retail for one or more cords.

Brokers buy in large quantities they pay the least amount, since they have their own cutters or have contracts with other operators (Table 3). Larger brokers typically purchase in the spring and summer to have a large inventory before winter. This practice allows them enough time to split and dry the wood before selling to their distributor. Overall there has not been too much of a change in prices operators receive for fuelwood during the last four years.

Operators that sort large trees can create value added items to increase their profit. Junipers with 6'-8' straight stems make excellent fence and corner posts. The return for posts is much greater than cutting these same straight pieces into fuelwood. Honey mesquite *(Prosopis glandulosa)* is worth more than a dollar a pound. Mesquite is a favorite for Southwestern furniture makers. To produce lumber for furniture stock, mesquite trees need to be at least 10 inches in diameter, and produce boards four feet or longer. In addition mesquite should be clear or have small defects. Furniture makers will pay $5.00 a board foot for quality mesquite.

TECHNIQUES THAT HELP SAVE TIME AND PRODUCE MORE FUELWOOD

Bennett estimates that non-commercial cutters spend the equivalent of two hundred dollars for a cord of fuelwood. A novice cutter would be wise too pay attention to this estimate. Hard working cutters with several years of experience can reduce that estimate to one hundred dollars or less.

Not all fuelwood cutters produce the same amount of wood each day. There are many variables. Knowing where to find a sustainable supply of fuelwood to selectively harvested without harming the ecosystem is necessary. Sawyers need to have systems developed that will maximize their productivity. Having extra sharpened chains, and additional chain saws in case one breaks down will make a difference in having a profitable day or going home disappointed.

The largest fuelwood operators cut thousands of cords a year to meet their contractual obligations. Arizona has five or six large commercial fuelwood operators (3,000+ cords) that package cubic foot bundles using plastic bags or stretch wrap. These are the packages people see every day displayed at convenience and many other stores throughout the state. The largest operators normally hire their own crews and pay them on a piece count basis.

One large operator has a contract to cut piñon pine and one seed juniper for a fee of $9.00 a cord. By the time a cord of fuelwood is hauled from the woodlands job-site into Phoenix, most operators have $90-100 invested. The crew doing the cutting and loading receive approximately $50.00 per cord. Hauling fuelwood from the Flagstaff-Seligman area to Phoenix costs between $20-$25 a cord. Transportation variables include the size and condition of the truck, distance hauled, road conditions, and whether the fuelwood is dry or green (Table 4).

Several truck brokers will not haul fuelwood because of bad experiences encountered in the past. Distributors prefer to haul wood bundles packaged and loaded on pallets. One buyer in California will buy loose blocks, if it is loaded on flat bed trailers with four foot side racks.

An operator at Lakeside, AZ has a method of loading loose blocks of wood into plastic bags that serve as pallets. This enables him to use a forklift to lift the bags into truck trailers. One disadvantage is the cost of the bags, they vary between $17 and $27 compared to $3-$5 for wooden pallets. An important advantage is that after the loose pieces are loaded by hand they can be loaded with a forklift. Loading by a forklift saves many hours of hand labor. These plastic bags are made out of a strong poly material and can be used several times.

Some of the largest operators that depend on ranchers for their wood supply are concerned about future fuelwood sources. One broker estimates he has three or four years supply remaining (Table 5).

Table 4.—Transportation costs truck and rail.

	Truck	Rail
San Carlos- Phx.	$275	---
San Carlos- L.A.	$550	$1.24/100# load at Phx.
Hondah- Phoenix	$475	---
Hondah-L.A.	$750	$1.24/100# load at Phx.

Table 5.—1993 Fuelwood harvest thousand board feet (MBF).

Land	AZ.	CO.	NM	NV	UT	Total
BIA	7,307	1,994	8,923	--	256	18,480
BLM*(1992)	587	4,174	--	3,047	4,381	12,189
PRIVATE	2,200	4,100	3,400	200	500	10,400
STATE	300	675	--	--	234	1,209
USFS	25,400	21,300	16,800	1,358	14,455	79,313
TOTAL	35,794	32,243	29,123	4,505	19,826	121,591

DIFFERENT METHODS OF PACKAGING FUELWOOD

The largest fuelwood operator in Arizona processes ponderosa pine *(Pinus Ponderosa)* from Forest Service multi-product sales. He also harvests PJ from a ranch in Northern Arizona. His Arizona operation including PP and PJ processes approximately 7,000 cords a year. His crews also cut 5,000 cords of oak and other species from private land in California.

This operation packages fuelwood bundles by stretch wrapping rather than using plastic bags. The fastest wrappers can wrap one thousand cubic foot bundles in an eight-hour shift. They place 40 packages per pallet or three pallets per cord. A van will hold 14 to 18 cords or 1680 to 2160 cu. ft. An average load consists of two thousand bundles loaded on 50 pallets.

When packaging fuelwood it is important to make sure there is enough wood in the package. Packaged fuelwood normally has labels indicating the kind and amount of wood they are buying. Weights and measures inspectors check packages to verify that the consumers are getting what they pay for. Many processors will intentionally load a bit more than required to pass weights and measures inspections.

Another technique is to sell .75 cu. ft. packages. Smaller packages create more work, but the average consumer generally does not notice any difference.

All fuelwood operators need a means of distributing their product. A large grocery distribution company near Phoenix delivers most of the packaged fuelwood to convenience and other stores throughout Arizona plus Las Vegas, Nevada. This company pays about $2.00 per bundle for packaged fuelwood they deliver.

This distributor will not accept stretch wrapped packages of fuelwood, because stretch wrapped bundles are open ended. This type of bundle can result in small amounts of bark and dust spilling on floors.

Plastic bags cost about 20 cents each depending on whether the bag is clear plastic or has a printed logo. A few years ago shrink wrap was the favored packaging medium. This system uses heavy plastic for packaging. Next these packages are placed on a conveyor belt and fed into an oven. Heat from the oven causes the heavy plastic to shrink tightly around the fuelwood. Shrink wrapping is slower and more expensive than stretch wrap or plastic bags.

Other packaging operations prefer cardboard boxes, because they stack better than plastic and contain twice as much wood. Cardboard boxes are much more expensive than plastic bags or wrap.

All operators mentioned uniformity, quality and reliability as the most important items to be successful in the fuelwood business. An established dealer in Northern New Mexico believes the key to any fuelwood business is consistency. Fuelwood cut to uniform lengths, limbs trimmed, and sold in quantities as agreed. A fuelwood operator will not stay in business if they attempt to sell green wood during the winter burning season. The product must be consistent day in and day out.

Because it is easy to start a fuelwood business the turnover rate of operators is very high. It is unusual to find operators that have been in business more than five or six years. This business is extremely competitive. Intense competition keeps wholesale prices low. Anyone can sell a few cords at retail prices, however; this will not be the case when selling hundreds of cords. The fuelwood business may look attractive, in reality most that venture the business go broke.

Many hard working operators have given up because they are unable to locate reliable supplies of material. Although the amount of fuelwood harvested has dropped, the demand exceeds the supply. When there is a limited supply of fuelwood federal and state resource manager's generally give priority to individuals rather than commercial operators.

SORT LARGE WOOD TO INCREASE PROFIT

When harvesting fuelwood it is easy to concentrate on a single output. Depending of the size, quality, and straightness of trees it is wise look at making other end products besides fuelwood. By sorting material more cash is generated by selling posts, poles and lumber. For example there is a demand for mesquite large enough to make lumber for furniture, bowls, and cutting boards. Mesquite boards 12" x 8" by 3/8" thick sanded and finished retail for $12.

There are many value added items made out of wood. Craftsmen turning mesquite is a big business in Texas. The good thing about most curio businesses is that they affordable. By starting small, craftspeople build their business to a size that meets their needs.

Although PJ harvesting has decreased there is still a large amount of material being used for fuelwood and other products. There will always be significant quantities of PJ available. Today there is less PJ available from public lands. This may not be the case a few years from now. There is a good prospect that several new businesses will emerge in the future that will use piñon-juniper.

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Ecosystem Management Research in an "Old Growth" Piñon-Juniper Woodland

William H. Kruse and Hazel M. Perry[1]

Abstract.—The Rocky Mountain Forest and Range Experiment Station of the USDA Forest Service is conducting research in piñon-juniper woodlands in cooperation with the Heber Ranger District, Apache-Sitgreaves National Forest. This paper describes the study, objectives, preliminary results since the study began in 1989, and anticipated results for when the study is concludes in 1999.

INTRODUCTION

Some piñon-juniper woodlands near Mud Tank on the Heber District of the Apache-Sitgreaves National Forest are being harvested for fuelwood. These woodlands, which we tenuously call "old growth" woodlands, appear to be older than 200 years, appear to have reached maximum growth, and appear to be mature and stable. Because ≥ 90% of the overstory was cut by 1993, this "old growth" condition has been extremely modified. Previous research (Arnold et al. 1964; Clary and Jameson 1981) has shown that the understory biomass often increases with overstory modification, but often quality forages and/or other important plant species do not respond as expected. Hence, in these situations, site quality is compromised if the anticipated quality understory biomass response is not increased or improved from overstory removal.

What specifically are the effects of overstory removal on slash, small mammal populations, and the nutrient bases? Are important nutrients being removed from the site with the fuelwood? How do the different plant communities and species populations respond—especially elk, deer, and livestock forage—to various treatments and to the nutrient regimes?

Slash, scattered and left on the site, is an important nutrient storage medium for slow release through decomposition into the site. Should the long-term productivity of the site be sustained as overstory production (for fuelwood and other wood products) or understory (as forages for livestock and wildlife)? Or are both possible by managing the understory for the short term and overstory products for the long term? How do the nutrient cycles affect these management options, and how does burning versus leaving the slash affect the nutrient cycles in both the short and long term?

Stable ecosystems are generally sustainable and, following disturbance, generally revert to the most stable condition. In the Mud Tanks Study, ecosystem dynamics are being followed in three areas: 1) understory/overstory relationships related to habitat type, 2) influence of nutrients and nutrient cycling relative to site productivity, and 3) relationship of the habitat type to the fauna, specifically small mammals. Small mammals are being studied because of their importance in the food chain and as an indicator of site productivity. Forage bases are also being evaluated for the larger ungulates. Evaluating these three areas will provide a basis to move from monitoring successional stages to managing the ecosystem.

The overstory/understory relationships include three overstory conditions; 1) complete removal, 2) commercial fuelwood removal only, leaving an advanced form of regeneration, and 3) a silviculture treatment, single-tree selection. Overstory species' regeneration following treatment will be studied simultaneously in the Mud Tank Study as it relates to available nutrients and slash and its affect on small mammals and forage production.

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OVERSTORY/UNDERSTORY RELATIONSHIP STUDIES

Austin (1987) presented data showing little successional change in a plant community within a mature piñon-juniper woodland during a ten-year period, suggesting a climax ecosystem. Following disturbance, his research shows a constant reduction of understory vegetation on sites as soon as tree species become reestablished. At least some piñon-juniper ecosystem structures appear quite responsive to recovery mechanisms, further suggesting stability.

When a forest or woodland ecosystem is in equilibrium, the primary flow of energy and nutrients is to maintain and sustain the overstory component (Smith 1966). The ecosystem appears most stable, displaying the least change, when the overstory is "old growth" or "most" mature. When changes or modifications are made to the overstory, the understory responds significantly in terms of increased understory biomass production and plant diversity (Arnold et al. 1964). Site productivity is further affected by the disposition of the slash (lop and scatter, burning, crushing), and the removal of the fuelwood nutrient base. What then, is the relationship between the overstory and the understory as it relates to site productivity? How is site productivity described?

An important aspect of the Mud Tanks research is to examine the understory plant community following disturbance to the overstory. Past research (Arnold et al. 1964) shows a definite increase in the quantity of the understory biomass production, but past research results (Clary et al. 1974) are mixed with regard to a change in the quality of the site which, in the past was a reflection of a sustainable, marketable product such as increased livestock forage production for beef or water runoff into reservoirs.

Study Area and Background

The Mud Tanks Study was initiated in 1989 on 33, 4.0 ha study units. Understory production data were taken on all study units. Small mammal live trapping began in 1990 on 16 units. The taking of overstory inventory, pre-harvest slash inventory, and soil/plant nutrient data commenced in 1990 and was completed in 1991 on 30 study units. These preliminary data were all pre-harvest inventory data and represent the untreated or natural condition. The first harvesting began in December 1991, and the data from 1992 and 1993 reflect some harvesting effects.

Table 1.—Total soil nutrients from Mud Tanks Study Area.

	%		%		ppm
Nitrogen	1.82	Magnesium	0.10	Zinc	18.82
Phosphorus	0.71	Potassium	1.09	Manganese	50.82
Calcium	0.42	Iron	0.02		

Nutrient Cycling Studies

The nutrient cycling component of this research examines soil-plant nutrient relationships and the cycling of the nutrients, following a series of overstory treatments, principally fuelwood harvest. Specific objectives are to determine changes in total and available nutrients associated with different overstory regimes assessing the interrelationships between nutrient concentrations in soils and plants, including slash. The research will determine effects of wood harvesting and slash burning on levels of selected nutrients in one understory species blue grama (*Bouteloua gracilis*) and the primary overstory species, *Pinus edulis* and *Juniperus monosperma*. Treatment effects emphasizing sustainability are central to the research objectives in determining whether or not sufficient nutrients are available in the concentrations to adequately sustain the ecosystem for the *desired future condition*.

Emphasis is being placed on nitrogen, phosphorus, and carbon because of their importance in southwestern ecosystems (Clary and Jameson, 1981 Evans 1988), but several other elements (calcium, potassium, magnesium, sodium, manganese, iron, and zinc) are also included. Table 1 shows some of the preliminary results prior to harvesting. All of the measurements were made on Kjeldahl digestions. Nitrogen was measured on an Antek nitrogen analyzer. Phosphorus was measured by ascorbic acid method. The magnesium, potassium, iron, zinc, and manganese were measured by atomic absorption spectrophotometry.

Total nutrient losses will be determined by comparing nitrogen, phosphorus, calcium, magnesium, potassium, iron, zinc, and managanese on slash, blue grama, and litter prior to and following fuelwood harvest and burning. The same nutrients, along with organic carbon, will be measured on soil collected before and after fuelwood harvest and fire.

Plant available nutrients will be assessed by measuring ammonia, nitrate, and phosphorus in the 0-2 and 2-10 cm soil depths in all plots before burning, immediately following burning, and several times following fire when forage quality is sampled.

Plant Nutrient Measurements

Nutrient studies of understory vegetation are limited to one species, blue grama, because it is the only ubiquitous species within the study area. Plant and associated soil samples were collected from 1990 to the present and are in the laboratory for processing. By 1995, all the burning will be completed and the sampling will continue through the entire period on uncut, cut *without* burning, and cut *with* burning treatments.

Selected soil and plant nutrients are being examined to determine if patterns or other sequential relationships exist between concentrations of soil nutrients and those in the plants. Particular emphasis will be given to nutrient loss via burning and biomass removal and how this relates to long-term uptake by overstory and understory plants. Again, emphasis is on those relationships that provide information on sustaining or pooling nutrients required for specific habitat type(s).

Understory/Overstory Baseline Data Results

Trees were measured by standard procedures on eight randomly located 0.04 ha circular plots within each 4 ha treatment area or unit (Table 2). The circular plots were measured prior to and immediately after harvest to determine levels of harvesting and non-commercial overstory survival. Slash was measured using the intercept method of Brown (1974). The null hypothesis is that different levels of harvesting, with and without slash disposal and burning, will not affect the survival of advance regeneration and growth, the understory plant components, and the small mammal populations.

A significant ($p < 0.001$) difference existed between years (1990 and 1991) on control and pretreatment study units (Fig. 1). This difference existed for both blue grama ($p < 0.006$) and perennial forbs ($p < 0.001$). No significant differences ($p > 0.05$) were determined for the other plant classes. This increased production was probably because of an exceptionally wet spring in 1991. Also, between 1990 and 1991, no significant differences were determined between the control

Table 2.—Understory, overstory, and slash baseline data.

	m^2	% Dom.
Juniperus deppeana alligator juniper	1.8 BA	13%
J. monosperma one-seed juniper	7.8 BA	54%
Pinus edulis piñon	3.7 BA	25%
P. ponderosa ponderosa pine	1.2 BA	8%
Total Basal Area	14.5 BA	100%

Slash: 8.66 tons/acre (pre-cutting) 55.71 mt/ha.(post)

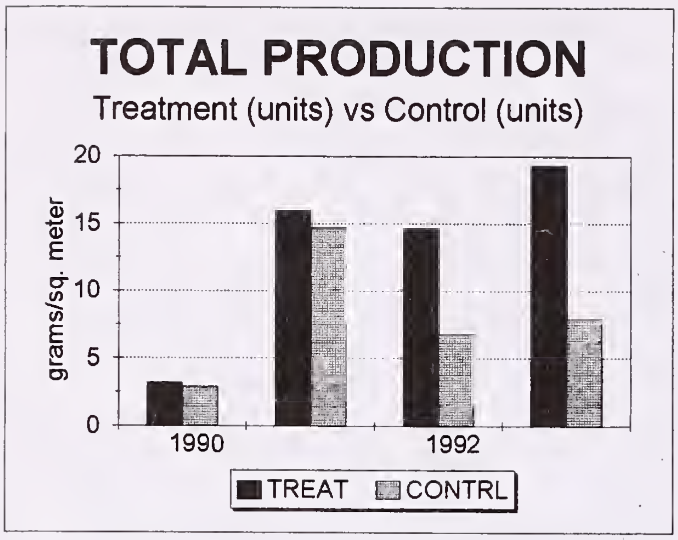
	UNCUT UNITS (understory production grams/meter²)				CUT UNITS	
	1990	1991	1992	1993	1992	1993
BG*	2.02	9.81	2.58	2.77	5.92	7.55
PG*	0.10	1.26	0.35	0.59	0.41	1.24
AG*	0.01	0.00	0.01	0.00	0.01	0.05
PF*	0.55	3.37	3.66	3.95	7.67	9.96
AF*	0.24	0.24	0.21	0.59	0.59	0.50
Total	2.92	14.68	6.81	7.90	14.60	19.30

BG = *Bouteloua gracilis* (blue grama), PG = Perennial Grass
AG = Annual Grass, PF = Perennial Forbs, AF = Annual Forb

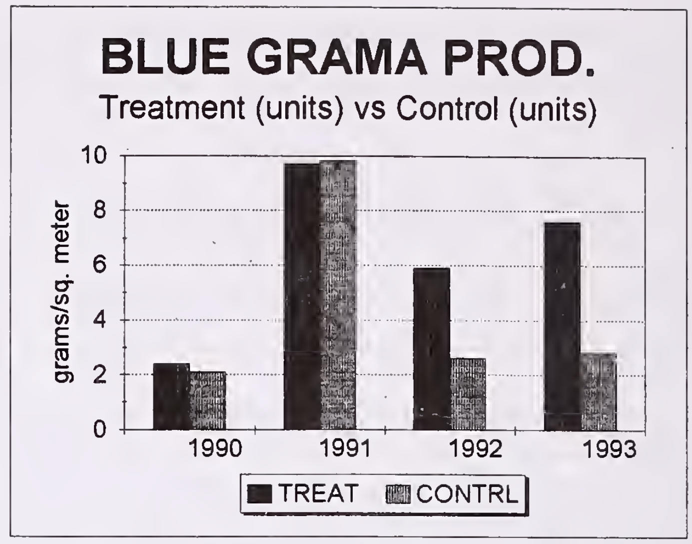
and the "to be cut" units suggesting similarity between all the study units. ANOVA tests performed on the 1991 vs. 1992 data also showed no significant differences between the study units or years. A few study units were harvested during 1992, but effects of the overstory removal are not evident yet.

By 1993, however, some significant changes were apparent (Fig. 1). Highly significant ($p < 0.001$) differences existed between harvested and control units. These differences were found for total production, blue grama, and perennial forbs. Other plant classes—annual grass, annual forbs, and perennial grasses—exhibited little or no change. Blue grama and the perennial forbs contribute most toward the total production (Fig. 2).

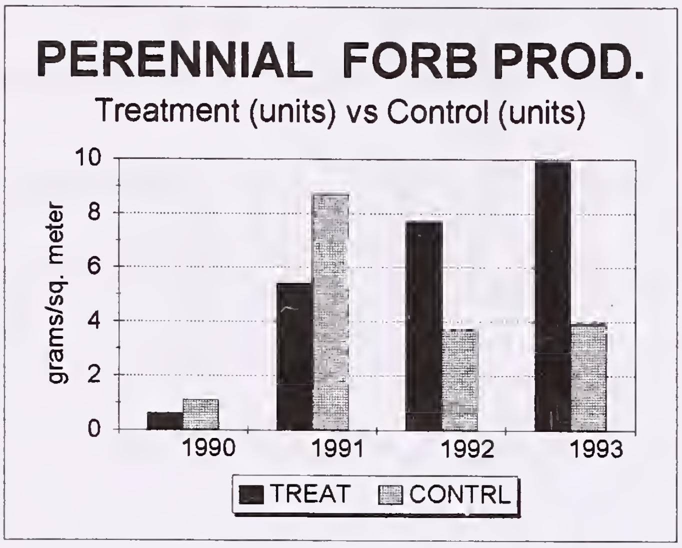
The understory production continues to be measured in every subplot by using an ocular estimate by plot technique employing double sampling (Cook and Stubbendieck 1986). Data collection commenced in September 1990 and will be continued each year thereafter, including the treatment years and three or four years post treatment. The data are being analyzed to test the null hypothesis that understory production does not differ among treatments. Years will be introduced into the analysis as a repeated measurement. Eventually, relationships between overstory parameters and understory production will also be examined to determine if functional models can be developed to predict understory yield from the overstory condition of piñon-juniper.



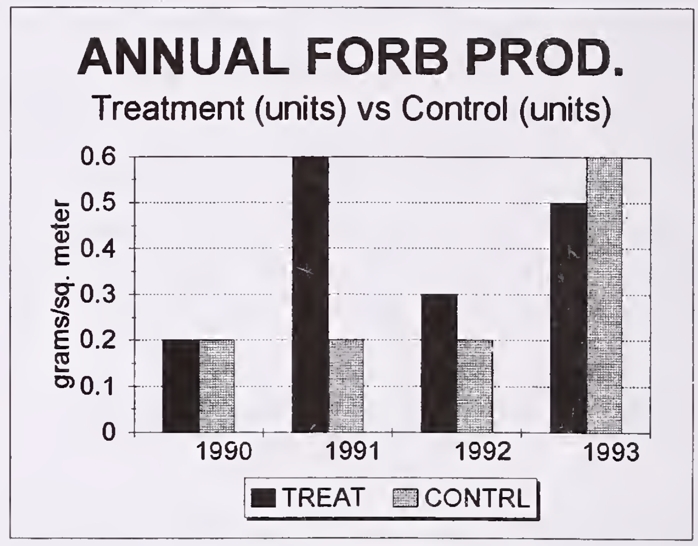
	1990	1991	1992	1993
TREAT	3.2	15.9	14.6	19.3
CONTRL	2.9	14.7	6.8	7.9



	1990	1991	1992	1993
TREAT	2.4	9.7	5.9	7.6
CONTRL	2.1	9.8	2.6	2.8



	1990	1991	1992	1993
TREAT	0.6	5.4	7.7	9.9
CONTRL	1.1	8.7	3.7	3.9



	1990	1991	1992	1993
TREAT	0.2	0.6	0.3	0.5
CONTRL	0.2	0.2	0.2	0.6

Figure 1.—Above ground understory biomass production (g/m^2) for total, blue grama, perennial, and annual forb production. Significant differences were between 1990 and 1991 (these plant classes) for production. No differences were determined between the control and the "to be harvested" units. Significant differences due to treatment were determined.

Small Mammal Measurements

As with the understory data collection, the relative abundance and species composition of small mammals are being evaluated. However, small mammal live-trapping is being limited to only two overstory treatments, type conversion and controls. Table 3 shows some preliminary results from the first four years of trapping (two pre-treatment years and two years that include some cut units). Trapping is being conducted during a four week period (July-August) each year. Species richness and eveness are being calculated for each treatment combination according to methods described by Ludwig and Reynolds (1988). The null hypotheses of no differences in (1) total number of small mammals or (2) total number of species among treatments are being tested.

Average captures for the deer mouse (*Peromyscus maniculatus*), piñon mouse (*P. truei*), all others, and total small mammal captures are represented in Table 3. These data express the dominance of the two *Peromyscus* species relative to the total numbers of all captured animals. A fluctuation in species diversity accompanies the annual fluctuation, however. Notable is the low number of "all others" suggesting a lack of species diversity for the area. A more detailed account of these results can be found in Kruse (1994), this symposium.

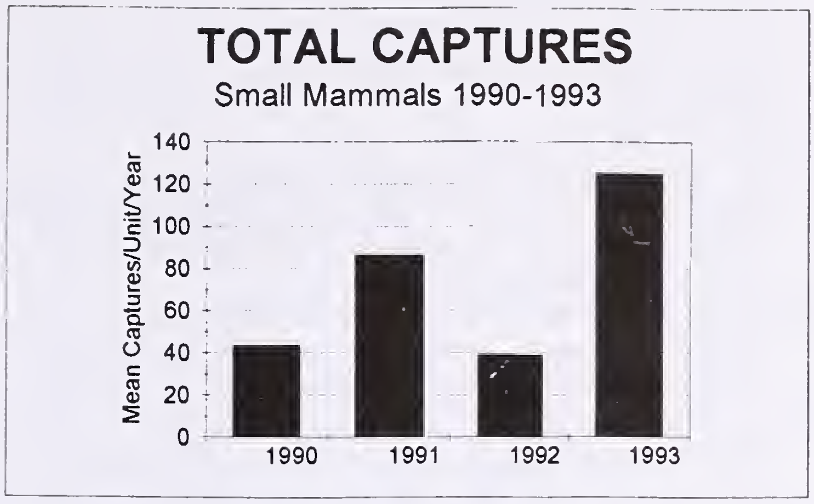
Table 3.—Mean captures for uncut and cut treatments by year.

	1990		1991		1992		1993	
	UC	C	UC	C	UC	C	UC	C
P. maniculatus	3.8	4.1	18.4	16.6	2.9	7.5	11.8	45.6
P. truei	16.3	12.8	20.1	19.4	12.5	10.4	30.5	20.0
All Others	3.0	3.5	6.1	5.5	2.1	3.7	5.6	10.7
Total animals	23.1	20.4	44.6	41.5	17.5	21.6	47.9	76.3

UC = Uncut, C = Cut

The small mammal populations fluctuated dramatically during the first four years of the study (Fig. 3). The first analysis showed significant differences between years, population densities, and unit study areas (Fig. 3).

A second analysis on all small mammal captures showed similarity among all plots prior to harvest. This analysis showed that all "to-be" cut (not now cut) units and all control (never-to-be cut) units were similar. The "Small Mammal Captures" graph also expresses significant doubling of total population numbers from 1990 to 1991.



Year:	1990	1991	1992	1993
Mean:	43.5	86.4	39.1	124.9
	+/- 6	+/- 8	+/- 8	+/- 18

Figure 3.—Difference between years 1990 vs 1991 ($p<0.001$). Difference between study units prior to harvest, N.S. Highly significant difference between control and treatment, 1992 vs 1993 ($p<0.001$) (Kruse 1994).

SUMMARY

Significance of the Research

Results from this research will have direct application on over 12 million ha of piñon-juniper woodlands in Arizona and New Mexico and implications on about 19 million ha throughout the western United States. Information gained from this study will provide a basis for developing improved guidelines for ecosystem management of the piñon-juniper woodland in the southwestern United States. The nutrient portion of this research project is especially important in that it magnifies an unprecedented endeavor to simultaneously study the effect of fuelwood harvesting and slash management on livestock and wildlife forages, small mammal populations, understory/overstory plant relationships, and nutrient cycling.

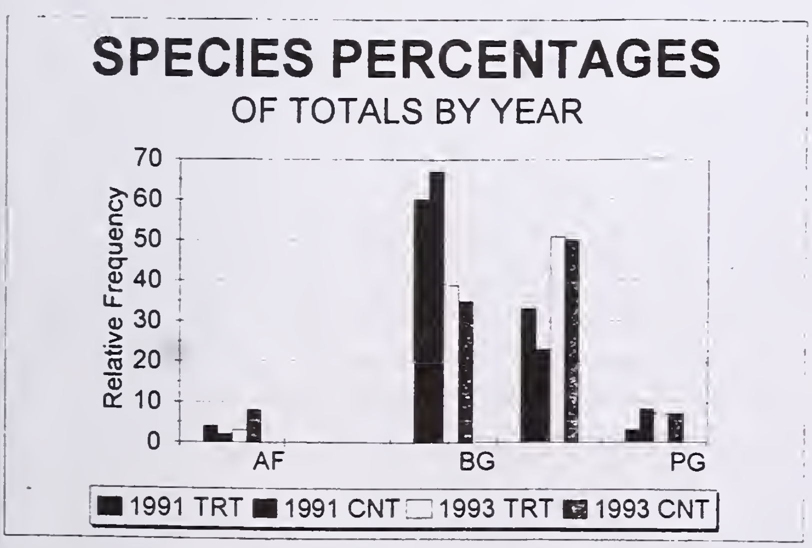


Figure 2.—Composition of understory biomass. F = annual forbs, AG = annual grass, BG = blue grama, PF = perennial forbs, PG = perennial grass.

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The Composition of Oils in *Pinus edulis*

Michael Blair, Telletha Valenski, Andrew Sykes, Russell Balda, and Gerald Caple[1]

Abstract.—Piñon nut oil was reacted with sodium methoxide in methanol to yield the free methyl esters. These methyl esters were analyzed by GC-mass spectrometry. The piñon seeds are 60% by weight oil; of this oil 90% were unsaturated fatty acids with 41% being mono 9-octadecenoic acid and 59% being 9,12-octadecadienoic acid. Small amounts of palmitic acid and stearic acid, both saturated oils, were found, as were some C_{20} species. Preliminary studies indicated the actual oil constituents varied in piñon seeds from different areas. The highly unsaturated oil of *Pinus edulis* seeds might be a useful dietary supplement, with the current health concerns about the lowering of saturated fats in the diet.

INTRODUCTION

Foraging birds such as Piñon Jays, Scrub Jays, and Clark's Nutcrackers, instinctively harvest piñon nuts for the high supplement of fat. They discriminate between good and bad seeds, cones with a large number of good seeds, and trees that produced cones with a large number of good seeds (Vander Wall and Balda, 1977). The piñon nut provides the birds with good nourishment throughout the cold winter months. This can also be said for the Native people who also forage off the nut.

Here we report on the composition of oils found in the piñon nut. The percentage of oil found in the piñon nut (*Pinus edulis*) is 58-62% (C.W. Bedkin, L.B. Shires). We have determined the ratios of saturated and unsaturated fats in piñon nuts by Gas chromotagraphy/Mass Spectroscopy (GC/MS) and compared these ratios to other commercial oils. The seeds were found from different areas of the southwest which gave variations in percentage of oil. In addition, a one seed analysis was done to make a comparison with larger quantities.

MATERIALS AND METHODS

After weighing the crushed nut, we separated the oil from the piñon nut by using a nonpolar solvent (hexane) to extract the oil, and then filtering the solution. The powder extraction was set aside to do a protein and carbohydrate analysis. After evaporating the solvent, the oil was reweighed to give the percent oil in the seed, which agreed with the range given in the introduction. For the preparation of methyl esters from the oil extraction, triglycerides were reacted with Sodium Methoxide (Olsson, Urban; Kaufmann, Peter; Hersolof G. Bengt). Methyl esters were separated from the nut and characterized by GC/MS. Methyl linoleate, methyl oleate, methyl stearate, and methyl palmitate were purchased from Aldrich Ghemical and used as standards.

GC-Mass Spectroscopy spectra were collected on an HP 5890 Series II GC fitted with a 12m * 0.2mm * 0.33um HP-1 crosslinked methyl silicone gum column interfaced to an HP 5971A Mass Selective Detector.

RESULTS/CONCLUSION

The specific oils in *Pinus edulis* were characterized as the methyl esters by GC/MS. This could be done on any quantity of piñon nuts, including a single nut analysis. Figure 1 is a typical GC/MS spectrum of a single nut analysis. We identified four major oils present in *Pinus edulis* plus a small percentage of higher C_{20} oils. The molecular weights and retention times of these methyl esters

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Table 1.—Retention Times of Methyl Esters (minutes).

	Palmitate	Linolenate	Linoleate	Oleate	Stearate
Mol. Wgt.	270	292	294	296	298
Shelled(Feb)	15.97		Shoulder	18.31	18.34
Shelled(June)	17.42		Shoulder	19.22	19.38
Freezer Nuts	17.1	18.55	18.77	18.85	19.05
Palmitate 270	17.19				
Linolenate 292		18.82			
Linoleate 294			18.92		
Oleate 296				18.96	
Stearate 298					19.04

are given in Table 1. The molecular weights and the retention times of methyl esters purchased from Aldrich closely match the methyl esters found in the piñon nut. The shelled nuts (Feb) were run under different GC conditions (higher Helium column pressure) accounting for the faster in retention times. The freezer nut sample obtained from a commercially available source and of unidentified history also contained an additional unsaturated oil at 18.55 min (asterisk-Figure 2).

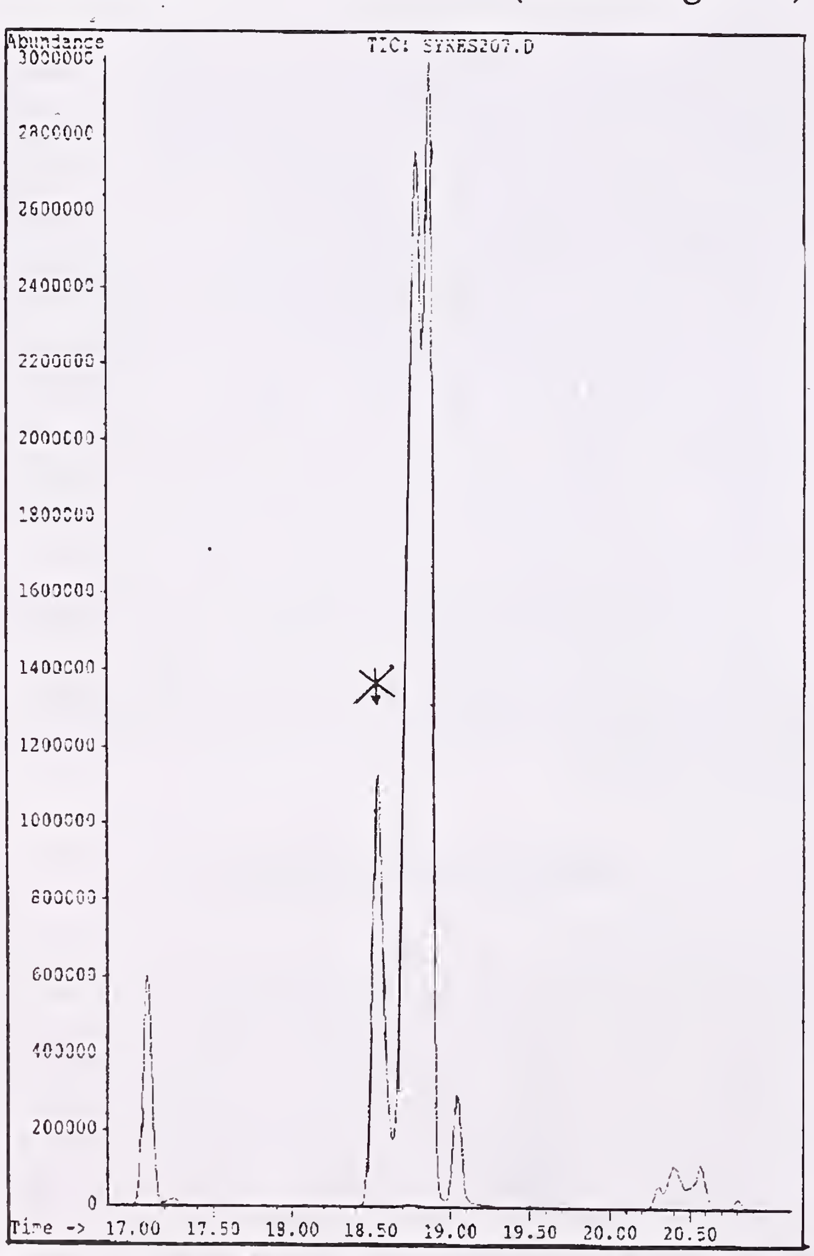

Figure 1.—Graph showing GC/MS characterization of methyl esters.

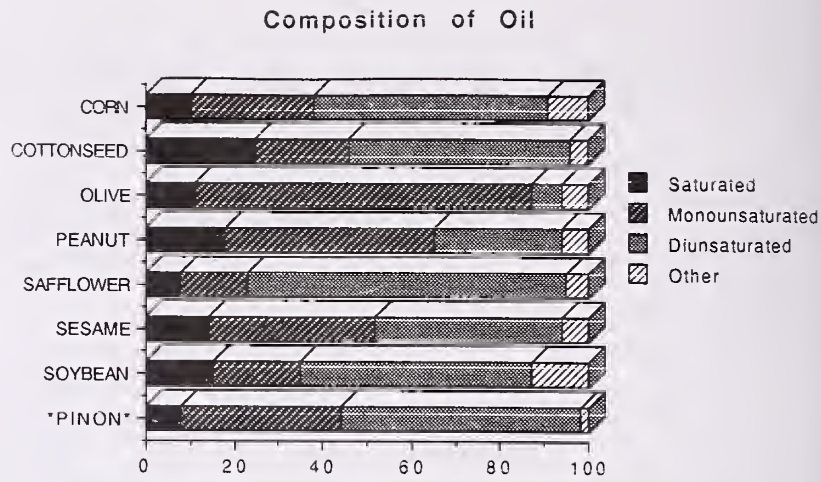

Figure 2.—Fat content of commercial oils including piñon.

Figure 2 compares the fat content of *Pinus edulis* to other common commercial oils (USDA Handbook # 8). The graph shows the nut is high in unsaturated fat (90%), but has its own unique content of mono and diunsaturated fats. The exact ratio of the mono and diunsaturated esters were determined by digital transformation of the linoleate and oleate peaks and fitting the data to two Gaussian peaks using a commercially available computer program (Peak Fit). The relative amounts of linoleate to oleate esters are 59% to 41% by this technique. Integration using the GC/MS software incorrectly determined the relative percentages as 44/56% for the linoleate/oleate ratio, almost the opposite from above, due to poor resolution of these peaks.

In the future we would like to develop a greater separation of the methyl esters using GC/MS. Preliminary evidence shows that a large number of isomers exist for methyl linoleate and methyl oleate. We would also like to know if seasonal changes cause the piñon nuts to have different percentage of oil.

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*U.S. GOVERNMENT PRINTING OFFICE: 1995-674-451/25030

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

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Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
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