JUNIPER ENCROACHMENT: POTENTIAL IMPACTS TO SOIL EROSION AND MORPHOLOGY

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Purpose: The purpose of this report is to assess the impact of juniper expansion on soil erosion and soil morphology, based upon available literature, theoretical relationships and personal observation. We have summarized much of the available literature on this topic and on that basis have formulated a number of hypotheses concerning the impact of juniper expansion to soil erosion by water and soil morphology.

LITERATURE REVIEW

Herbaceous Cover

The relationship between coverage and density of juniper to understory vegetation is fundamental to the impact of juniper encroachment to both soil morphology and soil erosion. If expansion has no or little impact to herbaceous cover, then the impact to soil morphology and erosion is minimal.

There is compelling evidence that in many or most cases, as juniper increases in density the understory cover decreases. This seems especially true for xeric sites (i.e. south facing slopes and shallow soils). Juniper species are considered successionally aggressive, and tend to reduce or in some circumstances virtually eliminate understory vegetation (Tausch and Tueller, 1990). Numerous studies have shown relatively rapid declines in understory vegetation as pinyon and juniper increase in density (Schott and Pieper, 1985, 1987; Tausch et al., 1981: Tausch and West, 1995). Juniper and pinyon-juniper woodlands generally have a greater percentage of understory at higher elevation sites and on slopes with aspect (West et al., 1978; Tausch and Tueller, 1990) suggesting that there is a moisture threshold below which understory cover cannot compete with juniper. A number of studies indicate that herbaceous vegetation increases dramatically when juniper is removed from a site by chaining or burning (Clary, 1971; Miller and Wigland, 1994, Everett and Sharrow, 1985), again suggesting that juniper limits understory vegetation by out-competing it for resources.

Our observations in northern New Mexico lead us to believe that there is a moisture threshold, below which juniper expansion has an especially devastating impact on herbaceous vegetation. At our study site, in Bandelier National Monument, New Mexico, pinyon-juniper woodlands are characterized by marked contrasts between southern-and northern-aspect slopes. On the more xeric south-facing slopes, the woodland exhibits extremely sparse understory vegetation and accelerated erosion, with about 30 cm of soil cover having been stripped. The north-facing have much more abundant grassy and herbaceous cover, and are not undergoing significant erosion

(Wilcox et al., 1995).

Soil Morphology

Juniper is evidently capable of thriving on a wide variety of soil types formed from very different parent materials. Observations of soil morphology patterns in juniper and pinyon-juniper woodlands have been quite limited and largely limited to discussions of soil depth and rockiness.

Mature juniper is more likely to be found on shallow, rocky soils, while younger juniper stands are typically on the deeper soil sites with fewer rock outcrops and less gravel (Burkhardt and Tisdale, 1969). In southwestern Idaho, Burkhardt and Tishdale (1976) found that juniper seedling establishment was favored in deeper, less well-drained soils, but that tree growth after establishment is favored in the shallower, better-drained soils of upper slopes. They also found that on southern-aspect slopes, moisture holding capacity of the soil is an important control on both establishment and growth rate of juniper. Establishment and growth are positively correlated to the amount of fine material (clay) in the soil, and negatively correlated with the percent of coarse fragments in the A horizon. The same pattern is seen on northern-aspect slopes, but the correlation is not as strong.

Davenport and Wilcox (1995) did a comparative study of soils under pinyon and juniper canopies to those of interspace soils. They found some weak but not statistically significant trends. Soils of the juniper canopies had thicker A horizons, thinner C horizons and slightly coarser overall profile textures than either pinyon or intercanopy soils; total soil depth under junipers was not significantly different than pinyon or intercanopy soils; soil pH was lower under juniper than in intercanopy soils, but not different from pinyon soils; juniper soils had the highest percentage of organic carbon and the highest electrical conductivity in surface horizons. Differences in canopy/ intercanopy soils may be related to differences in establishment and survival in different pre-existing soil conditions.

Soil Nutrient Patterns

Most soil studies in juniper woodlands have focused on soil nutrient distribution under canopies and in interspaces. It has been shown that juniper trees extract nutrients from interspace soils and concentrate those nutrients in the soils under canopies, mainly through deposition of litter (Covington and DeBano, 1990). Doescher et al. (1987) found that in western juniper woodlands of central Oregon, surface (0-8 cm) soil Ca concentrations were greatest near the boles of large juniper trees and decreased into grassy and bare interspaces. The concentration of Ca was greatest in the surface horizons and decreased in deeper horizons under canopies, while no depth trend was found in intercanopy areas. Similar patterns were found for soil organic matter and K. Soil pH was also highest under mature canopies, while low pH values were found under young juniper and in intercanopy zones. The highest levels of total N were found under the canopies of juvenile junipers (<40 years old). Concentrations of Mg, Na and P did not appear to differ among canopy and intercanopy zones in this study.

In even aged pinyon-juniper woodlands of Utah, McDaniel and Graham (1982) found somewhat different effects of tree canopies on soil nutrients. They found organic carbon levels to be highest in surface horizons under canopies; N and P were highest in surface horizons under canopies and in deeper horizons of the intercanopy soils. Soil surface pH was reported to be lowest in canopy soils, in contrast to that reported by Doescher et al. (1987). Differences in soil pH patterns between the two studies may be attributable to differences in tree age and to the presence of pinyon pine in the McDaniel and Graham (1992) study. McDaniel and Graham (1992) report a strong correlation between soil organic carbon and concentrations of N and P. The apparent linkage between organic carbon and some soil nutrients suggests that these nutrients are concentrated under canopies by root uptake and subsequent litter deposition by juniper and pinyon trees.

Barth (1980) examined nutrient levels only under pinyon canopies and interspaces of a pinyon-juniper woodland, but found that all of the macro- and micro nutrients analyzed (with the exception of Cu) were present in significantly higher concentrations (2-20 times higher) under canopies than adjacent shrub-dominated interspaces. He also reported highly significant correlations between soil age and concentration of several macronutrients and organic matter, indicating that the concentrating effect of trees increases over time.

Water Relations

Water availability is an important limiting factor for plant composition in the semiarid ecosystems dominated by juniper. The well-documented expansion of juniper woodlands over the past 12,000 years has been related to climate changes (Miller and Wigand, 1994) which presumably would alter the local availability of water. Lateral variations in soil moisture have been shown to be governed by the presence or absence of pinyon and juniper tree canopies (Breshears, 1993). In general, intercanopy soils receive higher precipitation than do canopy soils due to canopy interception (Johnsen, 1962). Breshears et al. (1995) suggest that the ability to use this intercanopy moisture may be an important determinant of the composition and distribution of woody species in pinyon-juniper woodlands. Their data also indicates that junipers make use of intercanopy water to a greater extent than pinyon pines. They showed further that juniper tend to rely more on shallow soil water; whereas pinyons make greater use of somewhat deeper water. This places junipers in direct competition for water with intercanopy grasses and other understory species which are shallow-rooted.

Runoff and erosion

Soil erosion research in pinyon-juniper woodlands and most especially juniper woodlands has been very limited, All observations of erosion from naturally occurring runoff have been made in pinyon-juniper woodlands of Arizona and New Mexico. A point we will emphasize repeatedly is in extrapolating results from one area to another, the erosive energy of rainfall events must be considered. For example, in New Mexico intense high-energy thunderstorms commonly produce surface runoff, while in the juniper woodlands of the northwest, surface runoff occurs much less frequently and is mostly produced by comparatively low energy rainfall.

Soil erosion research can be conducted in many ways and at many scales. Rangeland hydrology studies often rely on small plot rainfall simulation. These studies have been very useful and resulted in additional insight and clarification of processes, but are of limited value when we try to evaluate the relevance to larger scales and natural rainfall. Larger scale impacts can only be evaluated using watershed studies, which although more valuable require large expenditures of time and money. In this section of the literature review we have categorized studies according to scale of measurement and method of observation (rainfall simulation or natural).

Watershed scale studies: Most of the watershed scale hydrologic studies in pinyon-juniper woodland environments were conducted in the 1960s and 70s. The management objectives of the day did not call for a processed-based understanding of runoff and erosion; rather, the impetus for most of these studies was to test the hypotheses that removing the pinyon-juniper overstory would increase both water yield and forage production.

The best documented of these studies was done at Beaver Creek, Arizona (Clary et al. 1974; Baker 1982; Baker 1984). It was initiated following a severe drought in the 1950s, when several researchers began optimistically forecasting water-yield improvements from clearing of pinyon-juniper cover (Barr 1956). Information on erosion was also collected. Several treatments, including herbicide application and mechanical removal, were applied to small watersheds dominated by Utah juniper and alligator juniper. The treatments had little impact on runoff and erosion. Erosion rates were generally very low (<300 kg/ha).

The hydrologic impact of pinyon-juniper removal was also examined in Arizona on a much larger scale (Colling and Myrick 1966). Results showed that there was little if any increase in water yield from such removal.

Dortignac (1960) compared the early Beaver Creek findings with those of some little-known watershed work conducted in New Mexico and concluded that the runoff regimes of the Arizona and New Mexico watersheds were quite different-that whereas in New Mexico most of the runoff is generated by intense summer thunderstorms and is of short duration, in Arizona it is generally a winter phenomenon, produced by frontal storms, rain-on-snow, and/or snowmelt. These differences highlight the difficulty of transposing results of watershed studies conducted in the southwestern United States to the juniper woodlands of the northwest. Some similarities can, however, be drawn between the pinyon-juniper woodlands of Arizona to the juniper woodlands of the northwest in that runoff in the northwest in also mostly generated by low intensity winter and spring storms.

A small watershed scale study (1ha) has been initiated in northern New Mexico (Wilcox et al. 1995). Unlike the other watershed scale studies, this one is located in a rapidly eroding environment. Preliminary results indicate that erosion can be as high as 50,000 kg/ha during a single summer (when intense rainstorms are common). Most erosion occurred as a result of intense summer thunderstorms. Although substantial runoff was produced from a prolonged low intensity storm, comparatively little erosion was produced during this storm. *The erosive energy of rainstorms greatly affect erosion rates.*

No watershed scale studies have been implemented in juniper woodlands of the northwest. However, results from the Reynolds Creek Experimental Watershed, a sagebrush covered watershed in southwestern Idaho are applicable to many juniper woodlands of the Northwest. The climate of Reynolds Creek is very similar to that of many of the northwestern juniper woodlands, and by extension most likely so are runoff and erosion processes. Long-term observations of runoff and erosion indicate that at the lower elevation of the watershed, where annual average rainfall is <400 mm/yr, runoff is a small part of the water budget (1-3%) and occurs mostly as a result of rain-on-snow while soils are frozen. Average annual erosion rates are very low (<50 kg/ha) (Wilcox et al. 1989). Similar to sagebrush rangelands of the northwest, frozen soil runoff is the likely mechanism of runoff generation in juniper woodlands as well.

Hillslope scale studies: The effects of clearing of pinyon and juniper on surface runoff and erosion have been examined in several hillslope-scale studies. Wood and Javed (1991) and Gifford (1975a) found that runoff and erosion was greater if slash and debris were removed. When these were left in place, runoff and erosion were lower-presumably because the increased surface storage capacity allows more time for water to infiltrate. Wright et al. (1976) found that in central Texas burning of juniper increased runoff and erosion on steeper slopes but produced little change on smaller-gradients.

Wilcox and Breshears (1995) describe components of a recently established field study on a pinyon-juniper hillslope within Los Alamos National Laboratory. Runoff and interflow are continuously measured from a 1000 m^2 hillslope, in addition to weather and soil moisture. Within the hillslope runoff and erosion are measured from a suite of small plots, ranging from 1-8 m^2. In addition, six 30 m^2 plots (described in Wilcox, 1994) are located near by. Using these data we are able to establish that runoff and erosion decrease with scale. There is a substantial movement of water and sediments within the hillslope, but much less actually leaves the hillslope. Wilcox (1994) found that although most runoff from these areas is generated from summer thunderstorms a substantial amount of runoff occurred as a result of snowmelt while soils were frozen. *Frozen soil runoff, although a substantial part of the water budget, produced much less erosion than runoff produced from intense summer thunderstorms.* It was also found that cover conditions of the plots had substantial impact on the amount of runoff and erosion.

Small Plot Rainfall Simulation Studies: As noted earlier, small plot rainfall simulation has been a commonly used technique by rangeland hydrologists to study runoff and erosion phenomena on rangelands. Simulating rainfall allows the researcher to gather information more efficiently than if data were to be gathered from natural events. This is especially true for rangelands where runoff events can be very infrequent. It is often difficult, however to extrapolate data from small plots to larger scales.

A number of rainfall simulation studies have been conducted on pinyon-juniper woodlands. Only one (Gaither and Buckhouse 1983) has been conducted in juniper woodlands. They found infiltration capacity to be around 6.6 cm/hr. Erosion was not reported. Other studies have been conducted in Utah (Williams et al. 1969, 1972; Gifford et al. 1970), Nevada (Blackburn 1975;

Roundy et al. 1978) and New Mexico (Smith and Leopold 1942; Wilcox et al. 1988; Wilcox et al. 1989; Ward and Bolin 1989 ab; Ward and Bolton, 1991). Specific objectives of these studies ranged from evaluating management effects to plant community comparisons, however, each indicate that for undisturbed conditions (i.e. good cover) runoff and erosion potential is quite low. Blackburn (1975) and Roundy et al. (1978) highlighted the important hydrologic differences between canopy and intercanopy areas as a result of soil and vegetation differences; canopy areas generating significantly less runoff and erosion than intercanopy areas.

Factors Affecting Soil Erosion - Generalizations

The potential erosion of every site is affected by a number of factors but of greatest importance are; 1) amount of protective cover on the soil surface 2) slope angle 3) soil erodibility and 4) erosive energy of precipitation events.

Of the three factors affecting erodibility of a site (slope, cover, soil erodibility), we believe slope gradient to be most important. This has been demonstrated repeatedly on croplands (Zingg 1940, McCool et al. 1987, Liu et al. 1995) as well as rangelands (Wilcox and Wood, 1987). In their review of the topic Liu et al. concluded that erosion increases linearly as slope increases. Theoretical relationships between slope and erosion, presented in Schumm and Chorley (1984) indicate that the relationship will change depending on rainfall intensity, with slope differences being greater under higher rainfall intensity.

Next to slope, cover conditions probably have the greatest impact on site erodibility. The negative relationship between vegetation cover and runoff/erosion on rangelands has been demonstrated repeatedly. No consistent relationship, however, (i.e. one with universal predictive potential) between cover and erosion has been developed, probably because of inherent variabilities in rangelands. In the Revised Universal Soil Loss Equation, linear decrease in erosion with increases in cover is assumed. The relationship developed by Nobel (1963) as presented in Schumm and Chorley (1984) hypothesizes a nonlinear relationship whereby changes in cover from 0-8% and >50 have little impact on erosion, but that even small changes between 10 and 50% can substantially impact erosion rates. All cover is beneficial be it vascular plants, cryptogams, rocks or litter. However, vegetal cover is probably most effective in protecting the soil surface (Wilcox et al, 1988).

Erodibility of soils is affected by a number of factors, such as organic matter, structure and texture. Silty soils are typically much more erodible than sandy soils. For example, in RUSLE, erodibility of silty soils is 4-5 times higher than soils with a high sand component.

The erosive energy of precipitation events, or *erosivity*, greatly impacts erosion. No matter how erodible the site, water erosion will not occur if no surface runoff is generated. Wilcox (1994) demonstrated much lower erosion for snowmelt over frozen soil (no raindrop impact) than for summer thunderstorms. In a similar example Wilcox et al. (1995) noted much lower erosion rates for a prolonged frontal storm than for intense short-lived thunderstorms. This difference in erosion energy of precipitation events is the major reasons that one must be careful in extrapolating conclusions from pinyon-juniper studies in the southwest (intense and frequent thunderstorms) to juniper woodlands of the northwest.

HYPOTHESES

On the basis of our experience and review of the subject, we have formulated a number of hypotheses concerning the impact of juniper expansion on soil erosion and soil morphology. As already noted data are limited, and therefore some of our hypotheses are speculative and open to challenge. They are, however, based upon our best judgment.

Hypothesis 1: *Understory cover often diminishes as juniper increases, creating a mosaic landscape of canopy and intercanopy areas, each with very different water, nutrient and soil characteristics.*

Juniper aggressively competes for water and nutrients in intercanopy zones through its lateral rooting characteristics. In many cases, especially in xeric sites (i.e. south facing slopes, shallow soils) intercanopy vegetation cover is greatly reduced. When this happens

- nutrients are concentrated in canopy areas
- erodibility of intercanopy areas is increased
- microclimate of intercanopy areas is very extreme and unfavorable for plant germination
- infiltration capacities of canopy areas are greater than intercanopy areas
- soils build up in canopy areas and deflate in intercanopy areas.

Hypothesis 2: *Most (if not all) runoff and erosion from pinyon-juniper and juniper woodlands is generated from intercanopy areas.*

Soil and cover conditions in canopy and intercanopy areas are fundamentally different and profoundly affect not only runoff and erosion but the whole water budget. Tree canopies intercept water and lower the rainfall energy, duff layers under the canopy protect the soil and increase infiltrability.

Hypothesis 3: *Runoff and erosion in juniper woodlands is scale dependent and generally diminish as scale increases.*

In semiarid environments, as the scale increases so does the opportunity for water to infiltrate and sediment to be deposited. Our watershed studies in New Mexico clearly demonstrate diminishing runoff and erosion with increasing size. This scale effect is of more than just academic importance. It means that although erosion may be higher locally as a result of juniper expansion, the off site impacts are likely to be minimal. As Gifford (1985) points out, sediment (and associated nutrients) produced in pinyon-juniper woodlands will likely be redeposited in riparian areas and result in a net benefit to the whole ecosystem. *The exception is when channel* *erosion (in the case of gullies) is occurring. In this case erosion may actually increase with scale and off-site impacts may be substantial.*

Hypothesis 4: *Although juniper encroachment will in many cases, increase erodibility of sites, erosion rates will generally be quite low.*

Runoff is not common in these areas and it generally results from low energy storms. Therefore, even if considerable bare soil is exposed, water erosion will be quite low. Gifford (1987) concluded, on the basis of his research, that there was little basis for the common perception that accelerated erosion was occurring in pinyon-juniper woodlands of Utah. As noted earlier rainfall erosivity or energy of rainfall is one of the most important factors determining erosion. In these areas, surface runoff occurs infrequently and is mainly generated as frozen soil runoff rather than from intense thunderstorms. Wilcox (1994) demonstrated that erosion from frozen soil runoff was much lower than that from intense summer thunderstorms. Few if any measurements have been made of actual runoff events from juniper rangelands in the northwest. Sagebrush rangelands of Reynolds Creek are the best analog. Runoff and erosion rates from Reynolds Creek are very low. As previously noted, erosion rates were less than 50 kg/ha. Compare that value to the 50,000 kg/ha of sediment estimated to have been eroded from a hillslope in New Mexico in just one summer (Wilcox et al. 1995). There will be exceptions. These will be areas of highly erodible soils on slopes that are moderately steep to steep.

MANAGEMENT IMPLICATIONS/RECOMMENDATIONS

1. Off-site impacts due to erosion from juniper woodlands are probably minimal, and perhaps beneficial. In most semiarid environments, eroded sediments are quickly redeposited, most likely in riparian zones where they will supply additional nutrients. There are compelling reasons to reduce density of juniper in many locations, but improvement in water quality is not one of them.

2. Evaluate each site on a case-by-case basis. Just as one cannot assume that naturally occurring erosion rates are high because herbaceous cover is low, one cannot assume that accelerated erosion will not occur. Evidence of accelerated erosion includes gullying, high density of hillslope channels or rills, pedestaling, sediment deposition areas etc.

3. If burning or mechanical treatment is employed to reduce juniper cover the impact to the watershed will be short lived. Especially if slash is scattered over the area.

4. In making our assessment we have had to "go out on a limb". To our knowledge, there are no data on rates of water erosion from juniper woodlands. Erosion measurements need not require expensive investments in experimental watersheds. In our research we have employed several "low tech" techniques that have supplied valuable measurements of soil erosion. For example, we have used erosion bridges (permanently marked locations

where repeated measures of the microtopography can be made) and runoff/erosion plots with good success. Other techniques such as dating exposed tree roots, measuring sediments stored on the hillslope, and surveys of gullies or stream channels can provide valuable estimates of erosion.

REFERENCES

Arnold, J.F. 1964. Zonation of understory vegetation around a juniper tree. Journal of Range Management. 17:41-42.

Baker, M.B. 1982. Hydrologic regimes of forested areas in the Beaver Creek Watershed. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Baker, M.B. 1984. Changes in streamflow in an herbicide-treated pinyon-juniper watershed in Arizona. Water Resources Research 20:1699-1642.

Baker, M.B., L.F. DeBano, and P.F. Folliott. 1995. Soil loss in pinyon-juniper ecosystems and its influence on site productivity and desired future conditions. In Shaw, D.W., E.F. Aldon, C. LoSapio (tech coordinators). Desired Future Conditions for Pinyon-Juniper Ecosystems. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Gen. Tech. Rep. RM-258. Fort Collins, CO.

Barr, G.W. 1956. Recovering rainfall, Part I. Department of Agricultural Economics, University of Arizona, Tucson. 33pp.

Barth, R.C. 1980. Influence of pinyon pine trees on soil chemical and physical properties. Soil Science Society of America Journal 44:112-114.

Blackburn, W.H. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. Water Resources Research 11:929-937.

Blackburn, W.H. and C. M. Skau. 1974. Infiltration rates and sediment production of selected plant communities in Nevada. Journal of Range Management 27:476-480.

Breshears, D.D., O.B. Meyers, S.R. Johnson, C.W. Meyer, and S.N. Martens. 1995. Differential use of shallow intercanopy water by two semiarid-woodlands tree species. Los Alamos National Laboratory Report LA-UR-94-4375 (submitted Ecology).

Brotherson, J.D. and S.R. Rushforth. 1983. Influence of cryptogamic crusts on moisture relationships of soils in Navajo National Monument, Arizona. Great Basin Naturalist 43:73-78.

Buckhouse, J.C. and J.L. Mattison. 1980. Potential soil erosion of selected habitat types in the high desert region of central Oregon. Journal of Range Management 33:282-285.

Burkhardt, J.W. and E.W. Tisdale. 1969. Nature and successional status of western juniper vegetation in Idaho. Journal of Range Management 22:264-270.

Burkhardt, J.W. and E.W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 57:472-484.

Carrara, P.E. and T.R. Carroll. 1979. The determination of erosion rates from exposed tree roots in the Piceance Basin, Colorado. Earth Surface Processes 4:307-317.

Charley, J.L. and N.E. West. 1975. Plant-induced soil chemical patterns in some shrub-dominated semi-desert ecosystems of Utah. Journal of Ecology 63:945-963.

Chorley, R.J., S.A. Schumm, D.E. Sugden. 1984. Geomorphology. Methuen, London, 589 p.

Clary, W.P., M.B. Baker, P.F. O'Connell, T.N. Johnson, and R.E. Campbell. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Collings, M.R. and R.M. Myrick. 1966. Effects of juniper and pinyon eradication on streamflow from Corduroy Creek Basin, Arizona. US Geological Survey Professional Paper 491-B, Washington DC 12pp.

Covington, W.W. and L.F. DeBano. 1990. Effects of fire on pinyon-juniper soils. In J.S. Krammes (technical coordinator), Effects of Fire Management of southwestern Natural Resources. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Davenport, D.W. and B.P. Wilcox. 1995. Influence of pinyon-juniper canopy/intercanopy zones on soil physical properties. In review. Los Alamos National Laboratory Report No LA-UR.

Doescher, P. S., L.E. Eddleman and M.R. Vaitkus. 1987. Evaluation of soil nutrients, pH, and organic matter in rangelands dominated by western juniper. Northwest Science 61:97-102.

Dortignac, E.J. 1960. Water yield from pinyon-juniper woodlands. In: Water Yield in Relation to Environment in the Southwestern United States. Committee on Desert and Arid Zone Research, American Association for the Advancement of Science, Southwestern and Rocky Mountain Division. 74pp.

Everett, R.L. and S.H. Sharrow. 1985. Soil water and temperature in harvested and nonharvested pinyon-juniper stands. USDA, Forest Service; Intermountain Research Station Research Paper INT-342. Ogden, UT.

Everett, R.L., S.H. Sharrow, and D. Thran. 1986. Soil nutrient distribution under and adjacent to singleleaf crowns. Soil Science Society of America Journal 50:788-792.

Gaither, R.E. and J.C. Buckhouse. 1983. Infiltration rates of various vegetative communities within the Blue Mountains of Oregon. Journal of Range Management 36:58-60.

Gifford, G.F. 1975. Approximate annual water budgets of two chained pinyon-juniper sites. Journal of Range Management 28:73-74.

Gifford, G.F. 1975. Impacts of pinyon-juniper manipulation on watershed values. Pinyon-Juniper Ecosystems-A Symposium. Utah State University, Logan, UT. pp 127-140.

Gifford, G.F. 1987. Myths and fables and the pinyon-juniper type. In R.L. Everett (compiler) Preceedings-Pinyon-Juniper Conference, Reno, Nevada, p461-464.

Gifford, G.F., G. Williams, and G.B. Coltharp. 1970. Infiltration and erosion studies on pinyon-juniper conversion sites in southern Utah. Journal of Range Management 23:402-406.

Fresquez, P.R. 1990. Fungi associated with soils collected beneath and between pinyon and juniper canopies in New Mexico. Great Basin Naturalist 50:167-172.

Johnsen, T.N., Jr. 1962. One-seed juniper invasion of northern Arizona grasslands. Ecological Monographs 32:187-207.

Ladyman, J.A., R.E. Muldavin, and R. Fletcher. 1993. Pattern and relationships of terrestrial cryptogam cover in two pinyon-juniper communities in New Mexico. In Aldon, E.F., D.W. Shaw (Technical Coordinators) Managing pinyon-juniper ecosystems for sustainability and social needs, Santa Fe, NM. Gen Tech. Rep. RM-236. Fort Collins, CO. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Liu, B.Y., M.A. Nearing, L.M. Risse. 1995. Slope gradient effects on soil loss for steep slopes. Transactions of the American Society of Agricultural Engineers 37:1835-1840.

Loope, W.L. and G.F. Gifford. 1972. Influence of a soil microfloral crust on select properties of soils under pinyon-juniper in southeastern Utah. Journal of Soil and Water Conservation 27:164-167.

McDaniel, P.A. and R.C. Graham. 1992. Organic carbon distributions in shallow soils of pinyon-juniper woodlands. Soil Science Society of America Journal 56:499-504.

Miller, R.F. and P.E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands. BioScience 44:465-474.

Moir, W.H. 1979. Soil-vegetation patterns in central Peloncillo Mountains, New Mexico. American Midland Naturalist 102:317-331.

Pieper, R.D. 1990. Overstory-understory relations in pinyon-juniper woodlands in New Mexico.

Journal of Range Management 43:413-415.

Roundy, B.A., W.H. Blackburn, and R.E. Eckert. 1978. Influence of prescribed burning on infiltration and sediment production in the pinyon-juniper woodland, Nevada. Journal of Range Management 31:250-253.

Scholl, D.G. 1971. Soil wettability in Utah juniper stands. Soil Science Society of America Proceedings 35:344-345.

Schott, M.R. and R.D. Pieper. 1985. Influence of canopy characteristics of one-seed juniper on understory grasses. Journal of Range Management 38:328-331.

Schott, M.R. and R.D. Pieper. 1987. Overstory-understory interactions in southwestern pinyon-juniper vegetation. In R.L. Everett (compiler) Preceedings-Pinyon-Juniper Conference, Reno, Nevada, p461-464.

Smith, H.L. and L.B. Leopold. 1942. Infiltration studies in the Pecos River watreshed, New Mexico and Texas. Soil Science 53:195-204.

Tausch, R. J. and P.T. Tueller. 1990. Foliage biomass and cover relationships between tree- and shrub-dominated communities in pinyon-juniper woodlands. Great Basin Naturalist 50:121-134.

Tausch, R.J. and N.E. West. 1995. Plant species composition patterns with differences in tree dominance on a southwestern Utah pinyon-juniper site. In Shaw, D.W., E.F. Aldon, C. LoSapio (tech coordinators). Desired Future Conditions for Pinyon-Juniper Ecosystems. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Gen. Tech RM-258. Fort Collins, CO.

Tausch, R.J.,N.E. West and A.A. Nabi. 1981. Tree age and dominance patterns in Great Basin woodlands. Journal of Range Management 34:259-264.

Vaikus, M.R. and L.E. Eddleman. 1991. Tree size and understory phytomass production in a western juniper woodland. Great Basin Naturalist 51:236-243.

Ward, T.J. 1986. A study of runoff and erosion processess using large and small area rainfall simulators. New Mexico Water Resources Research Institute, Las Cruces, N.M. 71pp.

Ward, T.J. and S. Bolin. 1989a. Determination of hydrologic parameters for selected soils in Arizona and New Mexico utilizing rainfall simulation. New Mexico Water Resources Research Institute, Las Cruces, N.M. 84pp.

Ward, T.J. and S. Bolin. 1989b. A study of rainfall simulators, runoff and erosion processes, and nutrient yields on selected sites in Arizona and New Mexico. New Mexico Water

Resources Research Institute, Las Cruces, N.M. 68pp.

Ward, T.J. and S.M. Bolton. 1991. Hydrologic parameters for selected soils in Arizona and New Mexico as determined by rainfall simulation. New Mexico Water Resources Research Institute, Las Cruces, N.M. 79pp.

Wilcox, B.P. 1994. Runoff and erosion in intercanopy zones on pinyon-juniper woodlands. Journal of Range Management 47:285-295.

Wilcox, B.P. and D.D. Breshears. 1995. Hydrology and ecology of pinyon-juniper woodlands: conceptual framework and field studies. In Shaw, D.W., E.F. Aldon, C. LoSapio (tech coodinators). Desired Future Conditions for Pinyon-Juniper Ecosystems. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Gen. Tech. Rep RM-258. Fort Collins, CO.

Wilcox, B.P., C.L. Hanson, J.R. Wight, and W.H. Blackburn. 1989. Sagebrush rangeland hydrology and evaluation of the SPUR hydrology model. Water Resources Bulletin 25:653-666.

Wilcox, B.P., J.Pitlick, C.D. Allen, and D.W. Davenport. 1995. Runoff and erosion from a rapidly eroding pinyon-juniper hillslope. Journal of Soil and Water conservation (in press).

Wilcox, B.P., M.K. Wood, and J.M. Tromble. 1988. Factors influencing infiltrability of semiarid mountain slopes. Journal of Range Management 41:197-206.

Wilcox, B.P. and M.K. Wood. 1989. Factors influencing interrill erosion from semiarid slopes in New Mexico. Journal of Range Management 42:66-70.

Williams, G., G.F. Gifford, and G.B. Coltharp. 1969. Infiltrometer studies on treated vs. untreated pinyon-juniper sites in central Utah. Journal of Range Management 22:110-114.

Williams, G., G.F. Gifford, and G.B. Coltharp. 1972. Factors influencing infiltration and erosion on chained pinyon-juniper sites in central Utah. Journal of Range Management 25:201-205.

Wood, J.C., M.K. Wood, and J.M. Tromble. 1987. Important factors influencing water infiltration and sediment production on arid lands in New Mexico. Journal of Arid Environments 12:111-118.

Wood, M.K., D. Hereford, C. Sounders and A. Hill. 1994. Variations in plants, soils, water and erosion in a pinyon pine and juniper dominated range site. In Blackburn, F.B. Pierson, Jr., G.E. Schuman, and R. Zartmann (eds.) Variability in Rangeland Water Erosion Processes. Soil Science Society of America Special Publication, No 38. Madison, WI.

Zarn, M. 1977. Ecological characteristics of pinyon-juniper woodlands on the Colorado Plateau; a literature survey. USDI, BLM Technical Note.

Zinke, P.J. 1962. The pattern of influence of individual forest trees on soil properties. Ecology 43:130-133.