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Title: Effect of Western Juniper Removal on Ponderosa Pine and Associated Understory Vegetation.

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This research assessed the effect of western juniper (Juniperus occidentalis) removal on understory plant production and cover and ponderosa pine (Pinus ponderosa) growth and plant water status.

A complete randomized block design, with four blocks and four treatments was established in the summer of 1984 near Prineville, Oregon. The four treatments were: Control - all trees left at original densities, Pine Thinned - ponderosa pine was thinned to 5 m x 5 m spacing, Juniper Removed - all western juniper were removed, and Pine Thinned/Juniper Removed - ponderosa pine was thinned to 5 m x 5 m spacing and all western juniper were removed.

Understory plant production was obtained one year after tree removal, and cover two years after tree removal, to determine response to treatment. Plants were separated into species or

groups in the field, then dried and weighed. Dominant grasses on the sites were, bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), bottlebrush squirreltail (*Sitanion hystrex*), Sandberg bluegrass (*Poa sandbergii*), and cheatgrass (*Bromus tectorum*). Mountain big sagebrush (*Artemisia tridentata* ssp. *vayseyana*) and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) were the principal shrub species. Perennial grasses, total shrub, and total production and cover showed a significant response to western juniper removal. Wyoming big sagebrush, mountain big sagebrush and forbs showed no response to western juniper removal. Thinning ponderosa pine appeared to reduce production and cover of most groups.

Ponderosa pine basal area and height growth were examined for response to tree removal. Basal area growth was determined by measuring diameter at breast height (1.4 m) immediately after, one year after and two years after tree removal. Height growth was sampled in a similar manner using a metal tape on trees under 2 m and a Relaskop on trees over 2 meters. Response of ponderosa pine was similar to the understory vegetation. In both years growth of ponderosa pine was greater in treatments where western juniper was removed, although only the height response was significant. Small trees, under 5 cm in diameter, had significantly greater percent growth than the other trees.

Predawn needle xylem pressure potential and soil moisture were also observed. Measurements were taken five times at three week intervals throughout the summer using a pressure chamber. In general early season predawn xylem pressure potentials of ponderosa pine in treatments with western juniper appeared higher than pine in treatments with western juniper removed. This trend reversed midway through July.

Soil moisture was sampled gravimetrically on the same date as the pressure chamber measurements. Soil moisture response was similar to predawn xylem pressure potential response. Treatments with western juniper present started the season with higher soil moisture, but fell below the treatments without western juniper later.

EFFECT OF WESTERN JUNIPER REMOVAL ON PONDEROSA PINE AND ASSOCIATED UNDERSTORY VEGETATION

by

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INTRODUCTION

Encroachment of western juniper (Juniperus occidentalis) into productive sagebrush-grasslands has caused great concern. In the past 100 years western juniper has approximately doubled its range throughout Oregon, Washington, Idaho, Nevada, and California (Caraher 1978). Western juniper's highly competitive nature enables it to move into and dominate areas regardless of the plant community's ecological condition (Eddleman 1983, Young and Evans 1981, Burkhardt and Tisdale 1976). Once established western juniper has the potential to eliminate most other plants from the community.

Prior to the recent period of expansion, western juniper trees were limited to rocky ridge tops and areas with shallow rocky soils (Driscoll 1964). Climax stands were found to be open with a sparse understory, and high percentage of bare soil. Distribution of western juniper ranged from the edge of the sagebrush grassland through the ponderosa pine (Pinus ponderosa) forest into higher elevation Douglas-fir (Pseudotsuga menziesii) stands (Fowells 1965). Periodic wildfires in the sagebrush-grasslands and ponderosa pine forests were thought to be the major constraint on western juniper's distribution (Young and Evans 1981). Sparse understories of climax stands are not capable of carrying fires of sufficient intensity to kill mature juniper.

Fire suppression in the western United States has been cited as one of the causes of western juniper encroachment (Burkhardt and Tisdale 1976, Young and Evans 1981). Subtle shifts in climate and over grazing of domestic livestock, have also been linked to western juniper's resent expansion (Driscoll 1964, Eckart 1957, Vasek 1966, Mehringer and Wigand 1984). Increase in areas dominated by western juniper and density of existing stands on rangeland systems has been slow, resulting in a gradual decline of forage resources (Miller et al 1987).

Much of the attention has been focused on the encroachment of western juniper in to the drier sagebrush-grassland. The effect of western juniper on other woody plants has had little study. Ponderosa pine is often found in association with western juniper on more mesic, higher elevations and sites. Together the two forest types occupy some of the warmest climates in the Pacific Northwest (Minore 1979). With the recent decline in commercial forest lands dominated by ponderosa pine (Barrett 1979), it may be important to examine other areas for potential timber sources. In the past, management for wood fiber production was not feasible in the more xeric forests and woodlands because of slow seedling growth.

The ponderosa pine and Douglas fir zones constitute the main multiple or integrated use type in the northwestern Untied States and British Columbia (McLean 1983). Ponderosa pine dominates about 36% of the commercial forest lands and comprises a large percent of the total saw timber cut in eastern Oregon and

Washington (Barrett 1979). These lands also provide an important forage source for many domestic and wild herbivores. Thinning in ponderosa pine forests for increases in livestock forage alone is impractical, but when considered as an adjunct to timber improvement, increases in forage yields could become an important part of a farm/forestry program (McConnel and Smith 1970).

When considering management of marginally productive lands, it may become important to consider other uses which add to the area's value. No information is available on the effect of western juniper on other trees. It is not known if removal of western juniper in the ponderosa pine-western juniper margin will increase growth of ponderosa pine on these marginal sites. Production of understory vegetation has been shown to increase in other areas with the removal or thinning of the tree canopy (Vaitkus 1986, Vaitkus and Eddleman 1987, McConnell and Smith 1970). The objectives of this study were:

1) determine the response of basal area and height of ponderosa pine to thinning and western juniper removal,
2) determine the effect of western juniper removal and ponderosa pine thinning on soil moisture and predawn xylem potential of pine, and
3) determine the effect of western juniper removal and ponderosa pine thinning on understory vegetation.

LITERATURE REVIEW

Western Juniper and ponderosa pine are two distinctly different tree species, but together they occupy one of the driest woodland environments in Oregon. There is not a distinct boundary between western juniper woodland and ponderosa pine forest. An area, varying in size, with a mixture of plants and animals from both communities is common. (Young and Evans 1981, Hall 1978, Vasek 1966 Dealy et al. 1978,1964). Precipitation averages 312 millimeters in the ponderosa pine-western juniper transition near Bend, Oregon (Franklin and Dyrness 1974). Pacific marine air modifies the continental climate (Dealy et al 1978) producing hot dry summers, cold winters, and limited amounts of precipitation (Fowells 1965). Historically this area has been used mainly by domestic livestock because of low timber value and relatively good early spring and fall forage.

Western Juniper

In the western United States, western juniper is one of the nine tree sized junipers occupying the semiarid region and is often the only tree species in much of the northeastern portions of the Great Basin (Miller and Schultz 1987). The driest coniferous forest zone in the Pacific Northwest is dominated by this slow growing, long-lived tree (Gholz 1980). Western juniper has become accepted as a characteristic part of the landscape in central and eastern Oregon.

Sites with shallow rocky soils over fractured bedrock were historically the areas where western juniper dominated (Burkhardt and Tisdale 1969). But in the past eighty years, western juniper has expanded its range to more productive areas. Soils derived from a broad variety of parent materials support western juniper woodlands. Dealy and others (1964) found western juniper to occur on soils of igneous, sedimentary, and metamorphic origin. Profile development was often weak and textures varied from clayey to sandy.

The two subspecies of western juniper are spread across the Intermountain Northwest, being heavily concentrated and highly developed in central, south- central Oregon and northeastern California (Dealy et al 1964). The northern populations occur on a low range of hills in the broad basin just north of the junction of the Snake and Columbia Rivers (Vasek, 1966). Distribution of the northern subspecies, Juniperus occidentalis ssp occidentalis, generally follow Columbia River Basalts (Young and Evans 1981). At the southern end of its distribution in Nevada, Vasek (1966) found western juniper merged with Utah juniper (Juniperus osteosperma). In northern California, Juniperus occidentalis ssp. australis combines with the other subspecies of western juniper, Juniperus occidentalis ssp. occidentalis (Vasek 1966).

Woodland ecosystems normally have a wide spread in age classes. In stable woodland ecosystems if diameter is plotted against number of trees a reverse J-shaped curve results (Ronco 1987). Invading stands of western juniper do not have this type of distribution. Eddleman (1984) observed that large numbers of individuals became established in the 1930's, changing the shape of the curve. Establishment has dropped to where only a few seedlings could be found in invading stands.

Fire has played a key role in determining western juniper distribution (Burkhardt and Tisdale 1976, 1978 , Vasek 1966, Driscoll 1964). In the past, naturally occurring fires may have restricted the distribution of western juniper (Burkhardt and Tisdale 1976) to rocky ridge tops and scab areas. Fire suppression and introduction of domestic livestock has helped to reduce the natural fire frequency over much of the western juniper range (Burkhardt and Tisdale 1969), and possibly helped to accelerate western juniper encroachment. Twenty one western juniper communities have been identified in Oregon (Driscoll 1964, Hall 1973, Eckert 1957) and southwestern Idaho (Burkhardt and Tisdale 1969, 1976). Driscoll (1964) noted that the western juniper/big sagebrush/bluebunch wheatgrass (*Juniperus occidentalis*/*Artemisia tridentata*/*Agropyron spicatum*) association of central Oregon was the most xeric. The most mesic western juniper community, western juniper/big sagebrush/thread-leaf carex (*Juniperus occidentalis*/*Artemisia tridentata*/*Carex filifolia*), was identified by Franklin and Dyrness (1974) east of Bend, Oregon. Idaho fescue and bluebunch wheatgrass were identified as the most common perennial grasses found in association with western juniper (Franklin and Dyrness 1974). Other herbaceous plants often occurring with western juniper were, Thurber's needlegrass (*Stipa* *thurburiana*), junegrass (*Koleria cristata*), bottlebrush squirreltail (*Sitanion hystrix*), cheatgrass (*Bromus tectorum*), nineleaf lomatium (*Lomatium triteratum*), and *Astragalus* sp. (Vaitkus 1986).

Special adaptations to its environment permits western juniper to utilize resources unavailable to other plants. The evergreen nature allows it to display maximum leaf surface area during favorable growing condition early in the spring. Western juniper leaves are classified as xeromorphic by Miller and Schultz (1987). Structural adaptations in leaf morphology of western juniper allow maximum drought avoidance through low leaf area, low surface-to-volume ratio, thick cuticle layers, and protected stomata. Leaves are reduced to small overlapping scale-like structures, forming a chain-like cylinder of leaf-scales. The total stand leaf areas for western juniper woodlands are about one-third of adjacent ponderosa pine stands (Gholz 1980). Western juniper trees are short with canopies close to the ground. Gholz (1980) found sapwood area of a western juniper woodland was 700 cm^2/ha, much smaller than the over 2000 cm^2/ha often found in pine or fir forests. Sapwood of western juniper was 2.5% of stem volume, probably indicating that water storage within the stems is not a major adaptive feature. Although, Jeppesen (1978) indicated that storage of water in the bole could be a an advantage in dry environments.

Crowns of western juniper trees rarely, if ever, close to form a continuous overstory, but roots have been found to occupy the surface soils between trees (Young and Evans 1981). Tueller and Clark (1975) found roots of pinyon and juniper fully occupied the soil just under the surface. Western juniper in northern California occasionally have roots growing down into the fractured bedrock (Young and Evans 1981). Directly at the base of the tree, both above and below the major roots, there was a mass of multibranched very fine roots. This two tiered root system allows for extraction of deep moisture and nutrients and quick access to surface water and nutrients.

Nitrogen accumulations in ecosystems dominated by western juniper may actually be associated with litter and or biomass of juniper trees (Doescher et al 1987). The combination of stemflow from precipitation and litter accumulation at the base of western juniper trees may lead to nitrification directly under the canopy (Young and Evans 1987). Roots directly below a juniper canopy can draw from this nutrient pool. Other soil nutrients may also be affected by the presence of western juniper. Higher calcium concentrations have also been found under western juniper canopies by Doescher and others (1987). Calcium concentrations are highest in the surface soils (0-8cm) from the bole to mid canopy (Doescher et al 1987). Feeder roots, often found under the canopy and often next to the bole of the tree, may be capable of utilizing this source of nutrients and water. Redistribution of soil nutrients may be one of the ways that western juniper gains a competitive advantage. Burkhardt and Tisdale (1976) believed that soil physical characteristics of sites in southwestern Idaho were more important than vegetational characteristics for establishment and growth of western juniper.

Litter can also reduce evaporation from the soil surface, improving temperature relations, as well as providing additional nutrients. Young and Evans (1985) found litter under a western juniper tree to favor plant establishment and growth of annual and perennial grasses. Litter was not always found to be advantageous for plant growth. Litter fall in the pinyon-juniper woodlands of Nevada exceeded annual rates of decomposition (Evans et al 1975). Thick litter mats comprised of pinyon and juniper needles can physically restrict plant growth and possibly release allelochemicals. In New Mexico, perennial grass growth under pinyon-juniper woodlands was restricted by shading or heavier litter deposition under the canopy as compared to the edge (Schott and Pieper 1987).

Western Juniper Invasion

Encroachment of woody plants into more productive areas is an important problem to many land managers. In many cases a reduction in forage accompanies the increased shrub or tree density (Vallentine 1980). Many factors have been identified as the cause of woody plant invasion. The three most common factors are; reduction of competing vegetation by large grazing animals, suppression of periodic wildfires, and subtle, long term climatic shifts (Burkhardt and Tisdale 1976, Tausch et al 1981, Blackburn and Tueller 1970, Young and Evans 1981).

The expanding range and increased density of western juniper has been well documented (Mehringer and Wigand 1987, 1984, Burkhardt and Tisdale 1978, 1976, 1969, Young and Evans 1981, Adams 1974). Much attention has been directed toward the encroachment of western juniper into more productive lands because of the loss in forage production, loss of top soil, increased difficulty in handling livestock, and decrease in water yields (Bedell 1987, Burkhardt and Tisdale 1976). Sites with deep permeable soils were most susceptible to western juniper invasion (Burkhardt and Tisdale 1969). Big sagebrush-bluebunch wheatgrass vegetation on southerly slopes and big sagebrush-Idaho fescue-bluebunch wheatgrass on northerly slopes dominated these sites prior to western juniper invasion. Adams (1975) found that many portions of deer range in the northwestern states have experienced dramatic invasions by juniper forests during the past 100 years, usually with a concurrent decrease in palatable browse and grass species.

The physical character of an invading western juniper stand is very different from climax stands. Invading stands appear to be a forest, conspicuously lacking standing dead trees and logs (Caraher 1978). There are often very few older trees and no seedlings in the understory. The shape of the crowns also varies. Crowns of invading trees are often cone-shaped, having only one main trunk (Vaitkus 1986), while slow growing trees of climax stands have a rounded canopy shape. Burkhardt and Tisdale (1969) believed that western juniper invasion began in the 1860's, slowed until about 1900, then increased between 1930 and 1940. Since 1940 the invasion has slowed again and existing stands are increasing density. In central Oregon western juniper numbers were found to double every ten years from the late 1800's to the turn of the century (Eddleman 1987). From 1900 to 1910 western juniper density in central Oregon doubled every 6.6 years, followed by a period of gradual slowing by 1980, where populations doubled ever 18 years. Evans and Young (1981) found that western juniper on productive sites in northern California doubled their numbers every three years at the turn of the century. Western juniper on very harsh low sagebrush sites in the same area doubled their population every 48 years. There have been no climax stands found with densities similar to that of invading stands (Burkhardt and Tisdale 1969).

Dispersal of western juniper seeds often occurs by gravity pulling them down slope (Young and Evans 1981, Burkhardt and Tisdale 1976). Radioactive seeds were placed up slope by Burkhardt and Tisdale (1976), and they found seed dispersal to occur in all directions except in the winter. In the winter seed movement was strictly down slope. Movement of seeds across frozen soils by water has been observed by Eddleman (1987) in central Oregon.

Only a few animals have been identified as possible seed dispersal agents. Sheep have been accused of being a major carrier of western juniper seeds (Miller 1921). Small birds have also been identified as possible carriers of western juniper seeds

(Eddleman 1984, Young and Evans 1981). Both robins (Turdus migratorus) and Townsend Solitares (Myadestes towsendi) winter in the juniper zone of Oregon, and consume large numbers of western juniper berries digesting only the pulpy covering and depositing the seeds below perching sites (Saradell and Lederer 1982, Lederer 1977,). Fences crossing big sagebrush sites in the Juniper Hill area of northern California have been found to have 1.7 western juniper trees per 10 linear meters of fence, and fences crossing low sagebrush sites had 0.1 trees per 10 linear meters of fence (Young and Evans 1981).

Site factors that favor establishment of herbaceous species were found by Burkhardt and Tisdale (1976) to be favorable for western juniper establishment. Everett and Sharrow (1985) found that lack of on site perennial species provide increased opportunities for establishment of invading pinyon and juniper in Nevada. Establishment of western juniper may not be totally excluded by perennial plants, but it may be reduced. If grazing animals are allowed to overgraze an area, plant vigor will decrease, possibly opening the site to invasion. Jameson (1987) found that grazing and wet years had a synergistic effect on tree establishment. Destructive grazing followed by two years of high precipitation, the first for seed production and the second for establishment, is a favorable combination for woody plant invasion. These conditions would be beneficial to western juniper if conditions occurred during a peak berry production year.

Although grazing may reduce fuels for fires that would halt western juniper expansion, suppression of wildfires and overgrazing cannot explain prehistoric fluctuation in western juniper's range or density (Mehringer and Wigand 1987). Fluctuations in western juniper populations since the late-Holocene are equal or greater than those seen over the past hundred years (Mehringer and Wigand 1987). In the past juniper has responded to shifts in the climate, but in general these changes have taken very long periods of time. The influence of European man in the past 150 years may have helped to accelerate natural changes already in progress.

Ponderosa Pine

Ponderosa pine is a very important forest species throughout much of the drier areas in the western United States. It's range runs from the Fraser River in British Columbia in the north, to Mexico, in the south and from the Pacific coast of northern California and southern Oregon to Holt County, Nebraska (Fowells 1965). In Oregon and Washington ponderosa pine occupies a narrow band on the eastern slope of the Cascade Mountains, High Cascade Province, Blue Mountain Province, Okanogan Highlands, and drier areas in southwestern Oregon (Franklin and Dyrness 1974). Ponderosa pine is a climax species in the central Oregon Cascade Range, Ochoco and Blue Mountain and southern Oregon Cascade Range Forest zone (Siedel and Cochran 1981). Ponderosa pine is limited to environmentally drier forest sites, but reaches its greatest productivity on low moisture stress sites (Waring 1970). At the upper elevational limits, ponderosa pine forests may merge with Douglas-fir, grand fir (Abies grandis), or white fir (Abies concolor) depending on location. On the drier end of its distribution in Oregon, ponderosa pine comes up against sagebrush steppe or western juniper woodland. In some locations of southern Oregon lower elevation ponderosa pine forest mixes with Oregon white oak (Quercus garryana).

Dyrness and Youngberg (1966) found that in south-central Oregon competition for soil moisture limited the establishment and development of ponderosa pine seedlings. Establishment did occur in areas where mortality or logging removed overstory trees and released soil moisture. Ponderosa pine germination, growth, and establishment is greatest in July and August if adequate soil moisture is available (Barrett 1979).

Ponderosa pine grows on a variety of soil types throughout its range. Franklin and Dyrness (1974) found ponderosa pine growing in the northwest to occur on two main soil categories. Haplumbrepts were the most common soil found in lower elevation forests. In the pumice-plateau of south-central Oregon, Vitrandepts (immature regosolic) soils dominate under pine forests. Both soil types have weakly developed soil profiles, are well drained, and have coarse textures. Lodgepole pine encroaches when drainage is limited by the presence of a clay layer (Fowells 1965). Periodic wildfires helped to keep the primeval ponderosa pine forests in an open state. Seidel and Cochran (1981) believed that past fires kept pine forests in a mosaic of even-aged stands with one or two age classes in the understory. Fire removed trees killed by insects, lighting, or windthrow, helping to return nutrients back to the system (Weaver 1961). Fires were mostly low intensity, removing most of the understory vegetation. Cooper (1961) believes that groups of large old trees died simultaneously producing hot spots in the low intensity fires. These hot spots provided a suitable seedbed for pine reproduction provided there was an ample seed crop that year. Changes began to occur once domestic livestock and fire exclusion were introduced into the forest (White 1961). Domestic livestock reduced production of fine fuels and fire suppression stopped fires. Understory of presettlement ponderosa pine forests were dominated by a dense grass cover (Cooper 1960, Weaver 1961). Grass cover proved to be an effective barrier to seedling establishment. Removal of the grass cover may have opened sites to tree establishment and fire suppression allowed trees to become establish creating dense, overstocked stands. These over stocked stands are characterized by, greatly reduced tree growth and large volumes tied up in many small trees. In dense stands understory vegetation is reduced to extremely low levels (McConnell and Smith 1970).

Seven ponderosa pine plant communities have been identified in the Blue Mountain and 14 in the High Lava Plains Provinces (Barrett 1979, Volland 1976, Hall 1973). Plant community composition in ponderosa pine stands has been found to vary with geographic location, soils, elevation and aspect, and successional status (Franklin and Dyrness 1974). History of the stand also has an effect on the present plant community. In the Pacific Northwest ponderosa pine on mesic sites is most often associated with more shade tolerant conifers and shrubs. Snowberry (Symphoricarpos albus), ninebark (Physocarpus malvaceus), curlleaf mountain-mahogany (Cercocarpus ledifoilius), Archtostaphylos spp., and snowbrush (Ceanothus velutinus) are common shrubs found on moist ponderosa pine sites. Common grasses and forbs on these mesic sites are pine grass (Calamagrostis rubescens), Idaho fescue (Festuca idahoensis), Poa nervosa, elk sedge (Carex geyreri), Ross's sedge (Carex rossii), heartleaf arnica (Arnica cordifoilia), and white hawkweed (Hieracium albiflorum). Drier sites in the Pacific Northwest are typically characterized by an open park-like forests, with scattered understory vegetation. Bitterbrush, sagebrush, and wax current are common shrubs found in the drier end of ponderosa pine distribution. Understory vegetation on these drier sites is often dominated by herbaceous plants. Bluebunch wheatgrass is often the dominant plant in the understory of communities where soil moisture is depleted early in the growing season (Daubenmire 1968). Other grasses commonly found associated with bluebunch wheatgrass on these drier sites are, bottlebrush squirreltail and western needlegrass (Stipa occidentalis).

Ponderosa pine is one of the least shade tolerant trees in the Pacific Northwest (Minore 1979), although young ponderosa pine required only 10% full sunlight throughout the day to survive

(Waring 1970). On fairly productive sites in northern California, McDonald and Oliver (1984) found ponderosa pine survive and grow with a dense shrub cover. Although growth of trees in shrub fields was below that of trees in shrub-free plantation.

Herbaceous understory vegetation has differential effects on young ponderosa pine growth (Baron 1962, Larson and Schubert 1969, Barrett 1979, 1982, Oliver and McDonald 1984, Elliott and White 1987). Young seedlings send out a fast growing tap root possibly reaching deep untapped or under-utilized water sources (Fowells 1965). Shrubs appear to be the greatest competitor of ponderosa pine. Even small amounts of woody vegetation have been found to have long-lived negative effects on ponderosa pine growth over a broad range of site qualities (McDonald and Oliver 1984).

Barrett (1982) found that understory vegetation consistently decreased basal area increment at a variety of spacings. Growth reductions were most evident at the widest spacings. Young ponderosa pine competing with shrubs grew more slowly than trees free of shrub competition, regardless of spacing, during a six year growth period (McDonald and Oliver 1984). Periodic annual increment was reduce by as much as 51% by shrub competition. Soil water potential remained above field capacity throughout most of the summer in areas where shrubs, specifically bearmat (*Chamaebatia foliososa*), had been controlled (Conrad and Radosevich 1982, Radosevich 1984). As number of trees per unit area increases the effect of understory vegetation is reduced and intraspecific competition becomes dominant.

Competition influences both growth of individuals and how the growth is distributed. Much of the direct effect of competition on growth is mediated through its impact on crown size and structure and amount of carbon fixed (Perry 1985). Radosevich (1984) found that growth of ponderosa pine was inhibited by associated shrubs and competition was most critical during spring and summer. Controlling bearmat postponed soil moisture depletion past -1.5 MPa at 15 cm depth until August or September (Tappeiner and Radosevich 1982). The effect of bearmat on young ponderosa pine did not appear until the third year, when height growth was suppressed up to 25cm. Brix and Mitchell (1986) found that salal (Gaultheria shallon) utilized half of the extractable soil water when present under Douglas-fir. Substantial increases in wood fiber production can occur when understory vegetation is reduced (McConnell and Smith 1970).

The presence of a shrub canopy does not always cause reduced survival of tree seedlings. In some circumstances shrubs may input nitrogen to the soil and protect seedlings from harsh environmental conditions and physical damage. White fir survival in northern California was greatly increased when chaparral was left in place (Conrad and Radosevich 1982). Growth of white fir under the shrub canopy was slow, taking 75 to 100 years before trees where able to emerge from the shrub canopy, but conditions outside the shrub canopy did not permit tree establishment. In general all major climatic factors, including light, temperature, moisture, and wind, are less variable under closed brush canopies than in the open (Zavitkowski and Woodward 1970).

Once trees become established and grow for a period of time the effect of understory vegetation is reduced. Neighboring trees, of different and of the same species, begin to affect ponderosa pine growth more than understory vegetation. Larger trees are also effected by shrubs, grasses and forbs, but the detrimental effects are small.

In natural stands, where no silvicultural activity has taken place, replacement of dying trees often occurs on an individual basis or in small groups (Fox 1977). Silvicultural activity attempts to control this replacement. At high plant densities, mutual interference can decrease community yields and cause what is often termed stagnation (Perry 1985). Stagnation occurs most often in seral stands of ponderosa pine that have been disturbed. The stand shifts from a multi-aged structure to even age and size trees. Natural thinning agents will in time shift stagnated stands to a multi-age state, but this process is often slow (Bolt and Van Deusen 1974). Silvicultural thinning of stagnant stands helps to redistribute resources to fewer faster growing trees.

Thinning is used to remove trees that are; old and dying, diseased, severely damaged or, suppressing other individuals. Resources on the site can be funnelled into remaining trees after thinning. Reductions in stand transpirational area can be expected to increase available soil water (Brix and Mitchell 1986). On sites where soil moisture was sufficient and trees were exposed to ample sunlight, release either did not occur or was smaller in magnitude than observed on areas where sunlight was inadequate (Conrad and Radosevich 1982). Soil moisture was always higher in thinned red pine (Pinus resinosa) stands of Michigan (Sucoff and Hong 1974). Thinning may improve site water relations by reducing both overall stand transpiration surface area and live root density (Donner and Running 1986).

Barrett (1979) extensively studied thinning response of ponderosa pine in central Oregon. Pole sized ponderosa pine were found to respond at any age to thinning. Treatments where stand density was high, over 500 trees/acre had the greatest growth per unit of land area, but growth per individual tree was lowest (Barrett 1982). Ponderosa pine at wide spacing had the greatest individual growth, but lowest stand growth. Oliver (1979) found similar trends in northern California ponderosa pine forests. After thinning trees, plots thinned to low growing stock levels (40 and 70) had higher growth rates than ponderosa pine at higher stocking densities. Thinning highly productive sites shortened the time to reach merchantable size by almost 15 years (Oliver 1979). Initial densities below 395 trees/acre may produce usable trees in much less time, but quantity and volume production per area may suffer (Barrett 1979).

Effect of Tree Cover on Understory

Tree cover has many affects on understory plant production. The most obvious is reducing the levels of production through direct competition for available resources. Droughty subsoil and high basal area, as often found in the pine-juniper margin, create conditions where moisture supply to understory plants would be expected to be critical (Anderson et al 1969). In most cases the larger trees win the battle for resources. Competition often reinforces and perhaps magnifies any hierarchy in plant size (Perry 1985). Trees capture a majority of the available resources. The larger trees are better adapted to capture a larger amount of soil water, nutrients and sunlight because of their area of influence. The effect of competition upon photosynthesis could arise directly, though a decline in photosynthesis efficiency, or indirectly through a reduction of growth period (McMurtrie and Wolf 1983). Many effects of a tree overstory are constant across a variety of forest types. Thinning, spacing and slash treatment have had an effect on understory vegetation development; and this vegetation in turn has had a competitive effect on tree growth in certain plant communities (Barrett 1979).

There is a highly significant negative relationship between tree crown cover and herbage cover and yield (Young et al 1967, Clary 1987, Schott and Pieper 1987). The degree of overstory crown closure in the mixed coniferous forest of the Pacific Northwest is closely related to conifer reproduction, shrub cover, and production and the composition and production of herbaceous vegetation. In general as canopy cover, basal area, or volume of a forest increases, understory productivity declines. Anderson

(1969) identified two ways that understory development can be limited by a tree canopy; (1) the canopy and surface litter intercept precipitation, reducing amount of moisture reaching the forest floor and, (2) the dominant members of the forest community compete with the understory for moisture which does penetrate the forest floor. Light and water appear to interact and effect total forest production, especially in the drier forest of central and eastern Oregon.

Understory production can be increased by removing all or part of the overstory trees. For many years land managers have increased forage production by removing juniper. Western juniper removal in central Oregon has increased beef cattle stocking rates 50 to 300 percent (Bedell and Bunch 1978). A study in central Oregon examined the effect of removing western juniper on herbaceous plant production under the canopy and in the interspace area. Vaitkus (1986) found that plant production was higher two years after western juniper removal in the old canopy area than under the canopy of existing juniper. Interspace production was found to be higher the second year after tree removal. Release from competition with western juniper for moisture seemed to offset changes in growing season precipitation, except Sandberg bluegrass and bottlebrush squirreltail (Vaitkus and Eddleman 1987).

In northern California control of western juniper with picloram resulted in a increases in annual grasses (Evans 1984). Cheatgrass increased its density under the dead western juniper canopy and medusahead increased in the interspace. Medusahead was not present in the western juniper community at the time of picloram treatment, but seven years later it became the dominant grass in the interspace.

As little as 40 trees per acre in pinyon-juniper stands can reduce herbage production by one half (Short et al 1977). Chaining in pinyon-juniper stands in the southwest has increased understory production far above previous levels. Clary and others (1974) found that chaining, hand chopping residual trees and burning slash resulted in a 700 lb/acre increase in understory plants. This was a 600% increase over the previous production levels. The largest production increases occurred in perennial grasses, perennial forbs and half-shrubs. In Utah chaining and seeding pinyon-juniper stands increased production from 60 to 700 lb/ac (Clary 1973). On pinyon-juniper sites in Nevada, Everett and Sharrow (1985) found that total understory cover significantly increased following tree harvest on sites not subject to grazing. Sites dominated by annual plants showed no response to pinyon and juniper removal.

Highest level of understory cover under various densities of ponderosa pine was found in the treatments with 125 trees/acre in central Oregon (Barrett 1982). Cover values were lower at widest spacing than the treatment with 125 trees/acre. Additional shade provided by the higher cover at 125 trees/acre may have reduced environmental stress on the plants. At the wide spacings understory vegetation had its greatest affect on ponderosa pine growth (Barrett 1979). Grasses showed the greatest level of response in the first five years after thinning. Shrubs gradually replaced grasses as dominant understory vegetation.

In northern California Oliver (1979) found that understory vegetation became dominated by deerbrush (Ceanothus intergerrimus) four years after tree removal. Radosevich 1984, found that shrubs were detrimental to conifer regeneration in northern California. They also found that heavy shrub cover reduced herbaceous plant cover. Treatments where shrubs were chemically and physically controlled had higher ponderosa pine growth and herbaceous plant cover eight years after treatments. Herbaceous plants were effective in keeping out shrubs after initial control and were thought to be less competitive with the young ponderosa pine (White 1985).

In central Oregon ponderosa pine stands attacked by mountain pine beetles (Dendroctonus ponderosae) understory plant production increased from nearly zero before tree mortality, to 201 kg/ha five years after tree death (Kovacic et al 1985). After the fifth year understory production began to decline. Shrub biomass was slow to respond, but as years from initial attack increased shrub biomass increased. Grasses and sedges were negatively correlated with ponderosa pine diameter, while shrubs were positively correlated (Kovacic at al 1985). This may indicate that shrubs were better able to compete with ponderosa pine for water and nutrients. Control of western juniper with herbicides in northern California led to a rapid increase of cheatgrass (Evans and Young 1987). In subsequent years medusahead (*Taenatherum asperum*) became the dominant herbaceous species on the plot regardless of tree control. This led Evans and Young (1987) to conclude that control of western juniper does not automatically lead to dominance by desirable forage and browse species, but often disturbance in western juniper woodland leads to dominance by undesirable herbaceous weeds.

Western juniper removal on the Bonnieview Ranch in central Oregon not only resulted in increased beef production through more forage, but increased runoff and stream flow, improving conditions for downstream water users (Bedell 1987). Everett and Sharrow (1985) found that understory cover significantly increased after pinyon and juniper tree removal in Nevada. Cabling, hand chopping remaining trees, and burning of slash increased annual production by 600 percent in pinyon-juniper (*Pinus edulis* - *Juniperus osteosperma*) stands of Arizona (Clary et al 1974).

When fire was used to control singleleaf pinyon-Utah juniper understory plant cover was still below preburn levels up to five years after the fire (Everett and Ward 1984). Understory production of annuals peaked two years after chaining and perennials four years after chaining in pinyon-juniper in eastern Nevada (Tausch and Tueller 1977). Response of understory, regardless of treatment, was often slow and it was many years before succession progresses past the annual plant stage. Many of the silvicultural activities in ponderosa pine forests that increase tree growth also benefit understory production.

Understory production increased six pounds for every one percent decrease in tree canopy cover after thinning (McConnell and Smith 1970). At low canopy cover levels grasses were found to dominate the understory plant community while forbs dominated when canopy cover was high. The critical canopy densities in ponderosa pine forests of eastern Washington were between 10% and 55% (Eddleman and McLean 1969, Weber 1957). The herbage production under less than 10% canopy was similar to adjacent open grassland in excellent condition. Production under a canopy over 55% usually was small enough to be almost worthless as a forage source. Anderson and others (1969) found that understory vegetation developed poorly under light intensities less than four percent of full sunlight. Barrett (1982) found that understory cover was highest at wide spacings. Shrubs dominated understory cover at all spacings, but grass cover steadily increased as number of trees per acre decreased. Growth of understory plants on heavily thinned blocks increased over the five year pretreatment period, while lightly thinned blocks remained below pretreatments levels (Crouch 1986).

If no other factors are limiting photosynthesis of understory vegetation was found to be directly proportional to an increase in light from one percent to fifteen percent. In the twenty year spacing study conducted in central Oregon by Barrett (1982) understory cover peaked seven years after thinning in at all spacings. Dealy (1975) found a lag in understory response to lodgepole pine thinning. Productivity actually decreased in the first two years after thinning, but by the third year cover values exceeded prethinning levels.

Natural thinning can cause similar effects. Understory biomass was positively correlated with age since attack in ponderosa pine stands attacked by the mountain pine beetle (Kovacic et al 1985). Grasses, forbs, sedges, and shrubs invade open patches created by mountain pine beetle induced mortality of ponderosa pine. Shrub biomass was often low on recently attacked stands, but increased with time since attack.

Thinning or total tree removal will increase sunlight, soil moisture, nutrients, and space for growth by remaining plants. Use of winter moisture by western juniper was suggested by Jeppesen (1978) to be a major competitive advantage. Removal of western juniper was found to increase amounts of soil water available to forage species. It was also suggested by Oren and others (1987) that thinning ponderosa pine increased soil moisture. The beneficial effects of thinning on soil water conditions will result in a more favorable shoot water potential (Brix and Mitchell 1986). Remaining trees at all densities had the highest growth rates in treatments where understory vegetation had been removed (Barrett 1970). Understory manzanita developed so rapidly nine years following a precommercial thinning that remaining ponderosa pine lost all advantage of the thinning treatment (Fiske 1985). When managing and area for forage and timber, a spacing should be selected that will promote reasonably free growth of understory vegetation and the tree overstory.

METHODS

Site Description

Two study sites were located on private land in Crook County, Oregon, near Prineville. The primary site (One) was 26 km (12 mi) southeast of Prineville on a north to northeast facing slope above Comb's Flat (T17E R15S sec 27 and 35). This area contains three of the four blocks in the experimental design. A second satellite study site (Two) was established 33 km (15 mi) northwest of Prineville on a south facing slope above Lytle Creek, east of Grizzly Mountain (T15E R13S sec 14) and contained one block.

Sites were selected and established in areas where western juniper woodland and ponderosa pine forest merged. This ecotone contains a mixture of vegetation representative of the Western Juniper and Ponderosa Pine Zones of eastern Oregon. Franklin and Dyrness (1974) identified this area as a transition zone, and Hall (1980) suggests that this type is extensive enough to be a classified as a separate community. Western juniper dominates these sites, outnumbering ponderosa pine approximately three to one. In the Prineville area a majority of the western juniper trees established after 1930, with few individuals being present before that time (Eddleman 1987). Absence of mature juniper on the sites indicate that a majority of the trees probably established during the last 50 to 60 years when the junipers were actively expanding their range.

Understory vegetation varied from Site One to Site Two because of many inherent site factors and past management practices. The shrub component of both sites was similar in species present. Dominant shrubs of both areas were bitterbrush (*Purshia tridentata*), mountain big sagebrush (*Artemisia tridentata* ssp. *vayseyana*), wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), and wax current (*Ribes cereum*). Low sage (*Artemisia arbuscula*), grey rabbitbrush (*Chrysothamnus nauseosus*), green rabbitbrush (*Chrysothamnus viscidiflorus*), and serviceberry (*Amenlanchier alnifolia*) occurred occasionally across the study areas.

Site One had a good cover of perennial grasses and forbs. Bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), prairie junegrass (*Koleria cristata*), bottlebrush squirreltail (*Sitanion hystrix*) and Sandberg bluegrass (*Poa sandbergii*) were the dominant perennial grasses. Site Two contained all of the above perennial grasses, but at much lower densities. Cheatgrass (*Bromus tectorum*), six weeks fescue (*Vulpia octiflora*), and annual agrostis (*Agrostis interupta*) were significant species on Site Two. Also on site Two abundant annual forbs were autumn willowweed (*Epilobium paniculatum*), blepheripapus (*Blepheripapus scaber*), and tarweed (*Madia glomerata*) .

Soils from the area were formed from weathering volcanic parent material and formed a mosaic of soil types. The soils of Site One were classified as a Madeline/Canest Complex (Pommerining et al 1983). These soils were shallow with a maximum depth of 60cm (24in). Madeline soils were found on hill slopes and sides of ridges, and were classified as clayey, montmorillontic, frigid Lithic Argixerolls. Canest soil was the shallower of the two, and was found mostly on flats. The Canest soil was classified as a clayey, skeletal, montmorillonitic, frigid, Lithic Argixeroll. Site Two also had a mixture of deep and shallow soils. These soils were classified as a Gradone/Westebutte Complex. The Gradone soil was classified as a sandy, mixed, frigid, Aridic Haploxeroll and could be found mainly on foot slopes. The Westbutte soil was shallow and classified as, loamy, skeletal, mixed, frigid, Pachic Haploxeroll and was found midslope and on slope shoulders.

Experimental Design

A randomized block design, with four blocks and four treatments, was set up across the two study sites. Three of the four blocks were placed on Site One, above Comb's Flat while the fourth block was placed at site Two above Lytle Creek near Grizzly Mountain. Treatments were randomly assigned within each block. Treatments were 40 m x 100 m in area, running down slope, with a 20 m buffer strip between treatments. Treatments were continued 10 m into each buffer to reduce the effect from outside of the block. Four treatments were established;

1) Control - all trees were left at original densities,

2) Pine Thinned - ponderosa pine was thinned to 5.5 m x 5.5 m spacing and western juniper was left at pretreatment densities,

3) Juniper Removed - all western juniper trees were removed and ponderosa pine trees were left at pretreatment densities,

4) Pine Thinned/Juniper Removed - ponderosa pine was thinned to 5.5 m x 5.5 m spacing and all western juniper trees were removed.

Trees were removed during the summer and fall of 1984, using a chainsaw to fall and limb. Small clusters, or thickets of ponderosa pine was common across the study sites. Thickets were thinned to a 5.5 m x 5.5 m spacing. Ponderosa pine that was severly stressed or judged to have no future market value was removed from the thickets. Initial numbers and amount removed can be found in Table 1. Slash was piled and burned on site. Piles were kept small to reduce the effect of fire on vegetation in the area.

Height and diameter of trees were measured prior to treatment and ponderosa pine were measured again in the fall of 1985 and 1986. A metal diameter tape was used to measure diameter of trees over 5cm in diameter and a set of caliper were used on trees with diameters under 5cm. The spot where diameter was taken was permanently marked to ensure the same spot would be remeasured in the following years. Diameter of all western juniper and ponderosa pine under two meters tall was taken 30 cm above the

Table 1. Pre- and post-treatment western juniper and ponderosa pine density and basal area by blocks and treatments.

BLOCK	Treatment: Control Density	Control Basal Area	Pine Thinned Density	Pine Thinned Basal Area	Juniper Removed Density	Juniper Removed Basal Area	Pine Thinned Juniper Removed Density	Pine Thinned Juniper Removed Basal Area
	#/ha	m^2/ha	#/ha	m^2/ha	#/ha	m^2/ha	#/ha	m^2/ha
ONE								
Western Juniper								
Pre Treatment	250	4.3	273	3.9	187	3.4	204	3.7
Post Treatment	250	4.3	273	3.9	0	0.0	0	0.0
Ponderosa Pine								
Pre Treatment	71	0.7	46	1.0	49	0.8	76	1.5
Post Treatment	71	0.7	40	0.9	49	0.8	67	1.3
TWO								
Western Juniper								
Pre Treatment	100	3.6	112	4.0	135	9.6	72	1.2
Post Treatment	100	3.6	112	4.0	0	0.0	0	0.0
Ponderosa Pine								
Pre Treatment	77	2.8	55	2.5	37	1.9	84	2.9
Post Treatment	77	2.8	45	2.2	37	1.9	78	2.5
THREE								
Western Juniper								
Pre Treatment	321	3.7	331	3.2	298	2.7	350	3.3
Post Treatment	321	3.7	273	3.9	0	0.0	0	0.0
Ponderosa Pine								
Pre Treatment	65	1.5	80	1.7	119	1.8	101	1.9
Post Treatment	65	1.5	72	1.4	119	1.8	90	1.7
FOUR								
Western Juniper								
Pre Treatment	75	2.1	82	1.7	78	1.6	84	1.7
Post Treatment	75	2.1	82	1.7	0	0.0	0	0.0
Ponderosa Pine								
Pre Treatment	59	2.6	37	2.3	41	1.9	34	2.1
Post Treatment	59	2.6	31	1.4	37	1.7	31	2.1

ground surface. Diameter of ponderosa pine taller than two meters was obtained at 1.4 m. Height of trees under two meters was measured directly using a metal tape. Height of trees over two meters was measured using a Relaskop. Trees were then placed in one of five diameter classes (under 5 cm, 5-15 cm, 15-30 cm, 30-40 cm, and over 40 cm). Diameter was converted to basal area. Basal area and height for each pine was converted to percent growth by dividing current years growth by total tree basal area or height, and percent growth values were used in analysis.

In 1985 understory response to western juniper removal and ponderosa pine thinning was determined from herbaceous production in each treatment. Production was determined from ten randomly placed 40 m transects running across (width) each treatment with five 0.2 m^2 (40 cm x 50 cm) rectangular quadrats per transect. In each quadrat harbaceous vegetation was clipped to ground level and current years growth clipped from shrubs. Plant material was sorted in the field by species or group and placed into paper bags, oven dried, and weighed.

A miscommunication in the spring of 1986 resulted in an undetermined number of yearling steers being grazed on Site One. The animals were on the site for approximately three weeks before being discovered. At the point of discovery a significant amount of the current years growth had been removed. Therefore cover estimates were used in 1986 to monitor the response to treatment because of the undetermined level of biomass harvested by the steers. Cover was obtained from a 0.2 m^2 quadrat by estimating percent of foliage cover by species of species groups. Twenty 40 m transects were established running across each treatment and along each transect ten quadrats were randomly located.

Sampling of ponderosa pine predawn xylem potential (following Waring and Cleary 1967) and soil moisture occurred every three weeks starting the first week of June and continuing through September. Ponderosa pine were sampled by height class. Trees were placed in one of three height classes, under 1 m, 1 m - 3 m, and over 3 m based on height. Two trees in each size class in each treatment were selected and permanently marked for sampling. Every three weeks predawn moisture potential as determined between 2:00 am and 4:00 am. A needle fascicle was removed from the north, southeast, and southwest of each marked tree and immediately placed in a plastic bag and put in a cooler until inserted into the pressure chamber. No difference among fascicle locations was found therefore the three samples were averaged to reduce natural variation. As little time as possible was allowed to pass between the time the sample was removed from the tree until insertion into the pressure chamber.

Soil moisture was measured gravimetrically, on a three week interval and on the same days that predawn xylem potential was being measured. Three soil pits per treatment were dug and soil was collected from the surface (0 - 5 cm), middle (5 cm - 25 cm), and bottom (over 25 cm) of each pit. Soils were placed in sample cans and lids sealed with tape to reduce evaporative loss, taken to the laboratory, weighed, dried and reweighed.

Understory production and cover were analyzed using completely randomized block design analysis of variance. Means were separated using a Student-Newman-Keuls test at $P \leq 0.05$ (Steel and Torrie 1980).

A split-split plot analysis of variance was used to analyze ponderosa pine growth data. Main plots were treatments, subplots were size classes, and sub-subplots were year. Means were tested using Student-Newman-Keuls test at $P \leq 0.05$ (Steel and Torrie 1980).

Predawn xylem potential and soil moisture were analyzed using a modified strip-plot design as outlined by Petersen (1985). The strip-plot analysis of variance was used to allow for more subdivisions of the error variance. Year was designated as the main plot. Means were separated using a Student-Newman-Kuels test at $P \leq 0.05$ (Steel and Torrie 1980).

RESULTS

Understory Production 1985

Understory vegetative production in all treatments was dominated by grasses and forbs. Total production in 1985, ranged from 320 to 542 kg/ha (Table 2). Total understory production in the treatment where western juniper was removed was greater than the control and pine thinned treatments. However, the Pine Thinned, Control and Pine Thinned/Juniper Removed treatments were not different.

Total grass production ranged from 144 to 238 kg/ha. No significant differences were found between total grass production in Control, Juniper Removed/Pine Thinned and the Pine Thinned. Grass production was greater than the Control where only western juniper was removed (Table 2).

Perennial grass production far exceeded annual grass production in all treatments ranging from 139 to 210 kg/ha. Perennial grass production was dominated by bluebunch wheatgrass, Idaho fescue, bottlebrush squirreltail, and sandberg bluegrass. Total production of perennial bunchgrasses followed the same trend as total production. Production of perennial grasses in the Juniper Removed treatment was greater than the Control or Pine Thinned treatments.

Treatment did not affect production of bluebunch wheatgrass. Bluebunch wheatgrass production ranged from a high of 70.2 kg/ha in the Pine Thinned/Juniper Removed treatment to a low of

Table 2. First year (1985) understory plant production response to treatment.

Species	Control (kg/ha)	Pine Thinned (kg/ha)	Juniper Removed (kg/ha)	Pine Thinned/ Juniper Removed (kg/ha)	se
	Treatment				
Bluebunch wheatgrass	50.7	47.8	51.7	70.2	10.28
Idaho fescue	40.4	32.9	50.5	41.2	8.24
Bottlebrush squirreltail	17.7ab*	5.6a	42.0b	19.2ab	2.02
Sandberg bluegrass	24.2a	40.6b	47.1b	29.1a	5.76
Other Perennial Grasses	13.3	11.8	18.8	16.6	5.56
Total Perennial Grasses	146.3a	138.6a	209.9b	176.1ab	12.00
Cheatgrass	5.4	3.1	14.4	15.9	5.84
Other Annual Grasses	7.5	2.5	14.1	5.5	5.08
Total Annual Grasses	12.9ab	5.6a	28.5b	21.3ab	6.60
Total Grass	159.2a	144.2a	238.4b	197.5ab	12.40
Perennial Forb	100.2	67.2	91.5	65.7	10.28
Annual Forbs	112.5	72.8	119.9	87.0	10.52
Total Forbs	212.8	140.0	211.4	152.7	14.52
Big sagebrush	22.0	32.7	51.8	31.5	9.36
Other Shrubs	13.6	3.7	40.5	25.8	9.48
Total Shrubs	35.5a	36.3a	92.3b	57.3b	10.96
Total Production	407.5a	320.5a	542.0b	407.5ab	17.48

*Different letters denote significant ($p \leq 0.05$) differences between treatments, using Student-Newman-Keuls multiple range test.

47.8 kg/ha in the Pine Thinned treatment. Production of bottlebrush squirreltail was greater in the Juniper Removed treatment than the Pine Thinned treatment while Idaho fescue production was similar across treatments. Both tended to be highest where western juniper only was removed. Sandberg bluegrass production was highest in the Juniper Removed and Pine Thinned treatments.

Total annual grass production in the Juniper Removed treatment was greater than the production of annual grasses in the ponderosa pine thinned treatment. There was no difference in total annual grass production between the Control and the treatments where western juniper removal occurred. Production values appeared highest in the treatments where western juniper was removed.

Cheatgrass was the dominant annual grass on both sites. Annual grasses composed between 5 and 11% of the total grass production on all areas except the Grizzly Mountain site where it comprised up to 76% of the total grass production (Appendix Table 1).

Common yarrow (Achillea millefolium), basalt milkvetch (Astragalus filipes), arrowleaf arrowleaf balsamroot (Balsamorhiza sagittata), and tailcup lupine (Lupinus caudatus) were the dominant perennial forbs. Perennial forb production appeared greatest in the Control, however production in the Juniper Removed treatment was only 8.7 kg/ha less than the Control.

Four species represented a majority of the annual forbs found on both sites, autumn willoweed, elkhorn clarkia, blepheripappus and tarweed. Annual forb production appeared to be least in the Pine Thinned treatment and greatest in the Juniper Removed treatment.

Total shrub production in treatments where western juniper had been removed was greater than treatments with western juniper present. Total shrub production in the Juniper Removed treatment was not statistically different from the Pine Thinned/Juniper Removed treatments. No significant difference was found between the Pine Thinned and Control treatments.

To simplify analysis shrubs were separated into two groups, big sagebrush and other. The big sagebrush group was composed mainly of mountain big sagebrush and Wyoming big sagebrush. The other category was composed of all other shrubs found on the study area (bitterbrush, wax current, low sage, grey rabbitbrush, green rabbitbrush, and serviceberry).

Trends in big sagebrush production indicate that production was greatest in treatments where western juniper removal and/or ponderosa pine thinning occurred. Production of the other shrubs appears highest where juniper removal occurred and the lowest in the Pine Thinned treatment.

Understory Plant Cover 1986

Western juniper removal significantly increased understory plant cover (Table 3). Thinning ponderosa pine without removing western juniper, significantly reduced cover values below that of the Control. Perennial grasses and shrubs comprised a large percentage of the total understory cover in 1986.

Grass cover was about four times greater than forb and shrub cover (Table 3). Percent cover of all grasses was highest for the two juniper removal treatments. Total grass cover in the control was significantly less than the treatments where western juniper was removed, but larger than total grass cover values in the Pine Thinned treatment.

Percent cover for perennial grasses was highest in the Juniper Removed treatment, while the Pine Thinned/Juniper Removed treatment had percent cover values significantly higher than the treatments with western juniper present. The Control had significantly higher perennial grass cover than the Pine Thinned treatment.

Bluebunch wheatgrass, Idaho fescue, bottlebrush squirreltail, and Sandberg bluegrass cover was in most cases higher in the treatments where western juniper had been removed than in the treatments where western juniper was left at original densities.

Annual grasses made up a small percentage of the total grass cover on all sites, except at Grizzly Mountain site (Appendix

Table 3. Second year (1986) understory plant cover response to treatment.

Species	Control (%)	Pine Thinned (%)	Juniper Removed (%)	Pine Thinned/ Juniper Removed (%)	se
Bluebunch wheatgrass	1.1ab*	0.7a	1.9c	1.3b	1.01
Idaho fescue	2.6a	1.4b	3.7c	3.1ac	0.62
Bottlebrush squirreltail	1.9a	1.8a	2.5b	2.3b	0.89
Sandberg bluegrass	0.4a	0.4a	0.8b	0.7b	0.89
Other Perennial Grasses	0.9a	0.3b	0.6b	0.8a	0.47
Total Perennial Grasses	6.8a	4.7b	9.5c	8.2d	0.35
Cheatgrass	0.6ab	0.2c	0.4bc	0.8a	0.75
Other Annual Grasses	0.3a	0.1b	0.2ab	0.3a	0.21
Total Annual Grasses	0.9a	0.3b	0.6ab	1.1a	0.77
Total Grasses	7.7a	5.0b	10.1c	9.3c	1.09
Perennial Forbs	0.3a	0.3a	0.3a	0.3a	1.75
Annual Forbs	0.9a	0.6a	0.8a	1.0a	0.74
Total Forbs	1.2a	0.9b	1.1a	1.4a	2.13
Big sagebrush	1.2a	1.1a	2.0a	1.9a	1.02
Other Shrubs	0.8a	0.4a	0.6a	0.9a	0.86
Total Shrubs	2.0ab	1.3b	2.6ab	2.8a	0.97
Total Understory Cover	10.9a	7.2b	13.8c	13.4c	4.29

*Different letters denote significant ($p \leq 0.05$) difference between treatments, using Student-Newman-Kuels multiple range test.

Table 2). Total annual grass cover in the Pine Thinned/Juniper Removed and Control treatments were significantly greater than in the Pine Thinned treatment.

Percent cover of annual grasses was dominated in 1986 by cheatgrass. Percent cover appeared higher in the Pine Thinned/Juniper Removed and Control as compared to the Pine Thinned and Juniper Removed treatments. Percent cover of other annual grasses followed the same pattern as total annual grasses as a group.

Total percent cover of forbs was least in the Pine Thinned treatment and was not different among other treatments. Percent cover of perennial forbs was 0.3% across all four treatments (Table 3). Annual forb cover in the Pine Thinned treatment appeared lower than the other three treatments.

Mountain big sagebrush, Wyoming big sagebrush, wax current, bitterbrush, and grey rabbitbrush were the most common shrubs. Percent cover of all shrubs in the Pine Thinned/Juniper Removed treatment was significantly higher than percent cover for the Pine Thinned treatment but not higher than other treatments.

Mountain big sagebrush and Wyoming big sagebrush comprised a majority of the shrub cover and were grouped into the big sagebrush group. Percent cover of the big sagebrush group were not different but tended to be higher in the treatments where western juniper was removed and tended to be least in the Pine Thinned treatment.

Understory Plant Production 1986

Understory plant production data was collected on two of the four blocks in 1986. Block four (Lytle Creek site) was not grazed in 1986, and block 2 (above Comb's Flat) was lightly grazed. Block two is approximately two miles from water and therefore probably limited grazing.

A linear regression was run on production and cover to compare understory response (Table 4). For total understory there was a strong relationship between production and cover, $r^2 = 0.88$, $p \leq 0.05$ (Table 4). Bluebunch wheatgrass, Idaho fescue, and cheatgrass were the only grass species to have r^2 greater than 0.60. Bottlebrush squirreltail had an r^2 of 0.59, and a negative slope, -45.5 but a significant F value. Bottlebrush squirreltail, Other Perennial Grasses and Sandberg bluegrass were the only groups to have negative slopes.

Perennial forbs, total grass, and total perennial grass, also had a significant correlation between production and cover. A poor relationship existed between production and cover in the other perennial grass, annual forb, big sagebrush and other shrub groups.

Table 5 shows plant production estimates of species with r^2 values greater than 0.60. All estimates place production highest in the Juniper Removed Treatment and lowest in the Pine Thinned treatments. This follows the basic trend of plant cover in 1986 and production in 1985.

Sneva (1982) developed regression equations based on crop year (September through June) precipitation. Regression equations were also used to predict production of bluebunch wheatgrass, bottlebrush squirreltail, cheatgrass, perennial forbs, and the total production.

Table 4. Regression Analysis of Production and Cover Data from 1986.

Species/Group	Regression Equation	r^2
Bluebunch Wheatgrass	y=31.07x + 7.08	0.89**
Idaho Fescue	y=6.30x + 1.02	0.82*
Bottlebrush Squirreltail	y=-45.46x + 68.63	0.59**
Other Perennial Grasses	y=-9.59x + 36.07	0.02
Sandberg Bluegrass	y=-0.54x + 18.45	0.006
Total Perennial Grass	y=18.74x + 29.99	0.78**
Cheatgrass	y=8.59x + 2.11	0.89**
Other Annual Grasses	y=19.17x + 5.42	0.56*
Total Annual Grass	y=15.00x + 8.39	0.58*
Total Grass	y=11.07x + 8.16	0.90**
Perennial Forbs	y=18.91x + 31.66	0.72**
Annual Forbs	y=20.78x + 2.64	0.11
Total Forb	y=18.29x + 45.09	0.08
Big Sagebrush	y=14.49x + 38.43	0.08
Other Shrubs	y=85.73x + 18.43	0.06
Total Shrub	y=0.29x + 6.55	0.003
Total	y=20.82x + 43.71	0.88**

* Indicates significance at $p \leq 0.05$, ** indicates significance at $p \leq 0.01$. x = plant cover, y = plant species or group production.

Table 5. Estimates of production for 1986 using regression equations with $r^2 \geq 0.60$ derived from production and cover estimates from blocks 2 and 4 and equations developed by Sneva (1982).

Species	Treatments				
	Sneva (1982) (kg/ha)	Control (kg/ha)	Pine Thinned (kg/ha)	Juniper Removed (kg/ha)	Pine Thinned/ Juniper Removed (kg/ha)
Bluebunch Wheatgrass	41.38	97.18	44.36	140.68	125.15
Idaho Fescue	0.00	0.00	2.28	4.80	3.54
Bottlebrush Squirreltail	25.62	------	------	------	------
Total Perennial Grass	------	178.04	106.82	251.12	245.50
Cheatgrass	27.34	0.00	1.81	3.83	1.81
Total Annual Grass	------	9.89	9.89	23.39	20.39
Total Grass	------	96.72	54.65	141.00	137.68
Perennial Forb	45.00	107.30	97.85	186.79	109.19
Total	262.90	339.35	241.50	462.19	422.63

Ponderosa Pine Growth Response

Basal Area

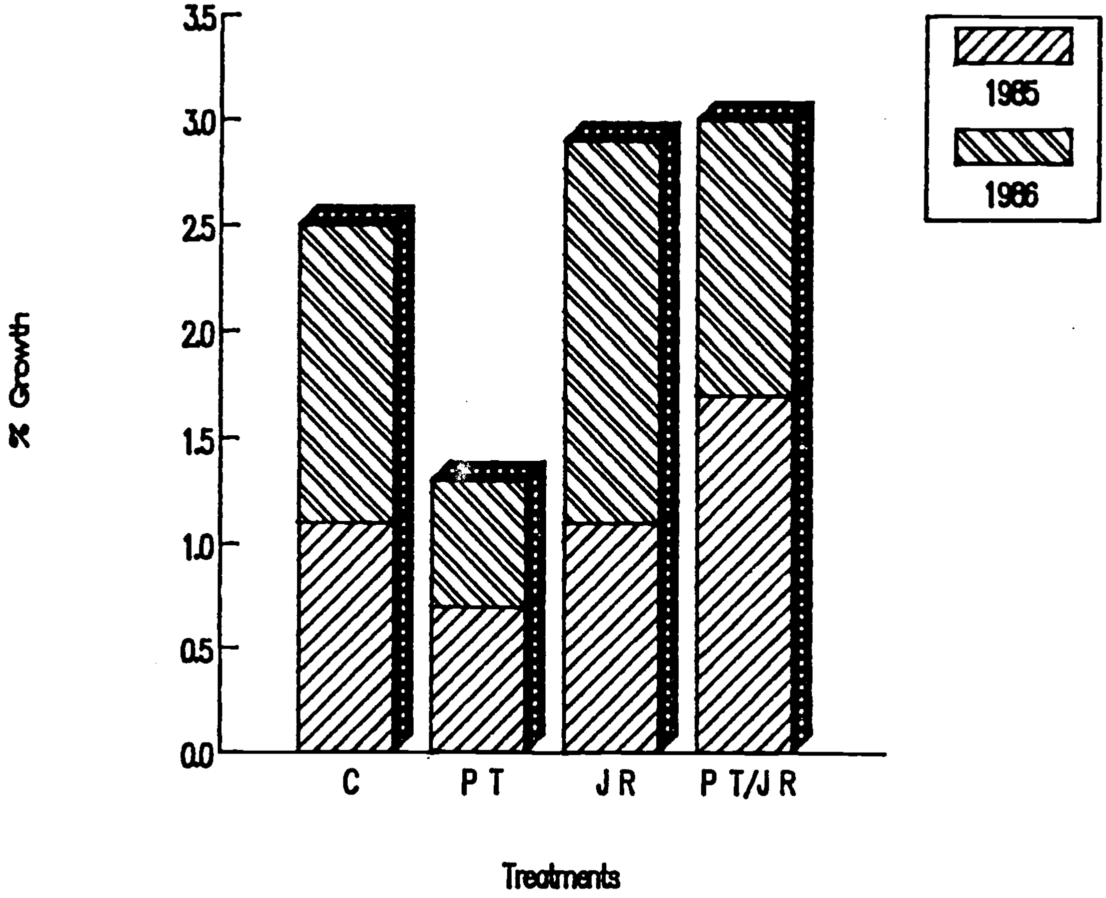
Although mean percent basal area growth of all ponderosa pine was greatest in the Pine Thinned/Juniper Removed treatment, there were no significant differences in percent basal area growth due to treatment (Figure 1).

Significant treatment differences did occur in trees under 5 cm in diameter in 1985. Percent basal area growth of ponderosa pine in the Control and Pine Thinned/Juniper Removed treatments were significantly greater than Pine Thinned and Juniper Removed treatments (Appendix Table 4). Control and Pine Thinned/Juniper Removed ponderosa pine under 5 cm in diameter had percent basal area growth value of 24.6% and 13.2%, significantly higher than the Pine Thinned and Juniper Removed treatments. There was no significant difference between the percent basal area growth in the Pine Thinned or Juniper Removed treatments.

Basal area growth was much the same in 1986 as in 1985. Percent growth in the Pine Thinned treatment was lowest of the four treatments. There were no significant differences between treatments. Unlike 1985, basal area growth appeared higher in the Juniper Removed treatment, and the Control had the second highest percent growth (Figure 1).

Ponderosa pine under 5 cm in diameter in the Juniper Removed treatment had the highest growth, 19.7%, the second year after tree removal (Appendix Table 4). Percent growth in the Juniper Removed treatment was not significantly different from the Pine Thinned treatment.

Figure 1. Mean percent basal area growth of all ponderosa pine trees.



C - Control, P T - Pine Thinned, J R - Juniper Removed,
P T/J R - Pine Thinned/Juniper Removed

Table 6. Two year mean percent basal area growth of ponderosa pine trees in five diameter classes. Percent basal area growth = current year basal area growth divided by total tree basal area.

	Treatment			
Diameter Classes	Control	Pine Thinned	Juniper Removed	Pine Thinned/ Juniper Removed
cm	(%)	(%)	(%)	(%)
Under 5	45.1Aa*	21.2BCa	19.0Ca	29.8Ba
5-15	5.0b	5.6b	9.6b	8.8b
15-30	3.1b	4.3b	10.9b	4.4b
30-40	4.2b	2.0b	2.5c	2.8b
Over 40	1.5b	0.9b	1.6c	2.2b

*Upper case letter indicate significant differences ($p \leq 0.05$) between treatments and lower case letters indicate significant differences ($p \leq 0.05$) between diameter classes within treatments.

Total percent growth of ponderosa pine for the study period followed the first year response. Percent basal area growth appeared higher in the treatments where western juniper had been removed and lowest where only ponderosa pine was thinned (Table 6).

Ponderosa pine under 5 cm in diameter had significantly higher percent basal area growth in the Control than in other treatments (Table 6). Percent basal area growth in the Pine Thinned/Juniper Removed treatment was 29.8%, significantly larger than the growth values in the Juniper Removed. Percent basal area growth of ponderosa pine under 5 cm in diameter was significantly greater than the larger diameter classes within in all four treatments. In the Juniper Removed treatment, pine in the 5 cm-15 cm and 15 cm-30 cm diameter classes had significantly higher percent basal area growth than trees in the larger two diameter classes (30 cm-40 cm, over 40 cm).

Percent basal area growth of ponderosa pine between 15 cm and 30 cm in diameter tended to be higher in the treatments where western juniper had been removed. Ponderosa pine in the 15 cm-30 cm diameter class had the highest percent basal area growth in the Juniper Removed treatment and the lowest growth in the Control. Larger two diameter classes (30 cm-40 cm, Over 40 cm) had basal area growth highest in the Control treatment.

In the 15 cm-30 cm and over 40 cm diameter classes, percent basal area growth appeared higher in the treatments where juniper had been removed. Percent basal area growth of pine with diameters 5 cm-15 cm and over 40 cm in diameter were highest in the Pine Thinned/Juniper Removed treatment. Percent basal area growth of ponderosa pine with diameters 5 cm-15 cm and 15 cm-30 cm, were greatest in the Juniper Removed treatment. The largest percent basal area growth for ponderosa pine in the 30 cm-40 cm diameter occurred in the Control treatment.

Height Growth

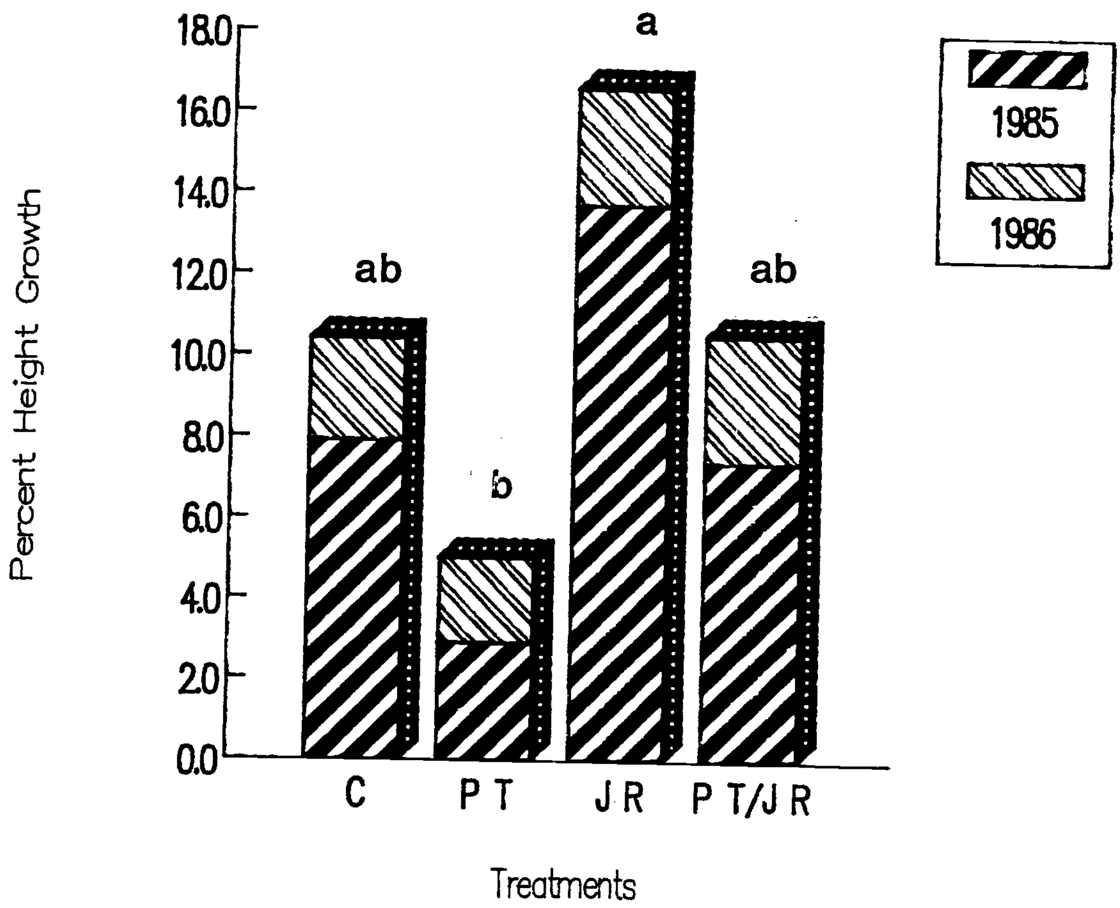
In 1985 mean percent height growth of ponderosa pine in the Juniper Removed treatment was greater than in the Pine Thinned treatment (Figure 2). Percent height growth appeared to be higher in the treatments where western juniper had been removed.

Percent height growth of ponderosa pine followed a similar trend in 1985 as in 1986, although values in the treatments where western juniper had been removed were more than two times smaller. Ponderosa pine in treatments where western juniper was removed had the highest percent height growth response (Figure 2).

Total mean percent height growth of ponderosa pine in the Juniper Removed treatment was significantly higher than the Pine Thinned, but not the Pine Thinned/Juniper Removed treatments (Figure 2). Height growth in the Juniper Removed treatment was 6.1% above the Pine Thinned/Juniper Removed treatment.

Percent height growth of ponderosa pine under 5 cm in diameter was greatest in the Pine Thinned treatment, significantly greater than other treatments (Table 7). There were no significant differences between the percent height growth of the Control and the Pine Thinned/Juniper Removed, but both were significantly greater than the Juniper Removed treatment.

Figure 2. Mean percent height growth of all ponderosa pine trees.



Letters indicate significant differences ($p \leq 0.05$) between treatments.
C - Control, P T - Pine Thinned, J R - Juniper Removed
P T/J R - Pine Thinned/Juniper Removed.

Table 7. Two year mean percent height growth of ponderosa pine trees in five diameter classes. Percent basal area growth = current year basal area growth divided by total tree basal area.

Diameter Classes	Treatment			
	Control	Pine Thinned	Juniper Removed	Pine Thinned/ Juniper Removed
cm	(%)	(%)	(%)	(%)
Under 5	19.4Ba	32.7Aa	1.5Cb	24.1Ba
5-15	12.7Bab	15.2ABb	18.0Aa	19.6A
15-30	11.4Bab	14.4ABb	12.3Bab	18.2A
30-40	10.7Aab	2.6Bc	7.6ABb	13.5A
Over 40	7.3Cb	13.3Bb	17.4ABa	20.0A

*Upper case letters indicate significant difference ($p \leq 0.05$) between treatments, and lower case letters indicate significant differences ($p \leq 0.05$) between diameter classes within treatments.

Percent height growth for individual height classes in 1985 and 1986 are reported in Appendix Table 5. Percent height growth of 5 cm-15 cm diameter ponderosa pine in treatments where western juniper had been removed were significantly greater than the percent growth of pine trees in the Control (Table 7). Ponderosa pine in the 15 cm-30 cm diameter class had the highest percent height growth in the Pine Thinned/Juniper Removed treatments greater than the Control and Juniper Removed treatments.

Ponderosa pine in the 30 cm - 40cm diameter class of the Pine Thinned/Juniper Removed and Control treatments had percent height growth higher than the Pine Thinned treatment. No difference in height growth occurred between the Pine Thinned and Juniper Removed treatments.

Ponderosa pine over 40 cm in diameter in treatments where ponderosa pine and/or western juniper removal occurred had significantly higher percent height growth than the Control. Percent height growth of ponderosa pine with diameters over 40 cm in the Pine Thinned/Juniper Removed treatment was significantly greater than the Pine Thinned treatment.

Percent height growth of ponderosa pine under 5 cm in diameter in the Juniper Removed treatment was significantly less than the 5 cm - 15 cm and over 40 cm diameter classes. In other treatments this classes' height growth percent was significantly greater than 30-40 cm trees.

Pine Thinned treatment ponderosa pine under 5 cm in diameter had the highest percent growth, significantly greater than the four larger size classes. Ponderosa pine in the 5 cm-15 cm, 15 cm-30 cm, and over 40 cm diameter class had significantly higher percent height growth than the trees between 30 and 40 cm.

Percent height growth in the Control for trees under 5 cm in diameter was higher than height growth of pine trees over 40 cm in diameter. There was no difference in percent growth between the ponderosa pine over 5 cm in diameter.

In the Pine Thinned/Juniper Removed treatment percent height growth was greatest in the smallest diameter class. There were no differences between the other size classes.

Percent height growth of ponderosa pine in the 5 cm - 15cm and over 40 cm diameter classes were greater than pine trees under 5 cm and between 30 and 40 cm.

Ponderosa Pine Predawn Xylem Potential

Predawn Xylem Potential - 1985

There was a significant date*treatment interaction in the analysis of ponderosa pine predawn xylem potential. A two-way table of means was constructed and examined for significant differences. There were no significant differences between the three size classes, therefore all size classes were grouped and analyzed. A list of predawn xylem potentials for all size classes can be found in Appendix Table 6.

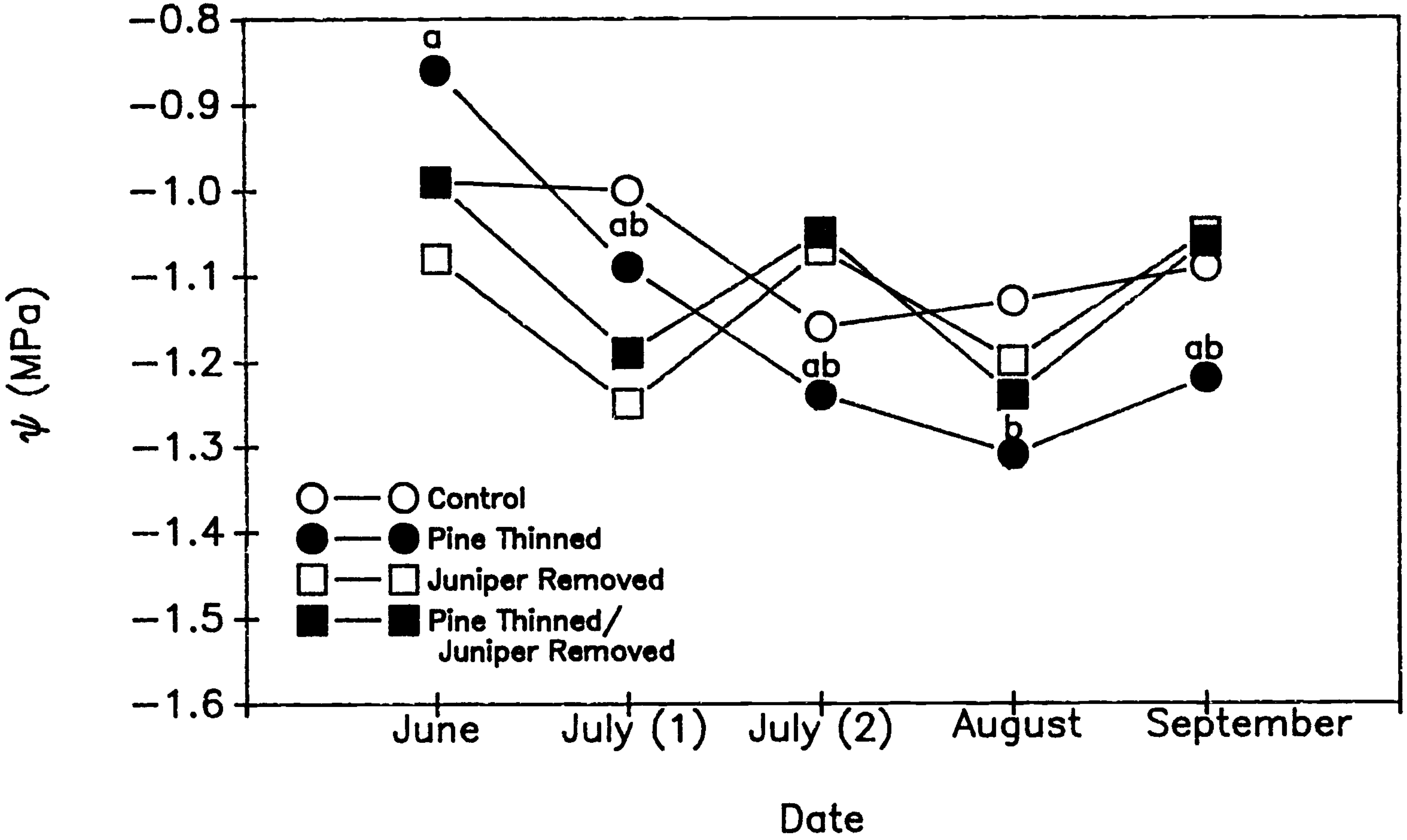
Predawn xylem potentials were not significantly different between treatments at any date throughout the sampling period (Figure 3). In general they were least negative in the Pine Thinned treatment early in the year and most negative late in the year relative to other treatments.

Only the Pine Thinned treatment showed any significant response to dates. The June reading was significantly greater than the predawn values recorded in late July and August (Figure 3). There was no significant difference between the predawn xylem potential of ponderosa pine at the August, September, and both July sampling dates.

Predawn Xylem Potential - 1986

In the second year there was also a significant treatment x date interaction. A two-way table of means was constructed and analyzed for differences. There were no significant differences between predawn readings of the different tree size trees, therefore all size were averaged within a treatment and analyzed.

Figure 3. Predawn xylem pressure potentials for ponderosa pine in 1985.

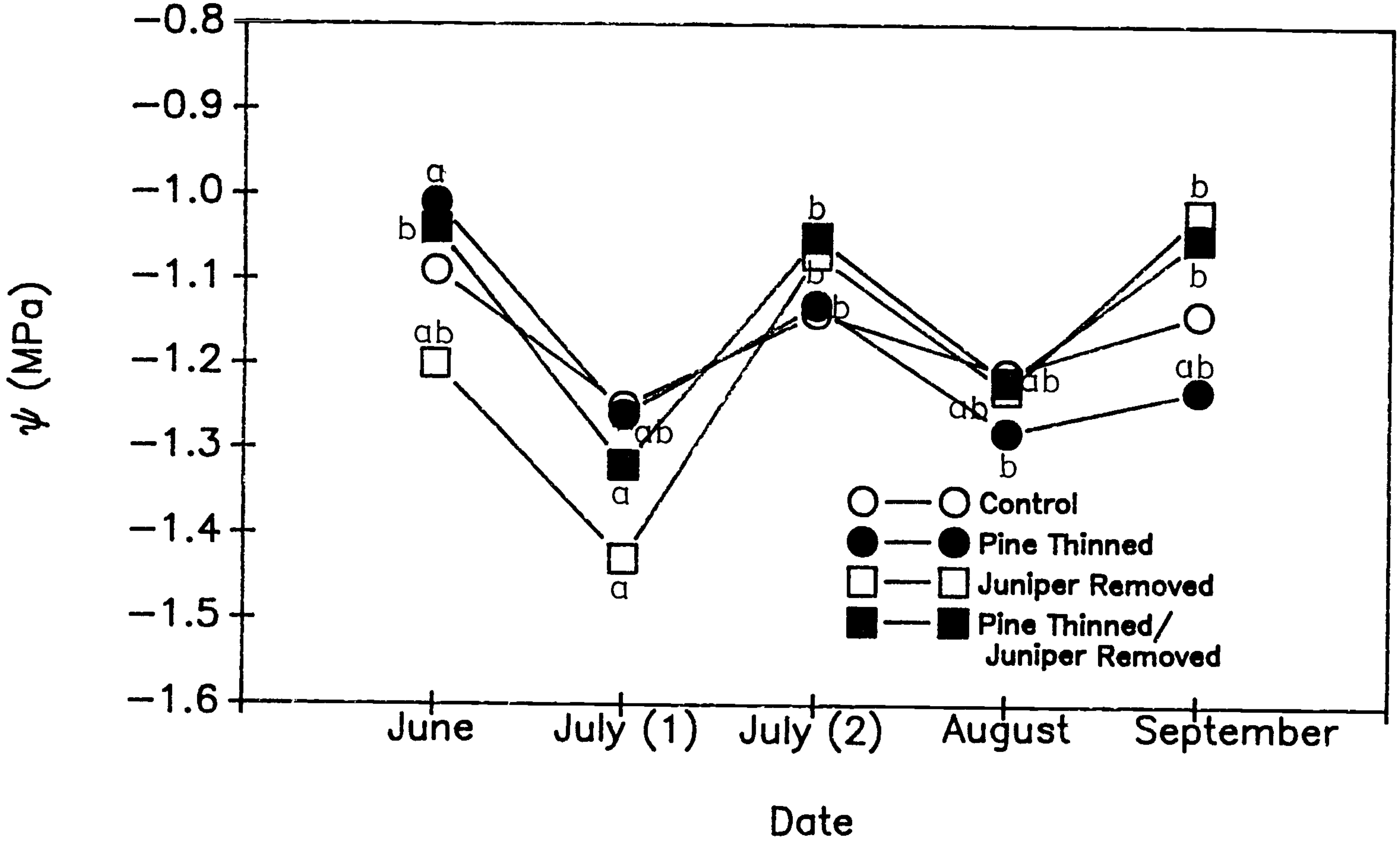


Letters indicate significant differences ($p \leq 0.05$) between sampling dates.

There were no significant differences between treatments at any one date throughout the sampling period (Figure 4). The Control was the only treatment in 1986 that did not have significant differences between dates. In general, predawn xylem potentials of the Pine Thinned treatment were high early and lowest later in the growing season (Figure 4). Predawn xylem potentials in the Juniper Removed treatment reached their lowest point in early July. The least negative values were recorded in late July and September, significantly different from early July values. Predawn xylem potential in June, late July, and September were greater than in early July for the Pine Thinned/Juniper Removed treatment.

Similar to the trend in 1985, treatments where western juniper had been removed varied by as much as 0.16 MPa early in the growing season and only 0.03 MPa at the last sampling date in September.

Figure 4. Predawn xylem pressure potentials for ponderosa pine in 1986.



Letters indicate significant differences ($p \leq 0.05$) between sampling dates.

Soil Moisture Response to Western Juniper Removal

Gravimetric Soil Moisture - 1985

In the first year after tree removal there were treatment x depth and treatment x date interactions. Two-way tables of means were constructed and the means were tested for significant differences ($p \leq 0.05$). Soil moisture by depth for each treatment can be found in Apppendix 7.

Treatment x Depth

The two-way table of means, treatment*depth, indicated that there were significant differences in soil moisture at the 5 cm-25 cm and 25 cm-50 cm depths (Table 8). No significant difference between treatments occurred in the soil surface (0-5 cm). Soil moisture at the 5 cm-25 cm depth was highest in the Juniper Removed (24.3%) treatment, significantly higher than soil moisture in the treatments with western juniper present. At the 25 cm-50 cm depth soil moisture in the treatments where western juniper had been removed was significantly higher than the Control treatment. Soil moisture was highest in the Juniper Removed treatment at the 5 cm-25 cm and 25 cm-50 cm depth and lowest in the Control treatment at the same depths.

Treatment x Date

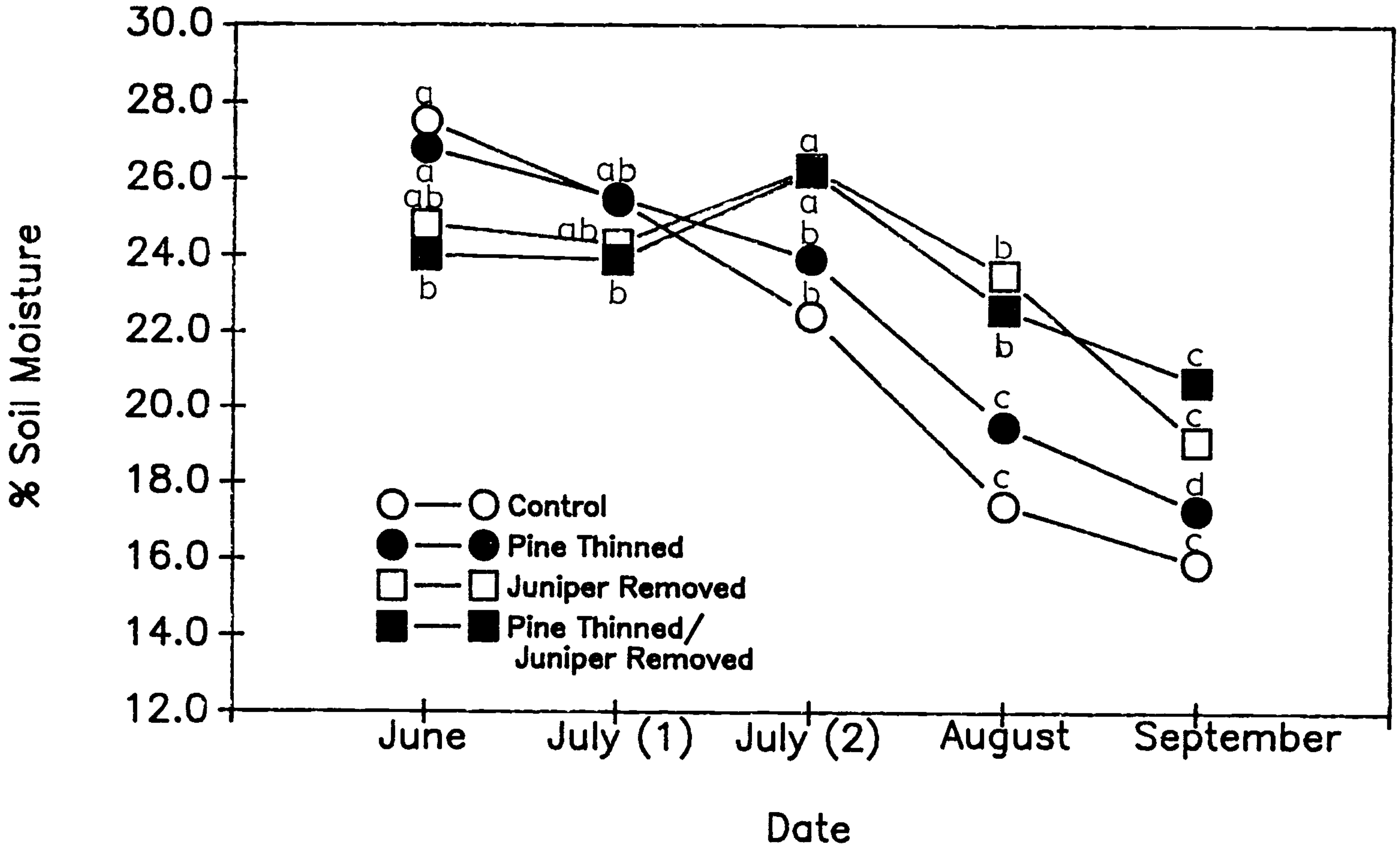
A treatment x date interaction was present in the analysis of the soil moisture data, and a two-way table of means was constructed to test for differences in means. There were no significant differences between treatments, but there were significant differences between dates within treatments.

Table 8. Soil Moisture Response to Treatment by Depth.

Depth	Control	Pine Thinned	Juniper Removed	Pine Thinned/ Juniper Removed
	Treatments			
cm	%	%	%	%
0- 5	20.2a*	21.7a	21.2a	22.8a
5-25	22.1b	22.2b	24.3a	23.3ab
25-50	22.9b	23.9ab	25.3a	24.3a

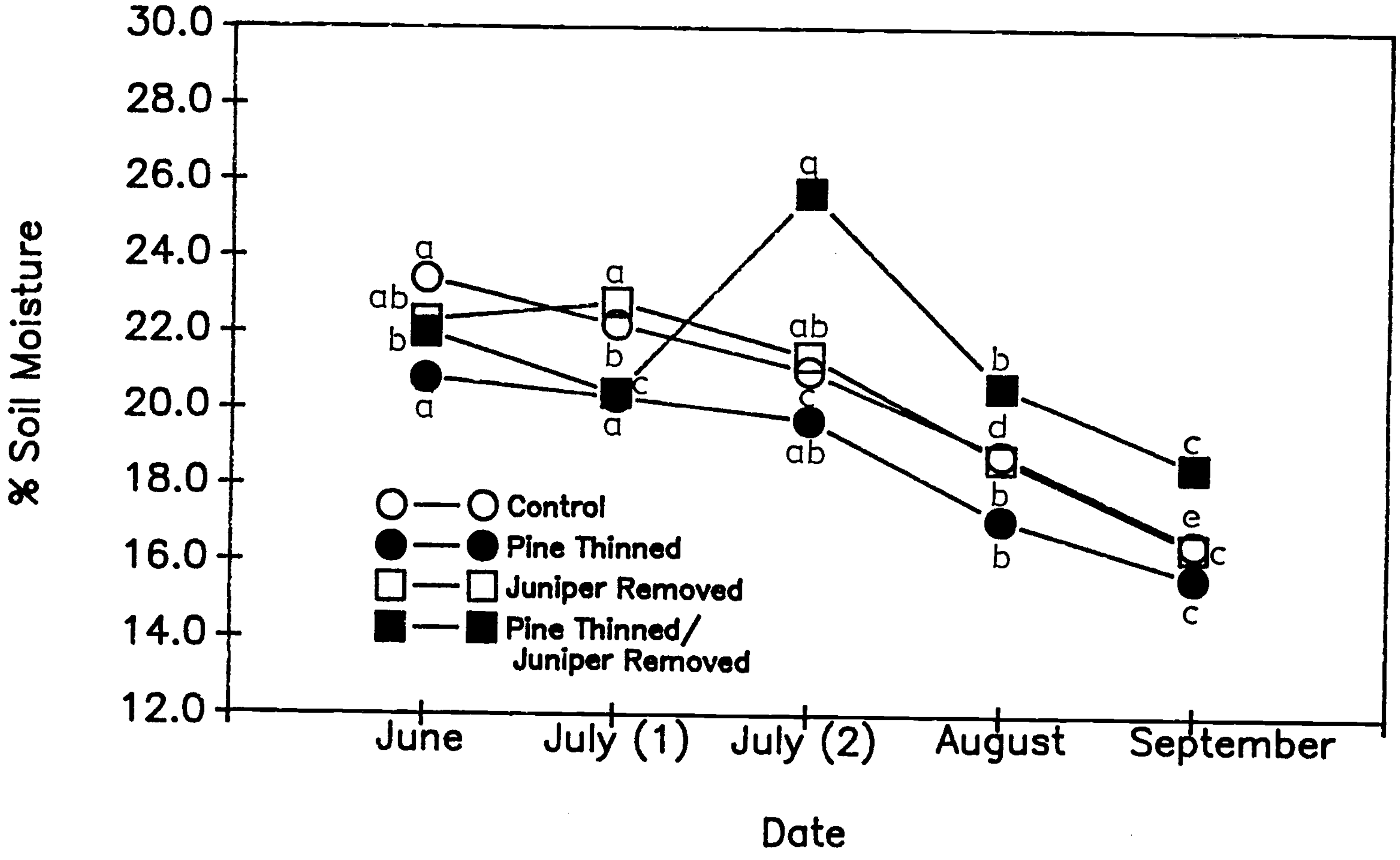
*Letters indicate significant difference ($p \leq 0.05$) between treatments.

Figure 5. Soil moisture in treatments by sampling dates in 1985.



Different letters indicate significant differences ($p \leq 0.05$) between sampling dates.

Figure 6. Soil moisture in treatments by sampling dates in 1986.



Different letters indicate significant differences ($p \leq 0.05$) between sampling dates.

Treatments with western juniper present showed a continual decline in soil moisture throughout the sampling period (Figure 5). In treatments where western juniper had been removed, soil moisture declined from June to early July and peaked in late July. Soil moisture in late July in the Juniper Removed treatment was greater than in August and September. In the Pine Thinned/Juniper Removed treatment the peak soil moisture occured in late July and was greater than all other dates.

Approximately 1.9 cm of rain fell across the study sites just prior to the second July sampling date. Soil moisture values for this date were significantly higher than values recorded in September.

Gravimetric Soil Moisture - 1986

There was a treatment x date interaction in the soil moisture the second year after tree removal. A two-way table of means was constructed and means were tested for significant differences. There were no significant differences between treatments at any date.

The Control and Pine Thinned treatments showed a continual decline in soil moisture throughout the sampling period (Figure 6). Soil moisture began with a high of 23.4 % and 20.8 % respectively in June and ended with a low of 16.5 % and 15. 6 % in September.

The Pine Thinned/Juniper Removed treatments exhibited an initial decline, then increased in response to mid-July precipitation so that soil moisture percentage at the second July sampling date was significantly higher than all other sampling dates. The June and early July soil moisture values were also significantly higher than the last two.

Soil moisture in the Juniper Removed treatment appeared to increase from the June to first July sampling dates. There was a decline in soil moisture from July to September. The early July sampling date had significantly higher soil moisture than later dates.

DISCUSSION

Understory Production and Cover.

Total understory production and cover was greatest in the treatments where western juniper was removed. Lowest total production and cover occurred in the Pine Thinned treatment. This pattern is similar to ponderosa pine response, perhaps indicating similar factors being involved in both understory and pine response.

Perennial grasses appeared to respond to treatment. The fibrous root system and ability to quickly produce abundant leaf area may have enabled grasses to take advantage of tree removal. Bluebunch wheatgrass, Idaho fescue, and bottlebrush squirreltail had the highest production one year after western juniper removal and ponderosa pine thinning. Bluebunch wheatgrass reached its greatest cover and production levels in the Pine Thinned/Juniper Removed treatment. By removing all the western juniper and thinning ponderosa pine, the site may have become more exposed to effects of direct sunlight, even though soil moisture was higher (Figures 5 and 6). Bluebunch wheatgrass is most often found in open dry sites in the sagebrush/grassland and juniper woodland of eastern Oregon and may be best suited to conditions in this treatment. Idaho fescue is found most often in more mesic communities and under the protection of shrubs and trees in warmer and drier areas (Doescher et al. 1984). Peak production and cover of Idaho fescue occurred in the Juniper Removed treatment. All other grasses also had the highest production in the Juniper Removed treatment. Heavy thinning, as in the Pine Thinned/Juniper Removed treatment, increased the level of solar energy that reaches the soil surface. In general for most grass species production and cover was lowest in treatments with western juniper present. Release from soil miosture competition appeared to be of greater benefit than effects of shade.

Shrub production was also greatest in treatments where western juniper had been removed. Big sagebrush is an evergreen shrub and capable of photosynthesis early in spring when most other plants are producing leaves. The deep roots of big sagebrush also permit it to tap deep water unavailable to many plants. Response of shrubs was greatest in the Juniper Removed treatment. Sagebrush production was lowest in the control, indicating it may have been in competition with ponderosa pine and western juniper, also deep rooted plants. Big sagebrush production in the Pine Thinned treatment was greater than the control possibly indicating release form competition of some kind. Other shrubs had the lowest production in the Pine Thinned treatments. Competition with ponderosa pine may be more severe for this group because production was lowest in the treatment where no thinning occurred. Western juniper in the Pine Thinned treatment may have been able to utilize the additional resources before the shrubs.

Two years may not be enough to determine the effects of ponderosa pine thinning and western juniper removal. A lag in the response of the understory vegetation could have occurred. A more significant response may occur in the near future. However less than seven miles away in a study conducted in Crook County, Viatkus (1986) found that removal of western juniper increased understory production markedly the first and second year following western juniper removal. Idaho fescue, bottlebrush squirreltail, and cheatgrass had a significant response to western juniper removal. Precipitation is lower on this site and no ponderosa pine was present. Sandberg bluegrass and perennial forb production differed slightly from areas with western juniper present treatments. Release from moisture competition with western juniper seemed to be the most important factor. (Viatkus and Eddleman 1987). Viatkus (1986) also noted that sandberg bluegrass production was more closely tied to growing season precipitation than to tree-removal effects.

In 1986 cover was used to monitor response of understory vegetation, but production estimates were obtained from the two ungrazed blocks (2 & 4). Linear regression equations were developed from production and cover values of blocks 2 and 4. Cover values from Table 3 were placed into regression equations with $R^2 \geq 0.60$ to obtain general production estimates for 1986.

Placing the cover values into the equation also illustrated that removing only western juniper would increase understory plant production more than the other treatments. Removing western juniper and thinning ponderosa pine in the same area would be the next best treatment. In most cases there was little difference between the control and Pine Thinned treatments. The only two exceptions were bluebunch wheatgrass and total grass production. Both of these groups had greater production estimates in the Control by at least 42 kg/ha.

Ponderosa Pine Growth Response.

Removal of western juniper and thinning of ponderosa pine had the greatest affect on trees under 5 cm in diameter. Large ponderosa pine exhibited less of a response than smaller trees. Additional resources made available by pine thinning and juniper removal may have occurred in the zone where the smaller ponderosa pine were capable of capturing the excess. Younger trees have a higher proportion of fine roots than larger trees, and higher root/shoot ratios and younger fine roots are more efficient in absorbing soil moisture. Age of needles is another factor affecting efficiency of resource use. There is a higher proportion of young needles in the canopies of young trees. Young ponderosa pine needles have higher photosynthetic rates than older foliage (Minore 1979) making them more efficient.

Older trees have higher maintenance costs because of the large volume of non-photosynthetic tissue (Waring and Schlesinger 1985). This could explain the lack of response in the larger ponderosa pine the first two years after juniper removal.

Ponderosa pine in dense areas often exhibits a lag in its response to thinning (Oren et al 1987, Brix and Mitchell 1986, Barrett 1982, Oliver, 1979a). Many factors have been attributed to this delayed response. One of the first consequences of thinning is an increase in root and leaf area (Perry 1985). The lag in basal area growth could be caused by the larger trees adding substantial levels of new needles. Roots may need time to grow into areas left vacant by removed trees. Younger trees may be able to adjust their leaf and root area faster than the larger trees, enabling younger ponderosa pine to respond quicker to additional resources. Brix and Mitchell (1986) found that root systems of Douglas-fir left after thinning might not be sufficient to absorb the additional moisture. Increased exposure of crowns after thinning and insufficient root area may lead to greater transpiration and moisture stress for the tree resulting in little growth response to release.

In this study thinning ponderosa pine appeared to lessen the response of both understory and ponderosa pine when compared to treatments where western juniper removal occurred. Basal area and height growth in treatments where thinning occurred was less than the growth where western juniper was removed. Growth in the Pine Thinned treatment was also below the Control. Because of the stand condition a relatively small number of ponderosa pine were removed. The Pine Thinned treatment was basically a light thinning of the overstory.

In other studies conducted in central Oregon, response of individual ponderosa pine to light levels of thinning was small, while heavy thinning tends to increase growth response. Oren and others (1987) found that diameter increases of ponderosa pine at lowest stocking densities was over twice that of pine in the highest stocking densities. Growth of ponderosa pine in dense stands after light thinning was found by Oliver (1979b) to be below the pre-thinning level. A far greater number of potential competitors were removed from the stand when western juniper was removed. Removing western juniper may be comparable to heavy thinning of ponderosa pine. On average 17.2 m^2/ha of basal area was removed in treatments where western juniper was removed. On average only 0.2 m^2/ha of ponderosa pine was removed in the thinning treatments.

Ponderosa pine in treatments where western juniper removal occurred had higher basal area and height growth response when compared to treatments with western juniper present. Barrett (1973) found higher growth rates up to three years following thinning. Growth dropped off in all the thinned stands in the fourth year following thinning.

In treatments where only ponderosa pine was thinned, the abundant western juniper may have exploited the released resources before other plant species. Western juniper is highly competitive for available resources (Miller et al 1987, Eddleman 1983, Jeppesen 1978).

The higher growth of ponderosa pine in the Juniper Removed treatment over the Pine Thinned/Juniper Removed treatment may have been a result of higher soil temperature. The level of tree removal in the Pine Thinned/Juniper Removed treatment may have opened the soil surface to higher amounts of solar radiation. Higher soil temperatures could increase the respiratory demand of the roots. Higher temperatures at the root surface can induce early root growth early in the season, but later trigger early dormancy. A long period of higher soil temperatures can lead to a negative carbohydrate balance of enhanced root respiration (Lyr and Hoffman 1967). Root growth of ponderosa pine in northern California was found to be minimal when soil temperatures were below 10° C (Oliver 1979a). Lyr and Hoffmann (1967) found that root growth of Pinus cembra, Pinus mugo, Pinus strobus, Pinus taeda ceased at 5°C. Growth of many higher elevation plants have exhibited root growth down to 2°C.

Predawn Xylem Potential of Ponderosa Pine and Soil Moisture.

Ponderosa pine in treatments where western juniper was removed appeared to have a higher demand for water early in the growing season and responded to precipitation during the growing season. This demand could have been caused by increased demand for water by understory and/or tree growth.

At no time throughout the sampling period were values below -2.0 MPa recorded. Water potentials below -2.0 MPa in ponderosa pine seedlings have been reported to reduce photosynthesis and growth (Cleary 1979, Elliot and White 1987). Predawn xylem potentials of ponderosa pine in treatments with western juniper present had higher (less negative) values early, indicating they did not require as much water as pine in treatments without western juniper. Reduction in the overstory cover may have opened the soil surface to increased evaporation early in the growing season. Soil moisture was also higher in these treatments early in the growing season. Ponderosa pine in the treatments without western juniper could have been subjected to higher soil temperatures, possibly breaking dormancy earlier than trees in the other treatments.

Midway through the sampling period a thunder storm occurred July 21, 1985 and July 25, 1986. Just over 1.9 cm of precipitation was recorded in 1985 and 1.0 cm in 1986. On the sampling date following these storms ponderosa pine in treatments without western juniper appeared to have higher predawn xylem potentials and soil moisture levels, however predawn xylem pressure potential and soil moisture values in treatments with western juniper continued to decline. Removing western juniper appeared to enable remaining ponderosa pine to respond to additional moisture. In a Montana study lodgepole pine in thinned treatments were capable of increasing their predawn xylem potentials after a rain storm (Donner and Running 1986). Quick response to additional moisture could give these trees an advantage over other plants.

Predawn xylem potentials on the last sample date in September declined in all treatments. Ponderosa pine in the Juniper Removed treatment had the high predawn readings (-1.05 MPa) while ponderosa pine in the Pine Thinned treatment had the lowest(-1.22 MPa). Ponderosa pine in treatments without western juniper had higher predawn xylem potentials than treatments with western juniper. Predawn xylem potential and soil moisture in the treatments without western juniper were higher than that in treatments with western juniper present. Predawn xylem potentials at the end of the sampling period in 1985 and 1986, were very similar even though earlier samples varied drastically (Table 7 and 8). Soil moisture in thinned stands of red pine (Pinus resinosa) was found by Sucoff and Hong (1974) to be higher than adjacent unthinned stands. Growth response of many species to thinning has been linked to reduced moisture stress (Zahner 1968, Sucoff and Hong 1974).

Over all effect of removing western juniper was to increase the predawn xylem potential of ponderosa pine later in the growing season, possibly extending the growth period beyond that found in stands with high levels of western juniper.

CONCLUSIONS

Variability in nature often makes it dificult to interpt results. Data must be studied carefully and trends interpeted. In this study some overall trends may give insight to some of the results.

Understory vegetation and ponderosa pine had a similar response to western juniper removal and ponderosa pine thinning. In general western juniper removal and ponderosa pine thinning appeared to slightly improve growth of smaller pine trees and understory plants. The small response may indicate that plants either are not capable of large response in two years, or the response occurs in an unobserved way.

The greatest total understory production and cover occurred in treatments where western juniper had been removed. Understory production and cover were least in the Pine Thinned treatment. Removal of western juniper appeared to remove the most important competitor of understory plants. Additional shade provided by remaining ponderosa pine could provide plants with protection from harsh summer conditions.

Large bunchgrasses showed the greatest increase in production and cover. There was a low percentage of annual plants on the study sites resulting in low production and cover values for those groups. Increases in annual plant production could be the result of disturbance that occurring during tree removal and slash disposal. On the Lytle Creek site, where annual plants comprised a higher percent of the community, annual plants had a significantly higher response. Dominant plants on the site before treatment were the groups to show the greatest response to western juniper removal. Established species seemed to have the ability to initially utilize additional resources made available by tree removal.

Shrub response was dominated by big sagebrush. Ponderosa pine and western juniper may have suppressed big sagebrush production. Other shrubs on the site seemed to be in direct competition with western juniper and little affected by ponderosa pine. Soil moisture data showed that removal of western juniper increased the overall percentage of water in the soil. It is not known whether or not this water was available to understory plants. Predawn xylem potentials of small ponderosa pine would indicate that this water was available. Early spring growth and fibrous roots close to the soil surface may give the grasses an initial advantage early.

Two years after removal of western juniper, growth of medium sized ponderosa pine increased. Small pine seemed to be favored by any tree removal possibly indicating that they were being suppressed by the larger trees. The largest ponderosa pine showed the smallest response to any type of treatment. Western juniper appeared to be a significant factor suppressing pine growth. If increasing intermediate sized ponderosa pine growth is to be a management objective in this area western juniper should be removed. Thinning of ponderosa pine may not be practical, because when small initial stand volume is reduced further and potentially merchantable trees are removed. Short term responses observed in this study indicate that the additional growth gained by thinning ponderosa pine would not off-set the loss in volume.

Growth of ponderosa pine in treatments where only the pine was thinned appeared to be below that of the Control plots. The aggressive nature of western juniper may allow it to move in and exploit the additional resources made available by thinning before other plants have a opportunity to do so.

Predawn xylem potentials and soil moisture indicate that removal of western juniper would be favorable to ponderosa pine growth. In general, predawn xylem potentials and soil moisture in treatments where western juniper was removed were higher later in the growing season. If other environmental factors, such as, air and soil temperature, relative humidity and precipitation remain favorable for growth, ponderosa pine in treatments where western juniper had been removed could have extended growing season. Removal of the dense western juniper canopy would allow soil temperatures to become favorable for growth earlier than in treatments where juniper was present.

Response of small ponderosa pine may have been suppressed by understory plants. Understory vegetation can be very competitive with young conifers since both are likely rooted in the same soil areas and draw from the same resource pool. It is possible that if understory vegetation was removed tree response may have been greater. Removal of understory plants in this area is not a viable management practice to most land owners. Both domestic livestock and wildlife use the forage in this area. These sites are generally not classified as commercial timber lands and management for softwood production is uncommon. Removing understory vegetation would eliminate this important annual forage source for what may be a small increase in pine growth. Management for both forage and timber would help to increase the economic value of this area.

Management of timber and forage resources often occur separately. Where forest stands are scheduled for thinning it is often used as a transitory range until canopy closure occurs and forage production falls below usable levels. Conversely, timber values of sparsely forested areas are often overlooked because of their value as spring, fall, and summer range for domestic livestock. Coordination of management objectives could increase the economic value of these areas. Forage production could be benefited by removal of western juniper and thinning of ponderosa pine, and response to thinning enhanced by reducing understory production through grazing.

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APPENDICIES

Appendix Table 1. Understory Production (kg/ha) by Site - 1985.

	Block One Treatment				Block Two Treatment			
Species	1	2	3	4	1	2	3	4
Agsp	68.9	43.7	74.8	80.4	102.0	110.7	105.6	185.9
Feid	64.8	18.5	67.2	92.3	8.3	4.4	3.5	3.2
Sihy	10.9	4.1	5.1	35.2	25.2	77.7	54.2	44.2
OPG	8.4	51.1	72.9	26.5	7.6	5.2	7.4	9.4
Posa	6.2	13.6	1.6	31.7	23.2	22.7	51.4	28.2
TPG	159.3	130.9	251.1	266.0	166.2	220.6	222.0	270.8
Brte	6.0	0.0	1.5	56.8	0.2	0.7	1.5	0.2
OAG	16.2	0.0	27.4	8.1	1.4	0.4	0.9	1.2
TAG	22.5	0.0	28.9	64.9	1.6	1.0	2.4	1.3
TG	181.8	130.9	250.4	330.9	167.8	221.6	224.4	272.1
PerForb	147.0	103.8	105.0	169.9	86.5	117.2	144.2	28.0
AnForb	53.6	18.4	77.3	115.1	26.0	14.8	52.5	29.8
TF	200.6	122.2	182.3	285.0	112.5	132.0	196.7	57.8
Artr	31.3	38.5	103.1	67.9	38.9	0.0	28.8	0.0
OShrub	32.1	9.2	3.2	24.8	2.0	1.6	14.0	9.4
TS	63.5	47.7	106.3	92.7	40.8	1.6	42.7	9.4
Total	445.7	300.7	539.0	708.5	321.1	355.1	463.8	339.3

	Block Three Treatment				Block Four Treatment			
Species	1	2	3	4	1	2	3	4
Agsp	31.9	2.3	26.4	4.8	0.0	34.6	0.0	9.5
Feid	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0
Sihy	71.4	35.4	80.6	19.9	0.0	0.0	0.0	8.5
OPG	8.0	1.4	44.9	17.6	44.3	11.9	110.5	14.5
Posa	39.2	51.6	34.4	39.4	26.0	36.9	30.0	22.2
TPG	150.6	90.7	209.5	113.8	109.1	83.4	140.5	54.6
Brte	0.9	0.0	2.1	2.6	14.5	11.8	52.6	4.0
OAG	0.7	0.0	3.9	0.0	11.7	9.7	24.1	12.7
TAG	1.5	0.0	6.0	2.6	26.2	21.5	76.7	16.8
TG	152.1	90.7	194.3	84.2	96.5	104.9	217.2	71.3
PerForb	159.2	40.0	106.7	40.3	8.0	7.8	9.9	24.5
AnForb	10.1	13.8	31.4	31.7	22.6	20.4	32.4	55.7
TF	169.2	53.9	138.1	71.9	30.6	28.2	42.3	47.1
Artr	14.3	92.1	75.3	58.1	3.4	0.0	0.0	0.0
OShrub	16.0	3.0	68.2	10.0	4.1	1.1	76.6	11.7
TS	30.3	95.1	143.5	68.1	7.5	1.1	76.8	11.7
Total	351.5	239.7	475.8	224.1	134.6	134.1	336.3	130.1

Agsp-Bluebunch wheatgrass, Feid-Idaho fescue, Sihy-Bottlebrush squirreltail, OPG-Other Perennial Grasses, Posa-Sandberg bluegrass, TPG-Total Perennial Grasses, Brte-Cheatgrass, OAG-Other Annual Grasses, TAG-Total Annual Grasses, TG-Total Grass, PerForb-Perennial Forbs, AnForb-Annual Forbs, TF-Total Forbs, Artr-Big sagebrush, OShrub-Other Shrubs, TS-Total Shrubs, Total-Total Understory Production. Treatment 1-Control, Treatment 2-Pine Thinned, Treatment 3-Juniper Removed, Treatment 4-Pine Thinned/Juniper Removed.

Appendix Table 2. Understory Vegetative Cover by Site - 1986

	Block One Treatment				Block Two Treatment			
Species	1	2	3	4	1	2	3	4
Agsp	0.8	1.5	2.9	1.1	2.9	1.2	4.3	3.8
Feid	4.4	1.6	5.1	4.8	1.3	1.5	3.1	3.4
Sihy	0.3	0.5	1.3	0.7	0.3	0.1	0.3	0.4
Posa	1.1	2.7	2.4	2.1	2.7	0.9	3.2	2.6
OPG	1.4	0.1	0.4	1.2	0.8	0.4	0.8	1.3
TPG	8.0	6.3	12.2	10.0	7.9	4.1	11.8	11.5
Brte	1.2	0.0	0.4	1.8	0.0	0.1	0.2	0.1
OAG	0.6	0.0	0.2	0.8	0.0	0.0	0.1	0.2
TAG	1.9	0.1	0.6	2.7	0.0	0.1	0.3	0.2
TG	9.8	6.4	12.8	12.7	8.0	4.2	12.0	11.7
PerForb	0.3	0.3	0.3	0.5	0.4	0.4	0.6	0.4
AnForb	1.7	0.4	1.2	1.9	0.7	1.0	1.0	0.8
TF	5.1	3.6	4.0	6.8	4.7	4.5	0.7	5.0
Artr	1.2	1.9	3.0	2.4	0.3	0.4	0.8	0.7
OShrub	0.7	0.3	0.8	1.0	1.3	0.4	0.4	0.9
TS	1.9	2.2	3.8	3.5	1.5	0.8	1.2	1.6
Total	16.9	12.2	20.5	22.9	14.2	9.5	20.1	18.2

	Block Three Treatment				Block Four Treatment			
Species	1	2	3	4	1	2	3	4
Agsp	0.8	0.2	0.5	0.2	0.1	0.1	0.0	0.3
Feid	4.3	2.6	6.3	4.3	0.4	0.2	0.2	0.0
Sihy	0.1	0.1	0.4	0.1	0.8	0.8	1.4	1.7
Posa	2.0	2.2	2.7	2.9	1.7	1.3	1.8	1.5
OPG	0.2	0.1	0.1	0.4	1.2	0.6	0.6	0.3
TPG	7.4	5.2	10.0	7.9	4.2	2.8	4.0	3.8
Brte	0.0	0.0	0.3	0.2	1.2	0.7	0.8	1.0
OAG	0.0	0.0	0.0	0.0	0.4	0.2	0.4	0.3
TAG	0.1	0.0	0.3	0.3	1.6	0.8	1.2	1.3
TG	7.5	5.2	10.4	8.1	5.8	3.7	5.2	5.0
PerForb	0.3	0.2	0.4	0.2	0.4	0.1	0.2	0.3
AnForb	0.7	0.4	0.9	0.4	0.4	0.6	0.3	1.0
TF	3.8	2.0	0.5	2.2	0.8	0.7	0.5	1.2
Artr	3.1	1.4	3.3	3.5	0.3	0.2	0.4	0.4
OShrub	0.4	0.4	1.1	1.3	0.6	0.3	0.0	0.3
TS	3.6	1.8	4.5	4.9	0.9	0.5	0.4	0.7
Total	14.8	9.1	19.5	15.2	7.6	4.9	6.1	6.9

Agsp-Bluebunch wheatgrass, Kocr-Junegrass, Feid-Idaho fescue, Sihy-Bottlebrush squirreltail, OPG-Other Perennial Grasses, Posa-Sandberg bluegrass, TPG-Total Perennial Grasses, Brte-Cheatgrass, OAG-Other Annual Grasses, TAG-Total Annual Grasses, TG-Total Grass, PerForb-Perennial Forbs, AnForb-Annual Forbs, TF-Total Forbs, Artr-Big sagebrush, OShrub-Other Shrubs, TS-Total Shrubs, Total-Total derstory Production. Treatment 1-Control, Treatment 2-Pine Thinned, Treatment 3-Juniper Removed, Treatment 4-Pine Thinned/Juniper Removed.

Appendix Table 3. Basal area and percent cover of western juniper and ponderosa pine by site.

Block One

	Western Juniper		Ponderosa Pine	
Treatment	BA (m2/ha)	Cover (%)	BA (m2/ha)	Cover (%)
Control	17.2	10.1	4.6	2.1
Pine Thinned	19.1	12.5	5.2	3.1
Juniper Removed	22.1	14.3	4.9	2.4
Pine Thinned/ Juniper Removed	18.4	12.3	4.7	2.6

Block Two

	Western Juniper		Ponderosa Pine	
Treatment	BA (m2/ha)	Cover (%)	BA (m2/ha)	Cover (%)
Control	15.9	9.3	6.3	3.5
Pine Thinned	17.3	9.7	5.5	2.8
Juniper Removed	16.5	8.7	4.1	3.0
Pine Thinned/ Juniper Removed	17.9	10.1	4.3	2.3

Block Three

	Western Juniper		Ponderosa Pine	
Treatment	BA (m2/ha)	Cover (%)	BA (m2/ha)	Cover (%)
Control	19.2	13.4	5.1	3.0
Pine Thinned	20.1	15.0	4.4	2.7
Juniper Removed	16.5	8.7	5.5	3.4
Pine Thinned/ Juniper Removed	17.9	10.1	5.1	3.1

Block Four

	Western Juniper		Ponderosa Pine	
Treatment	BA (m2/ha)	Cover (%)	BA (m2/ha)	Cover (%)
Control	12.4	7.6	4.0	2.6
Pine Thinned	15.9	8.2	2.7	1.9
Juniper Removed	13.3	6.5	5.5	3.4
Pine Thinned/ Juniper Removed	11.0	7.0	3.7	2.9

Appendix Table 4. Mean percent basal area growth of ponderosa pine trees in five diameter classes for 1985 and 1986. Percent basal area growth = current year basal area growth divided by total tree basal area.

		Treatment			
Year	Diameter Classes	Control	Pine Thinned	Juniper Removed	Pine Thinned/ Juniper Removed
	cm	(%)	(%)	(%)	(%)
1985					
	Under 5	24.6Aa*	5.7Ba	-0.6Ba	13.2Aa*
	5-15	1.3b	0.7a	2.8a	4.4a
	15-30	1.2b	0.6a	3.0a	2.4a
	30-40	1.3b	0.6a	1.2a	1.6a
	Over 40	1.0b	0.6a	0.8a	1.1a
1986					
	Under 5	13.1Aa	18.3ABa	19.7Ba	12.6Aa
	5-15	3.6b	7.6b	3.3b	4.0b
	15-30	1.9b	5.8b	7.7b	2.0b
	30-40	2.8b	1.3b	1.1b	1.1b
	Over 40	4.9b	0.3b	1.0b	1.1b

*Upper case letter indicate significant differences ($p \leq 0.05$) between treatments and lower case letters indicate significant differences ($p \leq 0.05$) between diameter classes within treatments.

Appendix Table 5. Mean percent height growth of ponderosa pine trees in five diameter classes for 1985 and 1986. Percent basal area growth = current year basal area growth divided by total tree basal area.

		Treatment			
Year	Diameter Classes	Control	Pine Thinned	Juniper Removed	Pine Thinned/ Juniper Removed
	cm	(%)	(%)	(%)	(%)
1985					
	Under5	9.2	6.7ab	0.0A	9.0
	5-15	9.7AB*	6.3Bab	11.2A	13.7A
	15-30	8.9	7.7ab	14.6A	9.2
	30-40	8.3AB	1.4Cb	12.1A	6.2B*
	Over 40	7.0	11.6a	17.4A	13.4
1986					
	Under 5	9.7A	27.9Ca	2.7B	13.5Aa
	5-15	2.8A	11.0Bb	7.1B	4.0AB
	15-30	2.4	8.3bc	3.4	3.0
	30-40	2.3	1.4c	1.4	1.4
	Over 40	1.8	1.7c	2.7	3.9

*Upper case letters indicate significant difference ($p \leq 0.05$) between treatments, and lower case letters indicate significant differences ($p \leq 0.05$) between diameter classes within treatments.

Appendix Table 6. Predawn xylem potential by height classes for 1985 and 1986.

Treatment	Height Classes	Sampling Date 1985 June (MPa)	1stJuly (MPa)	2ndJuly (MPa)	August (MPa)	September (MPa)
Control	Under 1m	-0.89	-0.93	-1.12	-1.04	-1.08
	1m-3m	-1.16	-0.95	-1.15	-1.17	-1.09
	Over 3m	-0.91	-1.13	-1.22	-1.16	-1.09
Pine Thinned	Under 1m	-0.91	-1.07	-1.20	-1.34	-1.27
	1m-3m	-0.81	-0.97	-1.22	-1.31	-1.25
	Over 3m	-0.85	-1.24	-1.29	-1.29	-1.15
Juniper Removed	Under 1m	-1.15	-1.30	-1.05	-1.19	-1.03
	1m-3m	-1.00	-1.18	-1.06	-1.24	-1.05
	Over 3m	-1.08	-1.27	-1.15	-1.28	-1.10
Pine Thinned/ Juniper Removed	Under 1m	-0.90	-1.16	-0.97	-1.19	-1.03
	1m-3m	-1.00	-1.24	-1.03	-1.24	-1.05
	Over 3m	-1.08	-1.16	-1.15	-1.28	-1.10

Treatment	Height Classes	Sampling Date 1986 June (MPa)	1stJuly (MPa)	2ndJuly (MPa)	August (MPa)	September (MPa)
Control	Under 1m	-1.04	-1.17	-1.10	-1.15	-1.10
	1m-3m	-1.17	-1.20	-1.09	-1.18	-1.10
	Over 3m	-1.05	-1.39	-1.22	-1.20	-1.21
Pine Thinned	Under 1m	-1.09	-1.39	-1.06	-1.24	-1.25
	1m-3m	-0.92	-1.21	-1.18	-1.34	-1.24
	Over 3m	-1.02	-1.38	-1.16	-1.26	-1.19
Juniper Removed	Under 1m	-1.18	-1.44	-1.00	-1.30	-1.07
	1m-3m	-1.21	-1.37	-1.09	-1.11	-0.97
	Over 3m	-1.20	-1.47	-1.12	-1.04	-1.19
Pine Thinned/ Juniper Removed	Under 1m	-0.90	-1.25	-1.04	-1.27	-1.06
	1m-3m	-1.10	-1.40	-0.96	-1.13	-1.01
	Over 3m	-1.13	-1.32	-1.15	-1.25	-1.07

Appendix Table 7. Soil moisture by depth for 1985 and 1986.

Sampling Date 1985

Treatment	Depth	June (%)	1stJuly (%)	2ndJuly (%)	August (%)	September (%)
Control	0-5cm	25.1	22.9	23.0	17.1	14.6
	5-25cm	28.0	25.9	22.8	17.3	16.3
	Over 25cm	29.4	27.0	23.4	17.8	16.7
Pine Thinned	0-5cm	24.9	24.1	22.7	19.1	17.5
	5-25cm	26.8	25.7	23.4	18.6	16.2
	Over 25cm	28.7	26.8	25.5	20.8	17.9
Juniper Removed	0-5cm	21.0	19.8	25.6	21.4	18.3
	5-25cm	26.0	25.6	25.8	24.4	19.1
	Over 25cm	27.3	27.4	27.4	24.7	19.8
Pine Thinned/ Juniper Removed	0-5cm	22.1	22.1	26.6	22.3	20.7
	5-25cm	24.3	23.5	26.0	22.6	20.0
	Over 25cm	25.5	26.0	26.0	22.8	21.3

Sampling Date 1986

Treatment	Depth	June (%)	1stJuly (%)	2ndJuly (%)	August (%)	September (%)
Control	0-5cm	20.7	20.6	19.6	17.3	14.2
	5-25cm	23.8	22.3	20.5	17.9	16.3
	Over 25cm	25.8	22.1	26.6	22.3	16.7
Pine Thinned	0-5cm	18.8	19.7	19.1	15.6	14.2
	5-25cm	10.9	20.0	19.5	16.8	15.3
	Over 3m	22.8	21.5	20.5	19.0	17.3
Juniper Removed	0-5cm	18.5	17.3	22.6	19.1	15.6
	5-25cm	16.2	19.3	21.3	17.8	16.5
	Over 3m	23.1	21.5	20.3	19.2	17.2
Pine Thinned/ Juniper Removed	0-5cm	19.1	17.6	21.1	19.5	17.1
	5-25cm	22.0	20.0	22.6	20.8	18.8
	Over 25cm	24.8	23.7	23.4	21.6	19.6